Journals of Gerontology: Psychological Sciences
cite as: *J Gerontol B Psychol Sci Soc Sci*, 2019, Vol. 74, No. 8, 1317–1325
doi:10.1093/geronb/gby045
Advance Access publication April 13, 2018

Special Issue: Leveraging the Power of Networks to Support Healthy Aging

Retrospective Attention in Short-Term Memory Has a Lasting Effect on Long-Term Memory Across Age

Jonathan Strunk, MS, Lauren Morgan, BS, Sarah Reaves, MS, Paul Verhaeghen, PhD, and Audrey Duarte, PhD

School of Psychology, Georgia Institute of Technology, Atlanta.

Address correspondence to: Jonathan Strunk, MS, School of Psychology, Georgia Institute of Technology, 654 Cherry Street NW, Atlanta, GA 30332-0170. E-mail: jstrunk@gatech.edu.

Received: January 5, 2018; Editorial Decision Date: April 4, 2018

Decision Editor: Angela Gutchess, PhD

Abstract

Objectives: Declines in both short- and long-term memory are typical of healthy aging. Recent findings suggest that retrodictive attentional cues ("retro-cues") that indicate the location of to-be-probed items in short-term memory (STM) have a lasting impact on long-term memory (LTM) performance in young adults. Whether older adults can also use retro-cues to facilitate both STM and LTM is unknown.
Method: Young and older adults performed a visual STM task in which spatially informative retro-cues or noninformative neutral-cues were presented during STM maintenance of real-world objects. We tested participants' memory at both STM and LTM delays for objects that were previously cued with retrodictive or neutral-cues during STM order to measure the lasting impact of retrospective attention on 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 in STM facilitate the encoding of objects into LTM such that they are more likely to be subsequently retrieved by older adults. Our results support the idea that retrospective attention can be an effective means by which older adults can improve their STM and LTM performance, even in the context of reduced memory capacity.

Keywords: Improvement, Objects, Retro-cues, Visual

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 (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;

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 retrodictive 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; Mok, Myers, Wallis, & Nobre, 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 nonspatial, 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 nonspatial 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 support long-term memory (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 presented during STM 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). Finally, emerging findings suggest that information retrieved from LTM can guide attention and enhance perception in young (Patai, Doallo, & Nobre, 2012; Stokes, Atherton, Patai, & Nobre, 2012; Summerfield, Lepsien, Gitelman, Mesulam, & Nobre, 2006) and older adults (Salvato, Patai, & Nobre, 2016). 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 STM performance, consistent with previous evidence, but these memory benefits persisted as LTM delays. 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 STM. In the current study, we investigated whether older adults would be able to use retrospective attention during STM 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. Seven young adults were excluded due to having incomplete datasets (i.e., 6 did not return for the second session, 1 had a corrupt data file). Nine 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 article.

Neuropsychological Assessment

A 25-min neuropsychological assessment battery was administered between the STM and LTM 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 LTM from the Memory Assessment Scale (Williams, 1991).

Materials

Seven hundred sixty-two color images of real world objects were collected from Hemera Technologies Photo-Objects DVDs, Bank of Standardized Stimuli

Table 1. Group Demographics and Neuropsychological Test Performance

	Young	Older
Demographics	25 (18–24 years)	30 (61–71 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)[a]	63.96 (3.45)	46.29 (9.26)*
List Learning (out of 12)[a]	12.00 (0.00)	11.04 (1.40)*
Letter Fluency (FAS)[a]	49.63 (15.99)	39.64 (11.16)*
Trails A[a]	22.82 (6.85)	34.95 (11.51)*
Trials B[a]	41.35 (8.97)	99.96 (37.87)*
List Recall—Free[a]	11.33 (0.96)	9.96 (1.64)*
List Recall—Cued[a]	11.29 (0.99)	10.18 (1.77)*
List Recognition[a]	11.96 (0.20)	12.04 (0.43)
Visual Recognition[a]	18.71 (1.78)	16.89 (1.77)*
Visual Reproduction[a]	8.96 (1.37)	5.71 (2.19)*
Verbal Span[a]	12.46 (2.73)	10.71 (2.12)*
Verbal Forward[a]	6.96 (1.40)	6.18 (1.44)
Verbal Backward[a]	5.38 (1.50)	4.50 (1.29)*
Delayed Vis Recognition[a]	19.29 (1.04)	17.54 (2.56)*
Delayed List Recall—Free[a]	11.67 (0.70)	9.96 (1.88)*
Delayed List Recall—Cued[a]	11.67 (0.48)	10.32 (1.85)*

