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Retrospective Cues Based on Object Features Improve Visual Working Memory Performance in Older Adults

Amanda L. Gilchrist,
Department of Psychology, Cottey College

Audrey Duarte, and
School of Psychology, Georgia Institute of Technology

Paul Verhaeghen
School of Psychology, Georgia Institute of Technology

Abstract

Research with younger adults has shown that retrospective cues can be used to orient top-down attention toward relevant items in working memory. We examined whether older adults could take advantage of these cues to improve memory performance. Younger and older adults were presented with visual arrays of five colored shapes; during maintenance, participants were either presented with an informative cue based on an object feature (here, object shape or color) that would be probed, or with an uninformative, neutral cue. Although older adults were less accurate overall, both age groups benefited from the presentation of an informative, feature-based cue relative to a neutral cue. Surprisingly, we also observed differences in the effectiveness of shape versus color cues and their effects upon post-cue memory load. These results suggest that older adults can use top-down attention to remove irrelevant items from visual working memory, provided that task-relevant features function as cues.

Keywords

aging; retrospective cueing; visual working memory; attention; object features

Introduction

Working memory, typically defined as what one is consciously aware of for brief periods of time, is inextricably linked with selective attention. Attention is required to update and adapt to a rapidly-changing external environment; this is done by orienting attention towards relevant stimuli and shifting attention away from irrelevant stimuli, possibly even subsequently inhibiting or removing these irrelevant items from memory. These attentional processes can be executed in either a bottom-up or a top-down manner. Selective attention operates in a bottom-up fashion when attention involuntarily orients towards unexpected,

Corresponding author: Amanda L. Gilchrist, Department of Psychology, 134 Alumnae Hall, Cottey College, Nevada, MO 64772, agilchrist@cottey.edu, Phone: (417) 667-8181, ext. 2276.

salient stimuli. In contrast, selective attention can also be oriented towards particular stimuli in a voluntary, top-down manner.

It is well-documented that adult aging is typically accompanied by declines in working memory performance and storage capacity (c.f., Cowan, Naveh-Benjamin, Kilb, & Saults, 2006; Gilchrist, Cowan, & Naveh-Benjamin, 2008; Naveh-Benjamin, Cowan, Kilb, & Chen, 2007). Previous research suggests that these declines are due to deficits in top-down attentional processing, particularly during periods of maintenance (e.g., Gazzaley et al., 2007; May, Hasher, & Kane, 1999). One aspect of this processing that has been posited to be particularly age-sensitive is the ability to delete or suppress irrelevant information from working memory (e.g., Hasher, Quig, & May, 1997). Research that has examined neural activity in younger and older adults during tasks that require suppression has bolstered this hypothesis. In an fMRI study by Gazzaley and colleagues (Gazzaley, Cooney, Rissman, & D'Esposito, 2005), younger and older participants were presented with sequences of faces and scenes. Participants were instructed to either remember or ignore a specific category (e.g., remember faces and ignore scenes), or to passively view all stimuli. Of particular interest were changes in activity in regions of sensory cortex, which are associated with maintenance of items in visual working memory (VWM; e.g., Gao et al., 2011; Vogel & Machizawa, 2004). Effective VWM performance was associated with enhancement of BOLD signal in the left parahippocampal gyrus for remembered stimuli compared to baseline, as well as a reduction in BOLD activity for ignored stimuli relative to baseline. Although both younger and older adults demonstrated enhanced activity for remembered stimuli, older adults were not able to suppress stimuli that were to be ignored. In addition to recruitment of sensory areas during VWM maintenance, frontal regions are also necessary for effective top-down selective attention. Given that regions of frontal cortex are susceptible to age-related atrophy, particularly the prefrontal cortex, it has been suggested that this region is the locus of inhibitory deficits that occur with age (Gazzeley et al., 2007, 2008).

