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Effects of Prior Knowledge on Active Vision and Memory in Younger and Older Adults

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In our daily lives we rely on prior knowledge to make predictions about the world around us such as where to search for and locate common objects. Yet, equally important in visual search is the ability to inhibit such processes when those predictions fail. Mounting evidence suggests that relative to younger adults, older adults have difficulty retrieving episodic memories and inhibiting prior knowledge, even when that knowledge is detrimental to the task at hand. However, the consequences of these age-related changes for visual search remain unclear. In the present study, we used eye movement monitoring to investigate whether overreliance on prior knowledge alters the gaze patterns and performance of older adults during visual search. Younger and older adults searched for target objects in congruent or incongruent locations in real-world scenes. As predicted, targets in congruent locations were detected faster than targets in incongruent locations, and this effect was enhanced in older adults. Analysis of viewing behavior revealed that prior knowledge effects emerged early in search, as evidenced by initial saccades, and continued throughout search, with greater viewing of congruent regions by older relative to younger adults, suggesting that schema biasing of online processing increases with age. Finally, both younger and older adults showed enhanced memory for the location of congruent targets and the identity of incongruent targets, with schema-guided viewing during search predicting poor memory for schema-incongruent targets in younger adults on both tasks. Our results provide novel evidence that older adults' overreliance on prior knowledge has consequences for both active vision and memory.

Keywords: aging, eye movements, memory, schemas, visual search

Why is it that we consistently find ourselves searching for keys and glasses, and yet, we can locate soap in a novel bathroom with ease? Our ability to locate targets in familiar scenes quickly and effortlessly depends upon schemas, knowledge networks built up from multiple repeated experiences (for review, see Gilboa & Marlatte, 2017). In our daily lives, we rely on schemas to generate predictions, make decisions, and interact smoothly with the world around us. But, what happens when our schemas are violated? In the case of visual search, research suggests that younger adults can rely on visual features (Itti & Koch, 2000) and episodic memory (Chun & Jiang, 1998, 2003) to guide search for schema-incongruent targets (for review, see, Henderson, 2017; Võ & Wolfe, 2013). However, the means by which older adults search for and locate those targets remains unclear. Compared with younger adults, older adults fare poorly on complex visual search tasks in which targets are defined by a conjunction of features rather than a single feature (Chau, Murphy, Rosenbaum, Ryan, & Hoffman, 2011; Plude & Doussard-Roosevelt, 1989; Wynn et al., 2016), and show corresponding declines in processing speed (Salthouse, 1996, 2000), low contrast spatial vision (Haegerstrom-Portnoy, Schneck, & Brabyn, 1999), and episodic memory (Craik, 1986; Rönnlund, Nyberg, Bäckman, & Nilsson, 2005). Critically, however, older adults retain access to, and consistently overrely on schemas, even when such prior knowledge is irrelevant for the task at hand (for review, see Umanath & Marsh, 2014). Although an extensive literature has documented the consequences of these age-related cognitive changes for memory, their effects on active vision are less clear. In the present study, we used a real-world visual search task to investigate the role of prior knowledge (and more specifically, schemas) in the visual search strategies of younger and older adults, and its consequences for subsequent memory.

Converging evidence from the visual search literature suggests that younger adults can use prior knowledge to guide visual search in real-world scenes (for review, see, Henderson, 2017; Võ & Wolfe, 2013). In their seminal study, Loftus and Mackworth (1978) showed that participants preferentially directed and maintained their gaze to an unexpected octopus in a barnyard scene compared with an expected tractor in that same scene, indicating that prior knowledge is used to guide active vision. Research suggests that knowledge about scene contexts, including statistical regularities (e.g., objects must rest on a surface) and learned schemas (e.g., tractors belong in barnyards), reduces the functional

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set size of scene regions that are to be searched by prioritizing relevant locations for scanning (Castelhano & Heaven, 2011; Neider & Zelinsky, 2006; Oliva, Wolfe, & Arsenio, 2004; Torralba, Oliva, Castelhano, & Henderson, 2006). In line with this account, a recent study from Henderson and Hayes (2017) demonstrated that observers' gaze patterns during scene viewing conformed more to the predictions of a semantic *meaning map* than to the predictions of a standard saliency map based on low-level features. Moreover, meaning maps outperformed saliency maps at all time points, suggesting that scene meaning and context are extracted and used to guide eye movements early in the viewing process.

Although schematic support reduces the strain on cognitive resources, it can be detrimental to search when targets are located in unexpected locations. In these situations, successful search is dependent on visual feature guidance and memory for the event in which the target object was last seen (i.e., episodic memory). Using a real-world visual search task, Võ and Wolfe (2013) showed that when target objects were located in schema-incongruent, relative to schema-congruent, locations, a higher percentage of distractor objects was fixated, indicative of a less efficient and directed search. Moreover, the decrease in search time from block 1 (novel) to block 2 (repeated) was greater for schema-incongruent targets relative to schema-congruent targets, suggesting that episodic memory can be used to guide search efficiently in the absence of schematic guidance. In another study, Oliva et al. (2004) showed that in the absence of visual input (when only a portion of a panoramic image was visible), younger adults adopted a memory-based strategy to report successfully the presence of objects in the nonvisible portion of the search array. Taken together, these studies suggest that younger adults' ability to flexibly recruit visual, semantic, and episodic strategies is critical for successful search. Yet, the manner in which older adults adapt their search strategies to changing contexts has been relatively unexplored.