Note: Standard deviations in parentheses. Superscript "a" indicates tests from the Memory Assessment Scale (Williams, 1991). Significantly different from Young (*p < .05). Seven older adults did not report years of education, and two older adults did not complete the MAS, Trails, and Letter Fluency tasks.

(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

Before beginning each session of the experiment, participants engaged in a 20-min practice of the tasks in which the pace increased up to the experimental pace by the end of practice. Participants practiced both STM and LTM trials. Given that there were two sessions of the experiment (see below), participants would have been aware that their memory would be tested at short- and long-term delays by the second session. Thus, we exposed all participants to both STM and LTM trials before starting the first session to equate any effects of prior knowledge of the memory tests on performance across session.

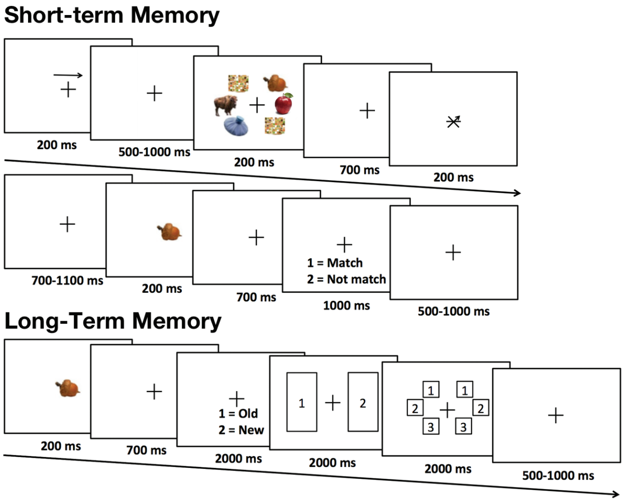

Figure 1. Schematic of the experimental design showing example stimuli and task requirements. The short-term memory (STM) schematic depicts a retro-cue trial, indicating that the item in the first position on the right side of the array will be probed (the acorn). Probes from the STM task are presented again in the long-term memory (LTM) task. Participants are asked if the item was present in the memory array and if "old," where it was located in the array for both the hemifield and exact vertical location. *Note:* STM probe duration was 500 ms for older adults (see Methods).

The experiment was divided into two sessions separated by a 2-week delay. Each session contained 88 STM trials and 132 LTM trials for a total of 176 STM trials and 264 LTM 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; 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.). 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 2 weeks. Behavioral data were combined across testing sessions.

STM 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 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 nonmatch 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 that 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, nonmatch, 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 nonmatch. Hits and misses were defined as "match" and "nonmatch" responses, respectively, to match trials. Correct rejections and false alarms were defined as "nonmatch" and "match" responses, respectively, to nonmatch trials. The task was divided into 8 mini blocks of 11 trials with a 10-s break between each block to minimize fatigue.

LTM 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 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-s 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 Tests

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.

STM Performance

Mean proportions of hit rates for match trials and correct rejection rates for nonmatch trials are shown for neutral-cue and retro-cue conditions in Table 2. Hits and misses were defined as "match" and "nonmatch" responses, respectively, to match trials. Correct rejections and false alarms were defined as "nonmatch" and "match" responses, respectively, to nonmatch trials. Item memory accuracy was estimated using Pr, that is, p(hits)-p(false alarms); in this metric, chance performance is zero (Snodgrass & Corwin, 1988). Mean reaction times (RTs) for hits and correct rejections are shown in Table 2. D-prime and criterion estimates of memory sensitivity and bias, respectively, are also shown in Table 2. Due to variability in whether participants waited to respond to the response prompt, RTs 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 Figure 2 with a Cue (neutral-cue, retro-cue) × Group (young, older) ANOVA. The ANOVA revealed