One paradigm that has recently been used to explicitly test whether age-related declines in VWM performance are due to deficits in inhibition of irrelevant items is the retrocue paradigm (Griffin & Nobre, 2003). In this task, participants are first briefly shown a memory array of to-be-remembered items. After a delay, a retroactive spatial cue ("retrocue") is presented to indicate the location of the to-be-probed item, after which the item is probed. The expectation is that, by directing the subject's attention toward the location of the critical item, the retrocue acts to make all other items in VWM task-irrelevant, thus reducing the effective memory load. In accordance with this prediction, retrocueing enhances memory accuracy and capacity measures in young adults (Landman, Spekreijse, & Lamme, 2003; Lepsien and Nobre, 2007; Makovski and Jiang, 2007; Makovski, Sussman, & Jiang., 2008; Matsukura, Luck, & Vecera, 2007).

To our knowledge, only one study, from our lab, has investigated the effects of retrocueing in older adults (Duarte et al., 2013) Younger and older adults were presented with a retrocueing task during which event-related potentials (ERPs) were recorded; an ERP of particular interest was contralateral delay activity (CDA). This waveform is typically associated with maintenance of items in VWM and can be considered an index of effective working memory load (e.g., Vogel & Machizawa, 2004). If retrocues improve working memory performance by reducing the effective load in VWM, it was expected that the size of the CDA would be modulated by the presence of a retrocue. Surprisingly, this occurred for both age groups. However, despite neural evidence that retrocues reduced working memory load, behavioral results suggested that older adults were not able to use these retrocues to their advantage. In younger adults, working memory performance was significantly more accurate on cued trials compared to trials in which no cue was presented, but this was not the case for older adults.

It may be premature, however, to conclude that older adults are unable to use retrocues to enhance working memory performance. In our previous study, as in the majority of the young-adult research on retrocueing described above, the cue was based on an item’s spatial location. Studies of VWM make use of feature-bound visual objects as stimuli. In addition to location, these features may include color, shape, orientation, and the like. Of these different features, location is often the least noticeable in real-world applications, and may not always be needed for accurate storage of VWM representations if it is not relevant to the task at hand (e.g., Cowan, Blume, & Saults, 2013; Gilchrist & Cowan, 2014; Woodman, Vogel, & Luck, 2012). Given that older adults encounter greater difficulty with remembering bindings between objects and their locations when it is relevant to the task(e.g., Chalfonte & Johnson, 1996), as it is for many retrocueing studies, it is worth examining whether older adults can effectively use cues related to other object features besides location.

Previous research has shown that the benefits procured by the presence of retrocues are influenced by the type of cue that is used. For example, Berryhill and colleagues (Berryhill, Richmond, Shay, & Olson, 2012; Experiment 1) observed retrocue benefits for arrows presented in central fixation, but not for dashes presented in peripheral array locations or digits that indicated the quadrant of the to-be-tested item (but see Matkusura, Cosman, Roper, Vatterott, & Vercera, 2014, which finds that cues in peripheral object locations can function as effectively as cues in central fixation). Moreover, cues based on object features such as color can function as effective retrocues in certain circumstances. Namely, a cue based on an object’s color can be as effective as a location-based cue, provided that the feature-bound objects in a visual array are relatively simple in structure (Li & Saiki, 2015). In light of these findings, we examined whether the age-related differences in the retrocueing effect reported by Duarte et al. (2013) would still be observed when younger and older adults were presented with retrocues that were based on object features that are often more discriminable than object location, such as color or shape.

A schematic of the task used in the current study is shown in Figure 1. We presented participants with an array of five colored shapes. After the display disappeared, and after a variable delay, on some trials participants received a retrospective color cue (e.g., ‘red’) or a retrospective shape cue (e.g., ‘circle’) and, after another delay, the participants were tested with a probe that included the cued color or shape. Depending on the retrocue that was used, the number of items that had to be maintained post-cue varied from trial to trial (between one and three). Finally, uninformative, neutral cues were also used in order to assess the working memory performance benefits induced by retrocues.

One notable aspect of this task is that the retrocue was verbal in nature. Aside from a study by Lepsien, Thornton, and Nobre (2011), which utilized letters to indicate which category of items (here, faces or scenes) was to be tested, no other study has utilized a verbal retrocue. We opted to use a verbal cue because of its semantic nature. It is well-documented that semantic memory is spared by aging (e.g., Kausler, 1994); as such, we believe that use of this type of cue allows older adults to capitalize on these intact processes.