Compared with younger adults, older adults show deficits on episodic memory tasks (Craik, 1986; Rönnlund et al., 2005), particularly those that tax memory for associations (Chalfonte & Johnson, 1996; Mitchell, Johnson, Raye, & D'Esposito, 2000; Naveh-Benjamin, 2000), and these deficits extend to active vision. For example, older adults take significantly longer than younger adults to detect complex targets in visual search tasks (Chau et al., 2011; Plude & Doussard-Roosevelt, 1989; Wynn et al., 2016). Older adults also show a reduction in the repetition effect (Heisz & Ryan, 2011), whereby repeated stimuli elicit fewer fixations and regions sampled than novel stimuli (Althoff & Cohen, 1999; Ryan, Althoff, Whitlow, & Cohen, 2000), and this reduction has been linked to standard measures of memory (Whitehead et al., 2018). Yet, despite age-related declines, older adults show spared performance on associative memory tasks that rely on prior knowledge (for review, see Umanath & Marsh, 2014). For example, when asked to recall the cost of realistically and unrealistically priced grocery store items, older adults show similar memory to younger adults for realistically priced items that are consistent with prior knowledge (Amer, Giovanello, Grady, & Hasher, 2018; Castel, 2005). Moreover, differences in viewing the internal features of faces is minimized between younger and older adults when those faces are age-matched (Firestone, Turk-Browne, & Ryan, 2007) or famous (Heisz & Ryan, 2011), suggesting that older adults can use prior experience (Rhodes & Anastasi, 2012) or knowledge to support binding of perceptual features.

Although prior knowledge can boost older adults' mnemonic performance, it can also be detrimental, particularly when such knowledge interferes with to-be-learned information. For example, older adults are more vulnerable to false memories than younger adults, especially when those memories are consistent with prior knowledge (Norman & Schacter, 1997). Older adults are also more likely to identify lure stimuli as old (Koutstaal, Schacter, & Brenner, 2001; Toner, Pirogovsky, Kirwan, & Gilbert, 2009), and are more susceptible to intrusions during episodic word-list recall relative to younger adults (Kahana, Dolan, Sauder, & Wingfield, 2005). These impairments have been hypothesized to emerge, at least in part, as a result of a more domain-general age-related deficit in inhibition (Hasher & Zacks, 1988; for review, see Lustig, Hasher, & Zacks, 2007). Indeed, studies using eye movement monitoring have demonstrated that age-related inhibitory deficits extend to active vision, with older adults making more saccades toward to-be-ignored cues (i.e., prosaccades; Olincy, Ross, Young, & Freedman, 1997; for review, see Munoz & Everling, 2004), abruptly presented salient cues (Kramer, Hahn, Irwin, & Theeuwes, 2000; Ryan, Leung, Turk-Browne, & Hasher, 2007), and more anticipatory saccades toward the location of expected cues (Ryan, Shen, & Reingold, 2006), relative to young adults. Yet, despite converging evidence indicating that older adults' inhibitory deficits have implications for a variety of cognitive processes and tasks, the extent of older adults' failure to inhibit prior knowledge, and how it interferes with learning of novel associations, remains unclear.

In the present study, we used eye movement monitoring to investigate the degree to which prior knowledge guides the visual search strategies of older adults, and the effect such guidance has on memory for schema-incongruent associations. We had younger and older adults search real-world scenes for target objects that were located in either schema-congruent or schema-incongruent locations across four repeated search blocks. To distinguish schema knowledge (obtained over the course of the lifetime) from statistical regularities (extracted over the course of an experiment), we manipulated the odds of target-scene schema congruency within each scene category (e.g., kitchen) such that targets were located in congruent locations in 100%, 50%, or 0% of search arrays (within a scene category). Following the search task, participants were given two surprise memory tasks in which they were asked to indicate the location of target objects (location task), and to identify target objects from a set of lures (object task).

Given that healthy aging is associated with declines in episodic memory and inhibition, and with increased reliance on prior knowledge, we predicted that older adults' performance would suffer more than that of younger adults in response to target-scene schema-incongruency. That is, relative to younger adults, older adults should show longer search times and direct more viewing toward schema-congruent regions during incongruent search trials. Moreover, we hypothesized that having a predictive context (i.e., a scene category that predicts the schema congruency of the target 100% of the time) would attenuate this effect, particularly in older adults, by providing environmental support and reducing inhibitory demands on incongruent search trials. Finally, we predicted that schema-related interference (i.e., viewing of congruent regions) during incongruent search trials would result in poor performance on subsequent memory tasks.