Table 2. Short-Term Memory: Response Proportions, Performance Indices, and Reaction Times for Each Cue Type and Age Group

	Young		Older	
Performance Measures	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)
Corrected recognition (Pr)	0.835 (0.089)	0.703 (0.105)	0.586 (0.239)	0.523 (0.194)
D-prime	3.10 (0.62)	2.41 (0.45)	1.96 (0.94)	1.73 (0.67)
Criterion	0.2 (0.37)	0.39 (0.39)	0.38 (0.33)	0.47 (0.35)
Hit reaction time	1,270 (95)	1,329 (105)	1,471 (258)	1,538 (274)
CR reaction time	1,275 (92)	1,308 (92)	1,532 (239)	1,574 (234)

Note: Standard deviations are in parentheses. Reaction times are in milliseconds and assessed from the probe onset. Pr is the corrected recognition measure (hit-false alarms) as defined in Snodgrass and Corwin (1988).

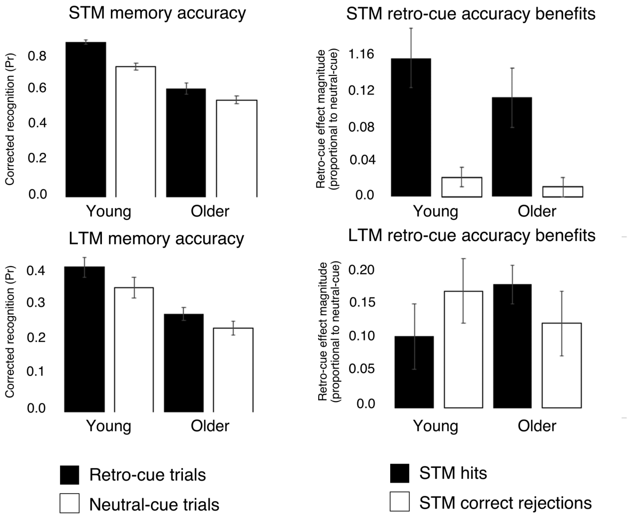

Figure 2. On the left, corrected recognition (Pr) estimates for retro-cue and neutral-cue trials at STM and LTM. On the right, retro-cue accuracy effects at both short and long-term memory for STM hits and STM correct rejections. Calculated as the (%retro-cue – %neutral-cue items) / % neutral-cue items for the same response category (e.g., retro-cue hits/neutral-cue hits), where values greater than 0 reflect a retro-cue memory benefit. Error bars reflect ±1 standard error of the mean.

significant main effects of Group [$F(1, 53) = 23.2$, $p < .001$, $\eta p^2 = 0.31$] and Cue [$F(1, 53) = 38.5$, $p < .001$, $\eta p^2 = 0.42$]. The Cue × Group interaction was also significant [$F(1, 53) = 4.8$, $p = .032$, $\eta p^2 = 0.08$]. Similar results were obtained using d-prime estimates: (Group [$F(1, 53) = 28.1$, $p < .001$, $\eta p^2 = 0.35$], Cue [$F(1, 53) = 29.1$, $p < .001$, $\eta p^2 = 0.35$], Cue × Group [$F(1, 53) = 6.8$, $p = .012$, $\eta p^2 = 0.11$]. 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 × 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. Therefore, we compared retro-cue memory benefits between young and older adults using proportional increases in memory accuracy [i.e., (retro-cue Pr – neutral-cue Pr)/neutral-cue Pr] in an independent sample *t*-test. This analysis showed that the retro-cue memory benefit did not differ between age groups [$t(53) = 1.1$, $p = .269$; Bayes factor (null/alternative) for the interaction was 3.89 in favor of the null hypothesis (Dienes, 2014)]. The same analysis using proportional increases in memory sensitivity (d-prime) also showed no significant difference in the retro-cue memory benefit between age groups [$t(53) = 1.54$, $p = .13$; Bayes factor (null/alternative) for the interaction was 2.16 in favor of the null hypothesis].