As noted above, the presence of a retrocue improves VWM performance; in young adults, this benefit becomes larger with greater reductions in effective memory load via retrocues (Lepsien et al., 2011). Thus, in the current study, highest accuracy should be observed on trials in which the retrocue refers to a single item, whereas the lowest accuracy should occur when the retrocue refers to a feature shared by three items. We wished to examine whether similar modulations in working memory performance would also occur in older adults, given that aging is often associated with a decline in working memory capacity (e.g., Bopp & Verhaeghen, 2005; Gilchrist et al., 2008). Retrocues reduce effective working memory load to manageable, sub-capacity levels, which should greatly benefit older adults. Such findings would provide strong evidence for preserved top-down attentional processes in old age.

Method

Participants

Twenty-eight younger adults (17 male, 11 female) and 24 older adults (14 male, 10 female) took part in the current study. Data from two younger adults (one male, one female) were not included in our analyses due to a programming error, leaving us with 26 younger adults with usable data. Younger adults were recruited from Georgia Institute of Technology; older adults were recruited from the metropolitan Atlanta area. Younger adults had a mean age of 20.6 years (*SD* = 1.79) with 14.37 years of education (*SD* = 1.74). Older adults had a mean age of 68.67 years (*SD* = 5.25) with 17.63 years of education (*SD* = 2.99) and a mean Shipley vocabulary test score of 32.88 (*SD* = 4.69). The difference in mean education levels between the two age groups was statistically significant, $t(48) = 4.76$, $p < .001$[1]. All participants received compensation of $10 per hour for their participation or, in the case of younger adults who opted to do so, received extra credit in an introductory psychology course. The total session duration was approximately 1.5 to 2 hours.

Stimuli, Apparatus, and Procedure

Participants were tested one at a time in a quiet booth. Prior to the experiment participants completed two blocks of practice trials, and were familiarized with all of the shapes and colors that would be presented in the experiment.

[1]A limitation of this research concerns characteristics of the older adult sample we used. As mentioned previously, the group of older adults had significantly more years of education than young adults, suggesting that this was a particularly high-performing group of older participants. It is unclear whether similar results would be obtained if the sample of older adults included a wider range of achievement levels. We plan to remedy this limitation in follow-up research.

All experimental trials followed the procedure described in further detail below (see Figure 1). All stimuli were presented against a gray background. Each trial began with a 1,000-ms fixation. Participants were then presented with a visual array of 5 colored shapes for 1,000 ms. Three different colors and three different shapes were present in the array; each color-shape combination was unique, and was never repeated by any other item within the array. Item colors were randomly selected from a pool of eight colors: *red*, *green*, *purple*, *yellow*, *blue*, *brown*, *black*, and *white*. Likewise, item shapes were randomly selected from a pool of eight shapes: *square*, *circle*, *triangle*, *star*, *moon*, *arrow*, *diamond*, and *plus*. All items in the array were located in an arc around the center of the screen; locations were randomly assigned to prevent visual grouping of items. Each shape in the array was 1.75 × 1.75 cm in size and subtended 4.01° of visual angle with a 50-cm viewing distance. Following the array presentation, there was a short delay, during which participants were expected to maintain the visual array in working memory; the delay included a fixation on the screen. This delay period ranged from 4,000 to 9,000 ms, and duration was randomly selected according to a logarithmic function (4,000–5,000 ms: 50% of trials; 6,000–7,000 ms: 35%; 8,000–9,000 ms: 15%). Participants then received a verbal retrocue in the center of the screen for 1,000 ms. For half of all experimental trials, the cue was neutral and uninformative (the word “Wait”); in that case, participants were instructed to continue maintaining the entire array. For the remaining half of trials, participants received either a shape cue (“circle”) or a color cue (“red”). Trials with retrocues and trials with neutral cues occurred equally often in the experiment; for the retrocue trials, shape cues were presented on 45 trials, and color cues were presented on another 45 trials. Retrocues indicated that the test probe would contain only the denoted shape or color as a relevant feature—this cue was always valid. Informative cues theoretically allowed participants to reduce their working memory load from the original five items down to one, two, or three items. Each possible reduction in load (e.g., 1, 2, or 3 items) occurred equally often in the task. A second delay period followed the retrocue. Like the first delay period, the duration randomly ranged between 4,000 and 9,000 ms, selected via a logarithmic function. After this second delay, participants were tested with a single-item probe, which either matched an item present in the original array or was previously unseen. The single-item probe was presented in the center of the screen for 2,000 ms. Participants indicated via a keypress whether the item was part of the original array or not. Match probes occurred on half of all trials; for trials in which a shape or color retrocue occurred, this probe item contained the cued feature. Mismatch trials were constructed as follows: For shape-cued trials and half of the neutral-cued trials the probe consisted of the cued shape in a color not shown in the array; for color-cued trials and half of the neutral-cued trials, the probe consisted of the cued color in a shape not shown in the array. Following the probe, an inter-trial interval (ITI) was presented between 4,000 and 12,000 ms. ITI duration was selected randomly according to a logarithmic function (4,000–6,000 ms: 50%; 7,000–9,000 ms: 35%; 10,000–12,000 ms: 15%). The order of trial types was randomized.