Method

Participants

Participants were 24 younger adults (YA: 10 males; age: M = 22.96 years, SD = 3.76), aged 18–32 and 24 older adults (OA: 9 males; age: M = 72.17 years, SD = 4.64), aged 63–81 with normal or corrected-to-normal vision. In previous studies, we have observed effects of age on eye movement behavior (gaze reinstatement: Wynn et al., 2016, 2019) using sample sizes of 20 per group. Moreover, a priori power analyses using G*Power (Faul, Erdfelder, Lang, & Buchner, 2007) indicated that a total sample of 14 people would be required to detect a main effect of size d = .96 (based on the significant effect of target-scene congruency on percent of fixated distractors reported in Võ & Wolfe, 2013) with 90% power using a one-way ANOVA with an alpha level of .05, and a total sample of 16 people would be required to detect a 2-way interaction effect size of d = .44 (based on the significant interaction of age and target-scene congruency on visual search response time reported in Neider & Kramer, 2011) with 90% power using a mixed ANOVA with an alpha level of .05. Participants were recruited through the Rotman Research Institute's adult participant pool. All participants provided informed consent before participating in the experiment in accordance with the ethical guidelines of the Rotman Research Institute and were compensated at a rate of $10/hr for their participation. Prior to the start of the experiment, older adults completed the Montreal Cognitive Assessment (MoCA; Nasreddine et al., 2005), a brief standardized neuropsychological test developed to screen for cognitive impairment (M = 27.14 (≥26 = pass), SD = 1.86).[1]

Apparatus

Stimuli were presented on a 1920 × 1080 resolution, 19" Dell M991 monitor. Monocular eye movements were recorded using a head-mounted EyeLink II eyetracking system at 500Hz sampling rate (SR Research Ltd., Mississauga, Ontario). Nine-point eye movement calibration was performed prior to the experiment and drift correction (>5°) was performed prior to each trial. Saccades, blinks, and fixations were defined by EyeLink as: saccades greater than .5° visual angle, period in which saccade signal was missing for three or more consecutive samples, and all remaining samples, respectively.

Stimuli

Stimuli consisted of 72 naturalistic scene images from 12 distinct indoor scene categories. Each scene contained a target object that was semantically related to the scene (e.g., a kettle in a kitchen), with each of the six scenes within a category containing a different exemplar of the same target. Target objects were selected such that participants would have some knowledge of the target's expected location based on prior experience. For each scene, we generated both a congruent and an incongruent version of that scene, with congruent scenes containing the target object in an expected (congruent) location and incongruent scenes containing the target object in an unexpected (incongruent) location (see Figure 1). The relative location of congruent and incongruent targets was consistent across scenes within the same category. For example, each congruent kitchen contained a target kettle on the stovetop, while each incongruent kitchen contained a kettle on the floor. Targets both within and across scenes were balanced in size and location (i.e., screen quadrant).

To facilitate analysis of eyetracking data during the search task, interest areas were manually drawn for each scene around any region that could be reasonably conceived of as congruent with the schema for that scene. For example, for the kitchen scenes, the interest area included the entire stovetop. For scenes in which the target could conceivably appear on any part of a relevant surface (e.g., the desk in the office), the entire surface was defined as an interest area. Scenes within categories were selected to be as similar as possible in structure and layout and thus interest area sizes were relatively stable within categories.

Procedure

Participants completed a repeated visual search task followed by two surprise memory tasks. For the visual search task, participants searched through 72 scene images four times each (once per block, for a total of 288 trials). Prior to the experiment, participants were instructed to search for the indicated target object in each scene and to press the mouse when they located the target. Participants were told that they would have multiple opportunities to search each scene, but they were not told that their memory for those scenes or targets would be tested. On each trial, participants were presented with the name of the target object for that trial (e.g., *Kettle*) for 1,500 ms, followed by the corresponding scene image. Participants were given 3 s to locate the target in each scene. To ensure that there were no discrepancies in viewing time across images, each scene image remained on the screen for 3 s, regardless of whether or not the target was located.

All participants completed six practice trials prior to the start of the experiment to become familiarized with the task. This ensured that participants were aware of the general task demands and expectations regarding the general shape and size of targets. Practice images were from the same scene categories that were used during the experiment, but were not repeated during the experiment. Given that some objects have the potential to appear in multiple shapes, we provided instructions to the participants prior to the experiment to clarify the expected shape of these particular objects. For example, all participants were instructed that they would be searching for a home phone and not a cell phone or a rotary phone in the office scenes, and for a liquid hand soap dispenser rather than a bar of soap in the bathroom scenes. In addition to these instructions, we instructed participants to ask questions during the experiment if they were unsure what the target object should look like.

Scene images were either congruent or incongruent, with the target object located in an expected or unexpected location, respectively. Scene categories (e.g., kitchen) were either predictive, with 100% of the scenes in that category containing the target in the same (congruent or incongruent) location, or unpredictive, with

[1] Four of 24 participants fell below the cutoff for normal performance. Exclusion of these participants did not change the results.

scenes in that category containing the target in either a congruent or incongruent location, with equal (50%) probability. Thus, each scene image belonged to one of four conditions: predictive-congruent, predictive-incongruent, unpredictive-congruent, and unpredictive-incongruent. Conditions were counterbalanced across participants to control for scene-specific viewing effects. In addition, scene categories were counterbalanced across conditions such that there was an equal number of scene exemplars in each condition (i.e., three scene categories and 18 scene exemplars each for predictive-congruent and predictive-incongruent conditions, and six scene categories and 18 scene exemplars for the unpredictive condition.).