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 "nonmatch" items, or both. Therefore, we compared retro-cue memory benefits between young and older adults for hits and correct rejections separately, using proportional estimates calculated as above [i.e., (retro-cue hit – neutral-cue hit)/(neutral-cue hit), (retro-cue CR – neutral-cue CR)/(neutral-cue CR)] in a Response (hit, CR) × Group ANOVA. These proportional estimates are shown in Figure 2. The ANOVA revealed a main effects of Response [$F(1,53)=16.1$, $p<.001$, $\eta p^2=0.23$], a marginal effect of Group [$F(1, 53) = 2.91$, $p = .09$, $\eta p^2 = 0.05$], but no significant interaction [$F(1, 53) = 1.20$, $p = .28$, $\eta p^2 = 0.02$; Bayes factor (null/alternative) for the interaction was 3.90 in favor of the null hypothesis]. 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.

To assess the effect of retro-cueing on RTs, we conducted a Cue (neutral-cue, retro-cue) × Response (hits, correct rejections) × Group (young, older) ANOVA on RTs shown in Table 2. A main effect of Group confirmed that older adults were slower than young adults [$F(1, 53) = 20.7$, $p < .001$, $\eta p^2 = 0.28$]. The main effect of Cue [$F(1, 53) = 35.6$, $p < .001$, $\eta p^2 = 0.40$] confirmed that participants were faster to respond to retro-cued than neutral-cued trials. The lack of Cue × Group interaction suggests that the retro-cue benefit for RTs was similar across age groups [$F(1, 53) < 1$, $\eta p^2 = 0.005$; Bayes factor (null/alternative) for the interaction was 7.52 in favor of the null hypothesis]. Finally, a Cue × Response interaction [$F(1, 53) = 6.3$, $p = .015$, $\eta p^2 = 0.11$] 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 to correct for age group differences in slowing (Faust, Balota, Spieler, & Ferraro, 1999).

LTM 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," that is, STM hits, or correctly rejected as "nonmatches," that is, 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 memory accuracy was estimated using Pr. D-prime and criterion estimates of memory sensitivity and bias, respectively, are also shown in Table 3. Mean RTs for LTM hits are also shown in the table. Mean RTs for LTM were assessed from the first response prompt, as virtually no responses were made before the onset of the response prompt.

Pr estimates for retro- and neutral-cue conditions are shown in Figure 2. 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 next wanted to determine whether these benefits would persist into LTM. To this end, we conducted a Cue (retro, neutral) × Response (STM hit, STM correct rejection) × Group ANOVA for Pr estimates for LTM hits that are shown in Table 3 with a Cue (neutral-cue, retro-cue) × Group (young, older) ANOVA. This revealed main effects of Group [$F(1, 53) = 9.1, p = .004, \eta p^2 = 0.15$] and Cue [$F(1, 53) = 25.8, p < .001, \eta p^2 = 0.33$] but no interactions [$F(1, 53)$s < 1.6, *ps* > .21, $\eta p^2 < 0.03$; Bayes factor (null/alternative) for the Group by Cue interaction was 6.95 in favor of the null hypothesis]. Similar results were obtained using d-prime estimates: (Group [$F(1, 53) = 11.6, p = .001, \eta p^2 = 0.18$], Cue [$F(1, 53) = 26.2, p < .001, \eta p^2 = 0.33$], no interactions [$F(1, 53)$s < 2.9, *ps* > 0.14, $\eta p^2 < 0.04$].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 compared proportional retro-cue effects for STM hit and STM correct rejection Pr estimates relative to "baseline" neutral-cue conditions for these response categories [i.e., (retro-cue STM hit – neutral-cue STM hit)/(neutral-cue STM hit), (retro-cue STM CR – neutral-cue STM CR)/(neutral-cue STM CR)] in a Response (hit, CR) × Group ANOVA. 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, *ps* > 0.17, $\eta p^2 < 0.03$; Bayes factor (null/alternative) for the Group by Response interaction was 6.95 in favor of the null hypothesis]. As can be seen in Figure 2, retro-cue effects in LTM were similar across STM hits and correct rejections 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) × Group (young, older) ANOVA for proportion of items with a correct exact location revealed a main effect of Group [$F(1, 53) = 47.1, p < .001, \eta p^2 = 0.47$] and no other effects [$F$s < 1, $\eta p^2 < 0.01$]. 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.