The experiment contained a total of 180 trials. To reduce fatigue, trials were broken down into five blocks of 36 trials each. Trials within a given block were computer-paced, but participants were able to take a short break before beginning the next block.

Our primary dependent measure of interest was accuracy in memory performance, defined as *hits* – *false alarms*, to correct for guessing (with false alarm rate serving as an analogue for guessing rate), or "*Pr*" (Snodgrass & Corwin, 1988). For *Pr* measures, chance = 0.

Results

General Retrocueing Effects

First, we were interested in whether there was a general benefit to VWM performance on trials in which an informative retrocue was presented, compared to trials with neutral cues. These data are shown in Figure 2, Panel A. *Pr* was analyzed by a repeated-measures ANOVA, with retrocue presence (i.e., retrocue, collapsed across shape and color cues, vs. neutral cue) as a within-subjects factor and age group as a between-subjects factor (see Table 1 for marginal means). First, we observed a significant effect of age group, F (1, 48) = 10.28, $p < .01$, $\eta_p^2 = .18$. Older adults were less accurate than younger adults. We also observed a significant effect of retrocue presence, F (1, 48) = 52.52, $p < .001$, $\eta_p^2 = .52$. Participants were more accurate on trials with retrocues compared to trials with neutral cues. Most important, there was no significant interaction between age group and retrocue presence, F (1, 48) = 1.05, $p = .31$. For both age groups, performance was higher for trials that contained informative retrocues compared to neutral cues, and both groups benefitted to the same extent from retrocueing.

Effects of Retrocue Type and Post-Cue Load

A primary goal of the current study was to examine whether older adults could use retrocues to benefit working memory performance. As reported above, we observed a general retrocue benefit for both younger and older adults. In our analyses, we also observed effects related to retrocue type and post-cue memory load (see Figure 2, Panels B and C). For these analyses, we included *Pr* only for trials that contained an informative retrocue. Data were analyzed with a repeated-measures ANOVA, with retrocue type (shape or color) and presumed post-cue load (1, 2, or 3) as within-subjects factors, and age group as a between-subjects factor (see Table 2 for marginal means). We observed a significant effect of age group, F (1, 48) = 6.95, $p <.05$, $\eta_p^2 = .13$: As observed with general retrocueing effects, younger adults had higher memory performance than older adults. Surprisingly, there was also a significant effect of cue type, F (1, 48) = 66.60, $p < .001$, $\eta_p^2 = .58$, with higher memory performance for shape-based retrocues than for color-based retrocues. Finally, we observed a significant effect of post-cue memory load, F (2, 96) = 7.28, $p < .01$, $\eta_p^2 = .13$: Memory performance generally declined as post-cue load increased. The performance difference between Load 1 and Load 2 was not significant in post hoc Newman-Keuls tests ($q = 0.95$, $p = .34$); all other comparisons between the three load conditions were significant (Load 1 vs. Load 3: $q = 3.64$, $p < .01$; Load 2 vs. Load 3: $q = 2.70$, $p < .01$).