Search blocks were divided into four epochs, each containing 24 trials, for a total of 72 trials per block. Each epoch contained two images from each scene category and six from each condition. Images were presented in the same epoch across all blocks to ensure that the delay between repetitions was consistent across images. Image presentation order was randomized within each epoch and block.

To impose a delay (~5 min) between the search task and the memory tasks, participants completed an additional search block (filler task) containing 48 novel images following all four repeated search blocks, and prior to the memory tasks. The novel scene images followed the same rules (i.e., belonged to the same condition) as previously searched images in the same scene category, such that scene categories that were predictive in the search task remained so in the filler task.[2] The images used for the filler task were not counterbalanced across participants and thus were not analyzed.

After participants completed the filler task, they were given two surprise memory tests, balanced in the order in which they were presented. For the location task (Figure 2A), participants were shown scenes that they had searched in the first part of the experiment (i.e., blocks 1–4) without target objects and were asked to indicate where the target object had been located in that scene by mouse press (they were not given information about the identity of the target). For the object task (Figure 2B), participants were shown scenes that they had searched in the first part of the experiment (i.e., blocks 1–4) without target objects for 3 s each, followed by an array of all possible (six) target exemplars for that scene category. Participants were told to select the target object that had appeared in the presented scene by number key press. Half of the images from each condition were presented in each test task

Figure 1. Examples of (A) a congruent scene image with kettle on the stove and (B) an incongruent scene image with kettle on the floor. Participants were given 3 s to search for and locate the target object (indicated by the box, which was not present during the study phase). See the online article for the color version of this figure.

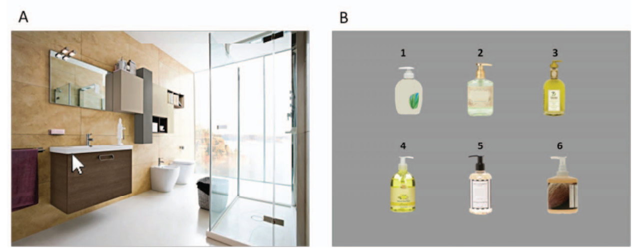

Figure 2. Procedure for the memory tests. (A) Location task: Participants were presented with scene images from the search phase and had to indicate via mouse press where the target object was located. (B) Object task: Participants were shown images from the search phase and had to indicate via key press which target object was present in that scene. See the online article for the color version of this figure.

so as to minimize interference across the tasks. There were no time restrictions on either task.

Data Analysis

Error trials, on which the participant incorrectly pressed the mouse, were removed from all analyses (mean % of total trials: YA = 2.68, OA = 4.51). Error trials were identified in two ways: (a) during the experiment, the experimenter recorded all trials on which the participant indicated that he or she pressed the mouse without having located the target, and (b) following the experiment, eyetracking data was manually inspected to identify trials on which a mouse press was made without any fixations on the target. In addition, trials on which calibration errors[3] occurred were excluded from all interest area analyses (mean % of total trials: YA = 0.80, OA = 1.53). For all other analyses, search time for unsuccessful trials was entered as the maximum, 3,000 ms. One younger adult subject was removed from analysis for the object task on the basis of having a mean score greater than 2.5 standard deviations from the young adult group mean.[4]

To evaluate performance on the search task, we conducted repeated measures ANOVAs (afex package) on Search Time (time to target detection in ms), % Successful Trials (proportion of trials on which the target was located within the 3s time limit), Congruent IA (interest area) % Viewing Time[5] (proportion of total viewing time spent in congruent interest areas, see Figure 3), and Congruent IA % Initial Saccades (proportion of initial saccades terminating in a congruent interest area), with Age (younger,

[2] Although we cannot speak to how an unrelated filler task might have affected the results, we opted to use the same search task for two reasons: (a) So that participants would not remove the eyetracker prior to the memory tasks, and (b) so that participants would not be surprised by a task switch, and would simply treat the filler task as an extension of the search task.

[3] Calibration errors were defined by both in-experiment and post hoc observations. During the experiment, errors in the intertrial drift correct were noted. Eye movements for each trial were also visually inspected post hoc to check for calibration errors. Trials were excluded from the interest area analysis on the basis of gross calibration errors wherein fixation on the target was markedly far removed from the target itself.

[4] Excluding this subject did not change the results.

[5] Note that this measure is a proportion and thus controls for variability in speed of response.

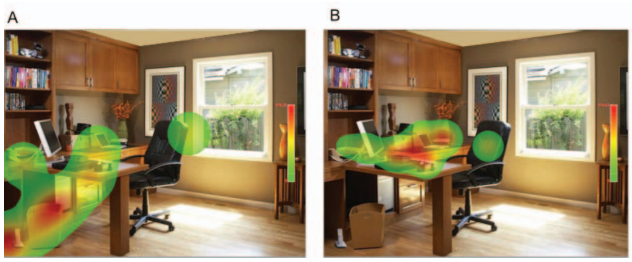

Figure 3. Examples of heat maps reflecting the overall fixation distributions for a younger adult (A) and older adult (B) subject searching a novel office scene (block 1) for a target telephone in an incongruent location (bottom left corner). In this example, the desk surface serves as the congruent interest area. Note that in this example, the older adult subject's search was unsuccessful. See the online article for the color version of this figure.

older) as a between-subjects factor and Congruency (congruent, incongruent), and Context (predictive, unpredictive) as within-subjects factors. To best differentiate episodic from schematic memory guidance, we ran separate ANOVAs on data from block 1 (novel search arrays) and aggregated data from blocks 2–4 (repeated search arrays). Whereas target detection on block 1 can be accomplished using either visual features or prior knowledge of schemas for guidance, search on blocks 2–4 can additionally benefit from episodic memory guidance. Planned comparisons of significant interactions were conducted with lsmeans with Bonferroni-corrected p values.