To assess the effect of retro-cueing on LTM RTs, we conducted a Cue (neutral-cue, retro-cue) × Response (hits, correct rejections) × Group (young, older) ANOVA on RTs shown in Table 3. A main effect of Group confirmed that older adults were slower than young adults [$F(1, 53) = 30.3, p < .001, \eta p^2 = 0.36$]. There were no effects involving Cue [all Fs < 1.17, *ps* > .28, $\eta p^2 < 0.02$]. 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.

Table 3. Long-Term Memory: Response Proportions, Performance Indices, and Reaction Times for Each Cue Type and Age Group

Performance Measures	Young		Older	
	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)
D-prime STM hits	1.68 (0.81)	1.47 (0.86)	1.15 (0.57)	0.92 (0.60)
D-prime STM CR	1.04 (0.53)	0.88 (0.55)	0.57 (0.38)	0.51 (0.39)
Criterion STM hits	0.11 (0.38)	0.22 (0.40)	−0.11 (0.49)	0.0 (0.40)
Criterion STM CR	0.43 (0.54)	0.52 (0.57)	0.17 (0.45)	0.20 (0.51)
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. Pr is the corrected recognition measure (hit-false alarms) as defined in Snodgrass and Corwin (1988).

Discussion and Implications

We examined the effect of aging on the relationship between retrospective attention, STM, and LTM. To the best of our knowledge, ours is the first study to investigate whether retro-cueing during STM leads to lasting memory benefits in LTM in both young and older adults. 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 LTM accuracy for the spatial location of objects.

Retro-Cue Benefits in LTM

One of the most interesting findings in our study was that retro-cue memory benefits were present in LTM to a similar degree for young and older adults. This suggests that the protective features afforded by the retro-cue are not limited to STM delays. Previous retro-cueing studies have largely focused on performance benefits for hits in STM, 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 nonmutually exclusive mechanisms but we believe that any of them could contribute to retro-cue effects for hits and correct rejections that were measured in LTM. 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.

Through these mechanisms, retrodictive cues during STM 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 nonmutually exclusive explanation is that somewhat different mechanisms support retro-cue LTM benefits for hits and correct rejections. For example, the novelty of the nonmatching 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.

Our results suggest that retro-cues selectively enhanced item memory but had no effect on location memory. 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.

Retro-Cue Benefits in STM

As has been shown in numerous prior studies, young adults showed the typical STM retro-cue benefit both in reduced RTs 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 et al., 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 nonspatial (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 (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.

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 and that these memory benefits persist into long-term delays, despite the relatively impoverished quality of their STM representations.

Conclusions

Numerous studies have attempted to ameliorate the STM and LTM 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 facilitates the encoding of STM probes thereby increasing the probability that they will retrieved from LTM 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 STM and LTM 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.

Funding

This research was supported in part by a NIA Ruth L. Kirschstein National Research Service Award (NRSA) Institutional Research Training Grant (5T32AG000175).

Acknowledgments

We thank all of our research participants.

Conflict of Interest

The authors declared that they had no conflicts of interest with respect to their authorship or the publication of this article.

References

Axmacher, N., Haupt, S., Cohen, M. X., Elger, C. E., & Fell, J. (2009). Interference of working memory load with long-term memory formation. *The European Journal of Neuroscience*, **29**, 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 United States of America*, **105**, 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**, e10773. doi:10.1371/journal.pone.0010773

Connelly, S. L., Hasher, L., & Zacks, R. T. (1991). Age and reading: The impact of distraction. *Psychology and Aging*, **6**, 533–541.

Dienes, Z. (2014). Using Bayes to get the most out of non-significant results. *Frontiers in Psychology*, **5**, 781. doi:10.3389/fpsyg.2014.00781

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**, 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**, 777–799.

Gazzaley, A., & Nobre, A. C. (2012). Top-down modulation: Bridging selective attention and working memory. *Trends in Cognitive Sciences*, **16**, 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. *Neuropsychology, Development, and Cognition. Section B, Aging, Neuropsychology and Cognition*, **23**, 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**, 1176–1194. doi:10.1162/089892903322598139

Hasher, L., Lustig, C., & Zacks, J. M. (2007). Inhibitory mechanisms and the control of attention. In Conway, A, Jarrold, C., Kane, M., Miyake, A., & Towse, J. (Eds.), *Variation in working memory*, 227-249. New York: Oxford University Press.