These significant effects were qualified by two significant interactions, which are shown in Figure 3. First, we found a significant age group × cue type interaction, F (1, 48) = 7.88, $p < .01$, $\eta_p^2 = .14$. Although both age groups were more accurate on trials with shape cues compared to color cues, there was a steeper decline in performance for older adults on color-cued trials. These findings were confirmed by an additional ANOVA, as well as a post hoc

Newman-Keuls test. There was a significant difference between the two age groups on color-cued trials, F (1, 48) = 11.15, $p < .01$, (Newman-Keuls: $q = 5.08$, $p < .001$), but there was no such difference for shape-cued trials, F (1, 48) = 1.59, $p = .21$ (Newman-Keuls, $q = 1.64$, $p = .25$).

Second, there was a significant interaction between cue type and post-cue load, F (2, 96) = 3.57, $p < .05$, $\eta_p^2 = .07$. As seen in Figure 3, memory performance for color cues conformed to the expected load effect—that is, more accurate VWM performance as post-cue load decreased. Interestingly, we did not observe this pattern for those trials that contained shape retrocues. Rather, performance on shape-cued trials was equivalent across all load conditions; this equivalence was confirmed in a post hoc Newman-Keuls test (Load 1 vs. Load 2: $q = -0.25$, $p = .86$; Load 1 vs. Load 3: $q = 0.61$, $p = .67$; Load 2 vs. Load 3: $q = 0.86$, $p = .82$).

Discussion

Our main question concerned whether or not older adults would be able to effectively utilize retrocues to delete irrelevant information from working memory. Our work was motivated by a recent study from our lab where older adults were not able to use spatial retrocues to increase memory performance in contrast to the young (Duarte et al., 2013), in keeping with prior studies of younger adults (e.g., Astle, Summerfield, Griffin, & Nobre, 2011; Griffin & Nobre, 2003; Makovski & Jiang, 2007). One potential issue with our prior study was its use of a spatially-based retrocue. Although the majority of retrocueing studies utilized a location-based cue, recent research suggests that retrocues based on other aspects of objects can be as effective as a spatial cue under appropriate circumstances (e.g., Lepsien et al., 2011, in which item category was cued, and Li & Saiki, 2015, in which color was cued). For this reason, in the current study, younger and older adults were presented with a verbal retrocue based on an object feature, either color or shape. We were interested in whether older adults were able to use top-down attentional processes to filter irrelevant information from VWM.

The results from this study suggest that older adults are able to use retrocues effectively. First, older adults showed increased performance on trials in which a retrocue was present, compared to trials that contained a neutral cue. Second, the retrocueing effect was statistically identical for younger and older adults, showing that both age groups benefit to the same degree. Note that, despite this, older adult performance was consistently poorer than young adults across each experimental condition. As shown in Figure 2, Panel A, older adults' performance levels on trials with a retrocue was equivalent to young adults' performance levels on trials with *neutral* cues.

A secondary goal of the current study was to examine how performance in the retrocueing task was modulated by the effective post-cue working memory load. Ideally, the smaller the memory load, the better memory performance should be. Our results confirmed that, overall, accuracy increased as post-cue load decreased for both young and older adults, providing evidence that the ability to use top-down attention is preserved in adult aging. However, the effect of post-cue load was complicated by an unexpected interaction with retrocue type. For shape-cued trials, no load effect was observed—participants were equally accurate across the board. In contrast, we observed the expected accuracy declines with increasing load for color-cued trials. These findings may relate to potential differences in discriminability between color and form, as evidenced by the finding that shape cues are more effective, which is discussed in greater detail below. This finding might have deeper implications for the understanding of top-down control over the contents of VWM. It may be that if items are sufficiently discriminable and/or easy to maintain, subjects choose to maintain them as they are rather than apply a filtering mechanism. This hypothesis should be addressed in future studies.