Performance on both the object (overall % correct) and location (pixel distance from the center of the target object) memory tasks were likewise evaluated with repeated measures ANOVAs with Age (younger, older) as a between-subjects factor and Congruency (congruent, incongruent), and Context (predictive, unpredictive) as within-subjects factors. Search arrays on which the target object was not located on block 4 of the search task (and thus not remembered) were removed prior to analysis.

Results

Search Task

Performance on the search task (% of successful trials on which the target was located within the 3s search limit) was high in both groups and increased across repeated search blocks, see Table 1. For all subsequent analyses, we analyzed the data from block 1 (novel search) and the aggregated data from blocks 2–4 (repeated search, i.e., search for which participants may use episodic memory guidance) separately.

Novel Search (Block 1)

Search time (ms). Results of the ANOVA for novel (block 1) Search Time (ms) revealed significant effects of Age, $F(1, 46) = 91.80$, $p < .001$, $\eta_p^2 = .67$, and Congruency, $F(1, 46) = 354.10$, $p < .001$, $\eta_p^2 = .89$, and a significant interaction of Age × Congruency, $F(1, 46) = 42.32$, $p < .001$, $\eta_p^2 = .48$ (see Figure 4A). An independent samples t test comparing the difference in mean search times (incongruent-congruent) between younger and older adults was significant, $t(45.81) = 6.403$, $p < .001$, $d = 1.85$, reflecting a larger age effect on incongruent trials, $t(69.46) = 11.506$, $p < .001$, relative to congruent trials, $t(69.46) = 5.470$, $p < .001$. Consistent with our predictions, this finding suggests that older adults are disproportionately impaired at detecting targets that violate schema expectations. Unexpectedly, we observed a significant effect of Context on search time, $F(1, 46) = 12.47$, $p = .001$, $\eta_p^2 = .21$, suggesting that environmental regularities, in this case, scene category labels that predict the congruency of the target location, are extracted early (within the first 72 trials) and used to guide search. Interactions of Context × Congruency, $F(1, 46) = .01$, $p = .94$, Context × Age, $F(1, 46) = .06$, $p = .81$, and Context × Congruency × Age, $F(1, 46) = 1.1$, $p = .30$, were not significant.

% successful trials. In line with the results of the ANOVA on Search Time, results of the ANOVA on % Successful Trials revealed significant effects of Age, $F(1, 46) = 127.53$, $p < .001$, $\eta_p^2 = .73$, Context, $F(1, 46) = 6.25$, $p = .02$, $\eta_p^2 = .12$, and Congruency, $F(1, 46) = 165.67$, $p < .001$, $\eta_p^2 = .78$, and a significant interaction of Age × Congruency, $F(1, 46) = 49.51$, $p < .001$, $\eta_p^2 = .52$. An independent samples t test comparing the difference in the mean % of successful trials (incongruent-congruent) between younger and older adults was also significant, $t(35.30) = 7.06$, $p < .001$, $d = 2.04$, with a greater age effect (i.e., difference between younger and older adults) on incongruent trials, $t(91.99) = -12.972$, $p < .001$, relative to congruent trials, $t(91.99) = -3.058$, $p = .003$. Interactions of Context × Congruency, $F(1, 46) = .01$, $p = .92$, Context × Age, $F(1, 46) = 1.91$, $p = .17$, and Context × Congruency × Age, $F(1, 46) = 1.92$, $p = .17$, were not significant.

Congruent IA % viewing time. Similar to the behavioral results, results of the ANOVA on novel (block 1) Congruent IA % Viewing Time (% of total viewing time in congruent areas) revealed significant effects of Age, $F(1, 46) = 15.29$, $p < .001$, $\eta_p^2 = .25$, and Congruency, $F(1, 46) = 461.34$, $p < .001$, $\eta_p^2 = .91$, and significant interactions of Age × Congruency, $F(1, 46) = 21.05$, $p < .001$, $\eta_p^2 = .31$, and Context × Congruency, $F(1, 46) = 4.70$, $p = .04$, $\eta_p^2 = .09$ (see Figure 4B). Post hoc tests revealed that older adults spent significantly more time viewing congruent interest areas during search for targets in incongruent locations relative to younger adults, $t(91.76) = 6.02$, $p < .001$, whereas age differences in Congruent IA % Viewing Time were not significant for targets located in congruent locations, $t(91.76) = -.634$, $p > .05$. Moreover, predictive contexts significantly attenuated the effect of schema-congruency by diminishing the amount of time spent in congruent interest areas on incongruent trials,