Hasher, L., Quig, M. B., & May, C. P. (1997). Inhibitory control over no-longer-relevant information: Adult age differences. *Memory & Cognition*, **25**, 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., Seemüller, A., & Rösler, F. (2007). Working memory maintenance contributes to long-term memory formation: Evidence from slow event-related brain potentials. *Cognitive, Affective & Behavioral Neuroscience*, **7**, 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**, 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**, 149–164.

Makovski, T., & Jiang, Y. V. (2007). Distributing versus focusing attention in visual short-term memory. *Psychonomic Bulletin & Review*, **14**, 1072–1078.

Makovski, T., & Pertzov, Y. (2015). Attention and memory protection: Interactions between retrospective attention cueing and interference. *Quarterly Journal of Experimental Psychology (2006)*, **68**, 1735–1743. 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, & Cognition*, **34**, 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 & Psychophysics*, **69**, 1422–1434.

May, C. P., Hasher, L., & Kane, M. J. (1999). The role of interference in memory span. *Memory & Cognition*, **27**, 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 (New York, N.Y.: 1991)*, **26**, 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. *Psychological Science*, **24**, 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 & Cognition*, **31**, 563–569.

Patai, E. Z., Doallo, S., & Nobre, A. C. (2012). Long-term memories bias sensitivity and target selection in complex scenes. *Journal of Cognitive Neuroscience*, **24**, 2281–2291. doi:10.1162/jocn_a_00294

Peich, M. C., Husain, M., & Bays, P. M. (2013). Age-related decline of precision and binding in visual working memory. *Psychology & Aging*, **28**, 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 & Aging*, **30**, 26–35. doi:10.1037/a0038396

Posner, M. I. (1980). Orienting of attention. *The Quarterly Journal of Experimental Psychology*, **32**, 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**, 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*, **1642**, 226–237. 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, & Cognition*, **39**, 1075–1096. doi:10.1037/a0031172

Rowe, G., Hasher, L., & Turcotte, J. (2008). Age differences in visuospatial working memory. *Psychology & Aging*, **23**, 79–84. doi:10.1037/0882-7974.23.1.79

Rozek, E., Kemper, S., & McDowd, J. (2012). Learning to ignore distracters. *Psychology & Aging*, **27**, 61–66. doi:10.1037/a0025578

Salvato, G., Patai, E. Z., & Nobre, A. C. (2016). Preserved memory-based orienting of attention with impaired explicit memory in healthy ageing. *Cortex*, **74**, 67–78. doi:10.1016/j.cortex.2015.10.019

Sligte, I. G., Scholte, H. S., & Lamme, V. A. (2008). Are there multiple visual short-term memory stores? *PLoS One*, **3**, e1699. doi:10.1371/journal.pone.0001699

Snodgrass, J. G., & Corwin, J. (1988). Pragmatics of measuring recognition memory: Applications to dementia and amnesia. *Journal of Experimental Psychology. General*, **117**, 34–50.

Souza, A. S. (2016). No age deficits in the ability to use attention to improve visual working memory. *Psychology and Aging*, **31**, 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. *Attention, Perception & Psychophysics*, **78**, 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 & Performance*, **42**, 890–910. doi:10.1037/xhp0000192

Stokes, M. G., Atherton, K., Patai, E. Z., & Nobre, A. C. (2012). Long-term memory prepares neural activity for perception. *Proceedings of the National Academy of Sciences of the United States of America*, **109**, E360–E367. doi:10.1073/pnas.1108555108

Summerfield, J. J., Lepsien, J., Gitelman, D. R., Mesulam, M. M., & Nobre, A. C. (2006). Orienting attention based on long-term memory experience. *Neuron*, **49**, 905–916. doi:10.1016/j.neuron.2006.01.021

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*. New York: Oxford University Press.

Williams, J. (1991). *Memory assessment scales professional manual*. Odessa, Florida: Psychological Assessment Resources.