Regarding the general effects of retrocue type, we unexpectedly observed that shape and color cues varied in efficacy. The results are very clear—accuracy was significantly higher for shape-cued trials than for color-cued trials. Given that maintenance of shape and color were both necessary to determine whether the test probe matched an array item, we did not expect to observe any difference. Recent research, however, suggests that the effectiveness of color-based cues diminishes when colored shapes are complex in nature, as more precise VWM representations are required (Li & Saiki, 2015; Quinlan & Cohen, 2011, 2012); to our knowledge, there are no studies that examine the efficacy of form-based cues based on the nature of stimuli. Given that this finding was unanticipated, particularly with respect to the extremely poor performance of older adults for color cues, it is worth examining the nature of these differences in future studies.

Our results raise the question of why the verbal, feature-based retrocue was effective for older adults when a location-based cue in a previous study (Duarte et al., 2013) was not. We believe that this is due to the nature of the cue that we used—namely, that the cue is semantic in nature. Healthy aging is accompanied by declines in working memory and episodic memory, due in part to age-related changes in frontal and temporal structures (e.g., Gazzaley et al., 2007; Raz et al., 2005). In contrast, semantic memory, which is more widely distributed throughout the brain (e.g., Binder, Desai, Graves, & Conant, 2009), is spared these age-related declines (e.g., Kausler, 1994). Given that a verbal, feature-based cue involves more semantic processing than a spatial cue, it is possible that older adults were able to captialize on these preserved features, freeing up cognitive resources for effective top-down modulation of VWM contents. Directly comparing the efficacy of feature-based (i.e., both color and shape) and spatial cues within the experimental paradigm would provide stronger evidence for this possibility (see Li & Saiki, 2015, for a direct comparison of color and location cues). We plan to address this in future research.

There is, however, an alternative explanation for our results, related to the nature of timing in our task. In general, retrocueing tasks utilize short durations for retrocueing presentation (e.g., 100–200 ms); in contrast, the retrocue in the current study was presented for 1000 ms. It could be argued that older adults showed a retrocueing benefit in the current study because they had more time to process the retrocue. (The implication would be that previous studies simply uncovered an age-related deficit in cue-processing times, not one in the effectivenss of cue utilization.) This explanation, however, does not fully account for the results that we obtained: Longer retrocue durations did not assist older adults when color was cued, and it is likely that performance would be even poorer for these trials with shorter cue durations.

In summation, adult aging is typically accompanied by declines in working memory performance. Our results suggest that, when task-relevant, noticeable object features are cued, older adults can use top-down attention to remove irrelevant items from VWM. When irrelevant items are removed, this reduces the effective memory load for older adults and leads to more accurate performance. This is especially important, as previous studies did not report a retrocueing benefit in older adults. Although older adults never reached the performance levels of the young, our findings point to a means of helping older adults improve working memory storage and maintenance. Namely, by directing attention toward relevant features, older adults can appropriately filter items from VWM.

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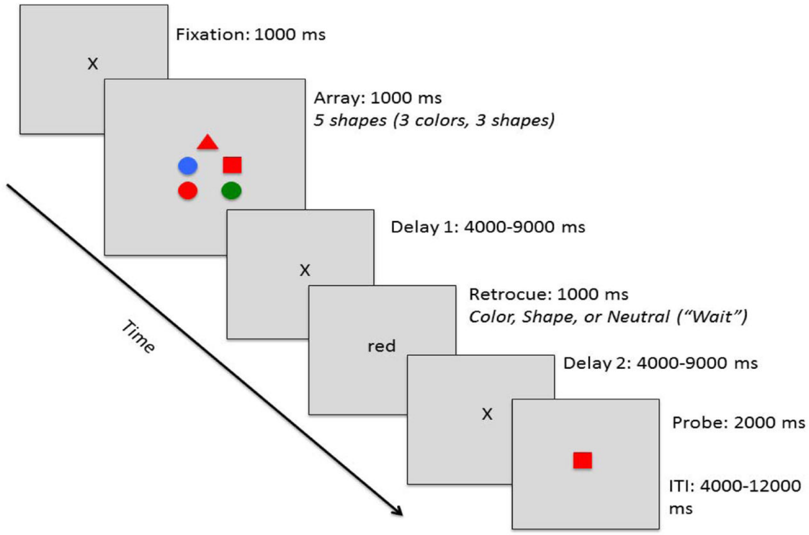

Figure 1.
Schematic of retrocueing procedure for current study.