Table 1
Percentage of Total Successful Trials by Age and Block

Age	Block	% Successful trials
YA	1	89.20
YA	2	96.54
YA	3	98.34
YA	4	99.04
OA	1	65.75
OA	2	78.87
OA	3	85.82
OA	4	89.41

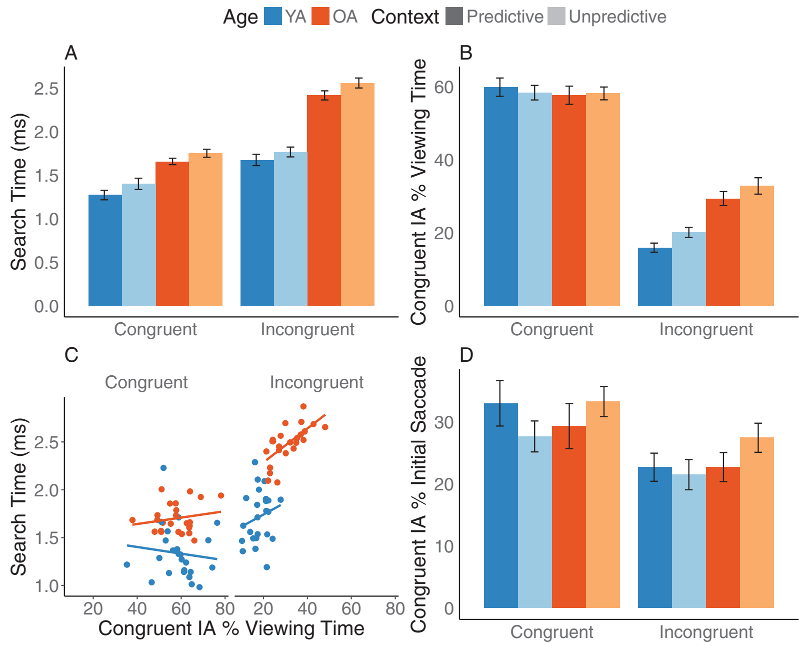

Figure 4. Results of novel search (block 1). (A) Search Time (ms) by Age, Congruency, and Context. (B) Congruent IA % Viewing Time by Age, Congruency, and Context. (C) Correlations between Search Time (ms) and Congruent IA % Viewing Time by Age and Congruency. (D) Congruent IA % Initial Saccades terminating in a congruent IA by Age, Congruency, and Context. See the online article for the color version of this figure.

$t(82.32) = -2.264$, $p = .026$, but not on congruent trials, $t(82.32) = 0.221$, $p > .05$. Effects of Context, $F(1, 46) = 1.55$, $p = .22$, Context × Age, $F(1, 46) = 0.16$, $p = .69$, and Context × Congruency × Age, $F(1, 46) = 0.14$, $p = .71$, were nonsignificant.

To further describe the relationship between eye movements and performance, we ran bootstrapped Pearson correlations (n = 5,000) of Search Time (ms) and Congruent IA % Viewing Time for younger and older adults on congruent and incongruent trials (see Figure 4C). Results of the bootstraps revealed a robust relationship between Search Time (ms) and Congruent IA % Viewing Time for older adults on incongruent trials ($r = .65$, 95% CI [.49, .81]), indicating that using a schema-driven search strategy negatively impacted older adults' performance on incongruent search arrays. We did not find evidence for such a relationship for younger or older adults on congruent trials (YA: $r = -.11$, 95% CI [−.53, .31]; OA: $r = .21$, 95% CI [−.21, .65]), nor for younger adults on incongruent trials ($r = .20$, 95% CI [−.17, .57]).

Congruent IA % initial saccades. Previous work has suggested that scene semantics can be extracted and used to guide viewing in as little as 250ms (Castelhano & Henderson, 2007; Hannula, Ryan, Tranel, & Cohen, 2007; Henderson & Hayes, 2017; Neider & Zelinsky, 2006). To determine whether the observed effects of prior knowledge and context emerged early during search, we subsequently examined the percentage of initial saccades that terminated in a congruent interest area. On average, participants' initial saccades were initiated 246.38ms (SD = 78.59) after scene onset, which occurred following a 1,500 ms word cue (e.g., *kettle*). Results of this ANOVA revealed a significant effect of Congruency, $F(1, 46) = 16.85$, $p < .001$, $\eta_p^2 = .27$, with a greater percentage of initial saccades directed toward a congruent IA on congruent relative to incongruent trials (Figure 4D). This result indicates that target-scene schema congruency is extracted from the scene early by both younger and older adults. Other effects were not significant [Age: $F(1, 46) = .89$, $p = .35$; Age × Congruency: $F(1, 46) = .26$, $p = .61$; Context: $F(1, 46) = .12$, $p = .73$; Age × Context: $F(1, 46) = 2.52$, $p = .12$; Context × Congruency: $F(1, 46) = .38$, $p = .54$; Age × Context × Congruency: $F(1, 46) = .07$, $p = .79$].

Results summary. Taken together, the results from novel search (block 1) suggest that in both younger and older adults, target-scene schema congruency supports visual search performance. Moreover, results of the viewing analysis suggest that schemas guide eye movements during active vision, with schema-guided eye movements mediating search performance. Schema effects on both behavioral and eye movement measures of search performance differ as a function of age, with older adults relying on schemas to a greater extent than younger adults. Finally, in line with previous work, results of the analysis on initial saccades suggest that semantic information, in this case, schema congruency, is processed early in search (<250ms) by both younger and older adults.

Repeated Search (Blocks 2–4)

Search time (ms). Results of the ANOVA for repeated (blocks 2–4) Search Time (ms) revealed significant main effects of Age, $F(1, 46) = 59.78$, $p < .001$, $\eta_p^2 = .57$, Congruency, $F(1, 46) = 54.54$, $p < .001$, $\eta_p^2 = .54$, and Context, $F(1, 46) = 84.38$, $p < .001$, $\eta_p^2 = .65$, as well as significant interactions of Age × Congruency, $F(1, 46) = 36.29$, $p < .001$, $\eta_p^2 = .44$, Age ×

Context, $F(1, 46) = 6.09$, $p = .02$, $\eta_p^2 = .12$, and Context × Congruency, $F(1, 46) = 5.03$, $p = .03$, $\eta_p^2 = .1$, and an indeterminate interaction of Age × Context × Congruency, $F(1, 46) = 2.98$, $p = .09$, $\eta_p^2 = .06$ (see Figure 5A). Post hoc tests revealed that as in block 1, older adults detected targets more quickly when they were located in a schema-congruent as opposed to a schema-incongruent location, $t(46) = -9.482$, $p < .001$. However, unlike the novel search (block 1) results, younger adults did not show a significant search time advantage for targets located in schema-congruent relative to schema-incongruent locations during repeated search (blocks 2–4), $t(46) = -.962$, $p > .05$, suggesting that they no longer use a schema-based strategy when episodic memory guidance is available. Moreover, whereas predictive contexts significantly benefitted search for targets located in incongruent locations, $t(85.61) = -3.628$, $p < .001$, context did not have a significant effect on search for targets located in congruent locations, $t(85.61) = 1.458$, $p > .05$. Independent samples *t* test comparing the difference in mean search times (predictive-unpredictive) between younger and older adults, $t(47) = -2.484$, $p = .018$, $d = -.72$, further indicated that predictive contexts had a greater search time benefit for older adults, $t(46) = -227.59$, $p < .001$, than for younger adults, $t(46) = -129.24$, $p < .001$.

% successful trials. Extending the results of the ANOVA on Search Time, results of the ANOVA on % Successful Trials for repeated blocks (2–4) revealed significant effects of Age, $F(1, 46) = 72.38$, $p < .001$, $\eta_p^2 = .61$, Congruency, $F(1, 46) = 34.94$, $p < .001$, $\eta_p^2 = .43$, and Context, $F(1, 46) = 22.56$, $p < .001$, $\eta_p^2 = .33$, as well as significant interactions of Age × Congruency, $F(1, 46) = 24.09$, $p < .001$, $\eta_p^2 = .34$, Age × Context, $F(1, 46) = 7.40$, $p = .009$, $\eta_p^2 = .14$, and Context × Congruency, $F(1, 46) = 5.64$, $p = .02$, $\eta_p^2 = .11$. The interaction of Age × Context × Congruency was not significant, $F(1, 46) = 1.69$, $p = .2$. Post hoc tests revealed that older, but not younger adults detected more targets when they were in schema-congruent as opposed to schema-incongruent locations [OA: $t(46) = 7.65$, $p < .001$; YA: $t(46) = 0.709$, $p > .05$]. Moreover, predictive contexts significantly benefitted search for targets located in incongruent locations, $t(90.54) = 4.92$, $p < .001$, but not congruent locations, $t(90.54) = 1.355$, $p = .179$. Finally, older adults, $t(46) = 5.282$, $p < .001$, but not younger adults, $t(46) = 1.435$, $p = .158$, derived a target detection benefit from predictive context cues.

Congruent IA % viewing time. Results of the ANOVA for blocks 2–4 Congruent IA % Viewing Time revealed significant main effects of Age, $F(1, 46) = 27.05$, $p < .001$, $\eta_p^2 = .37$, and Congruency, $F(1, 46) = 769.20$, $p < .001$, $\eta_p^2 = .94$, reflecting greater schema-guided viewing by older adults relative to younger adults and on congruent trials relative to incongruent trials. We also observed significant interactions of Age × Congruency, $F(1, 46) = 4.13$, $p = .05$, $\eta_p^2 = .08$, and Context × Congruency, $F(1, 46) = 17.8$, $p < .001$, $\eta_p^2 = .28$, and a marginally significant interaction of Age × Context × Congruency [, $F(1, 46) = 3.49$, $p = .07$, $\eta_p^2 = .07$ (see Figure 5B). Post hoc tests revealed that relative to younger adults, older adults spent more time viewing congruent interest areas during search for targets in incongruent locations, $t(45.84) = 2.007$, $p = .05$, but not congruent locations, $t(90.02) = 1.855$, $p = .07$. Moreover, predictive contexts significantly attenuated the congruency effect by diminishing the amount of time spent in congruent interest areas on incongruent trials,