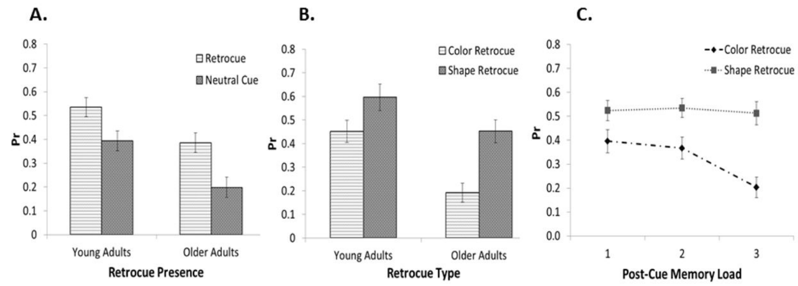

Figure 2.

A) Effect of retrocue presence (i.e., retrocue or neutral cue) on Pr in young and older adults, B) Effect of retrocue type (shape or color) on Pr in young and older adults, C) Effect of retrocue type and post-cue working memory load on Pr. For all panels, error bars are standard errors of the mean.

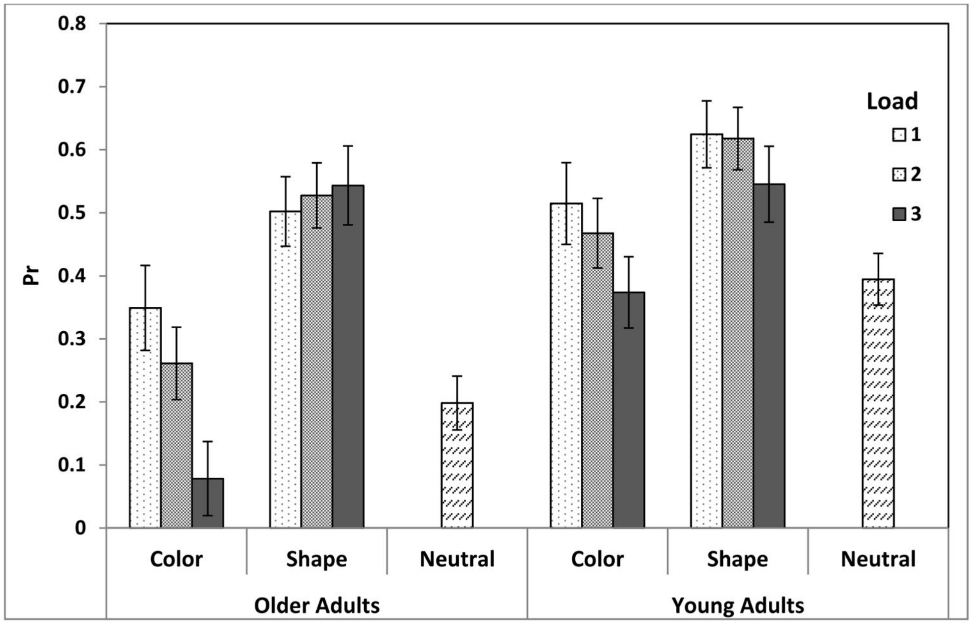

Figure 3.
Effects of retrocue presence, retrocue type, and post-cue working memory load on Pr in young and older adults. Error bars are standard errors of the mean.

Table 1

Marginal Pr means and standard errors for retrocue presence and age group.

Retrocue Presence	
Retrocue: .46 (.03)	*Neutral Cue:* .30 (.03)
Age Group	
Young Adults: .47 (.04)	*Older Adults:* .29 (.04)

Table 2

Marginal Pr means and standard errors for retrocue type, age group, and post-cue memory load.

Retrocue Type		
Color Retrocue: .34 (.03)		*Shape Retrocue:* .56 (.03)
Age Group		
Young Adults: .52 (.04)		*Older Adults:* .38 (.04)
Post-Cue Memory Load		
Load 1: .50 (.04)	*Load 2:* .47 (.03)	*Load 3:* .39 (.03)