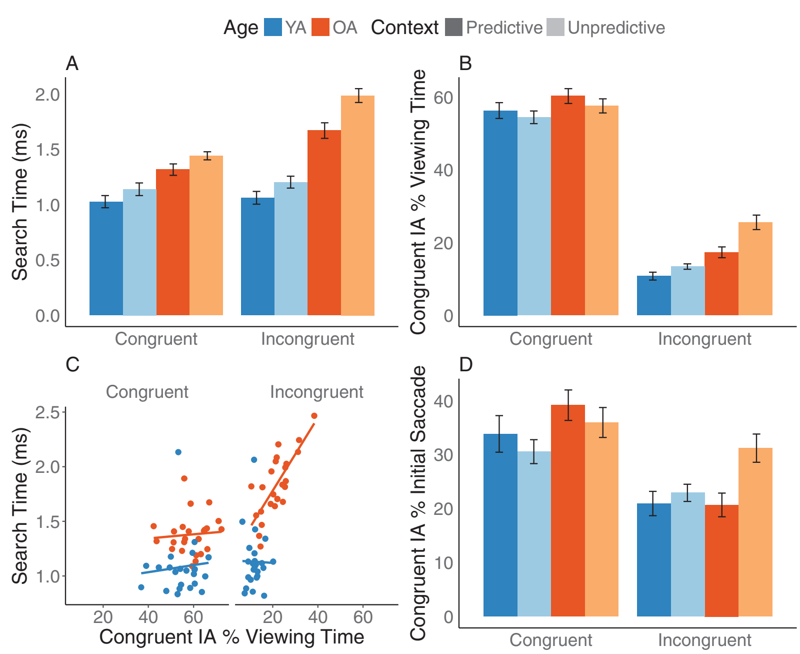

Figure 5. Results of repeated search (blocks 2–4). (A) Search Time (ms) by Age, Congruency, and Context. (B) Congruent IA % Viewing Time by Age, Congruency, and Context. (C) Correlations between Search Time (ms) and Congruent IA % Viewing Time by Age and Congruency. (D) Congruent IA % Initial Saccades terminating in a congruent IA by Age, Congruency, and Context. See the online article for the color version of this figure.

$t(85.61) = -3.628$, $p < .001$, but not on congruent trials, $t(85.61) = 1.458$, $p > .05$.

Similarly to Block 1, bootstrapped correlations (see Figure 5C) revealed a robust relationship between Search Time (ms) and Congruent IA % Viewing Time for older adults on incongruent trials ($r = .77$, 95% CI [.59, .97]), but not for younger or older adults on congruent trials (YA: $r = .10$, 95% CI [−.27, .40]; OA: $r = .08$, 95% CI [−.22, .37]) nor for younger adults on incongruent trials ($r = -.01$, 95% CI [−.42, .37]).

Congruent IA % initial saccades. Results of the ANOVA on initial saccade landing position revealed significant effects of Age, $F(1, 46) = 6.07$, $p = .02$, $\eta_p^2 = .12$, and Congruency, $F(1, 46) = 37.91$, $p < .001$, $\eta_p^2 = .45$, with a greater percentage of initial saccades directed toward a congruent IA by older adults relative to younger adults and on congruent relative to incongruent trials, and a significant interaction of Congruency × Context, $F(1, 46) = 11.25$, $p = .002$, $\eta_p^2 = .2$ (see Figure 5D). Post hoc tests revealed that predictive contexts significantly attenuated early schema guidance for incongruent targets only, $t(78.03) = -2.198$, $p = .031$; congruent: $t(78.03) = 1.404$, $p = .164$. All other effects were nonsignificant [Context: $F(1, 46) = 0.22$, $p = .64$; Age × Context: $F(1, 46) = 0.75$, $p = .39$; Age × Congruency: $F(1, 46) = 0.18$, $p = .68$; Age × Context × Congruency: $F(1, 46) = 2.32$, $p = .13$].

Results summary. Extending the results from novel search (block 1), the results from repeated search (blocks 2–4) suggest that whereas repetition abolishes schema effects in younger adults, older adults continue to rely on prior knowledge even when searching for targets in previously seen incongruent locations, suggesting that more effective sources of search guidance (i.e., episodic memory) may be unavailable or just not used. Moreover, across both groups, schema effects were attenuated when predictive cues preceded search, suggesting that contextual guidance can support search for incongruent targets.

Memory Tasks

Location memory task. Following the search task, participants completed two surprise memory tasks. For the target location task, participants were shown half of the scenes presented at study and were required to select the location of a previously presented target object in a corresponding scene (note that greater distance from target location indicates poor performance). Results of the ANOVA on target location performance (pixel distance from the location of the mouse press to the center of the target) revealed significant effects of Age, $F(1, 46) = 5.81$, $p = .02$, $\eta_p^2 = .11$, Congruency, $F(1, 46) = 27.11$, $p < .0001$, $\eta_p^2 = .37$, and Context, $F(1, 46) = 11.84$, $p = .001$, $\eta_p^2 = .20$, on performance (see Figure 6A). Location memory accuracy was higher (i.e., lower pixel distance to target) for younger adults relative to older adults, congruent targets relative to incongruent targets, and predictive contexts, M (SD) = 143.79 (77.76), relative to unpredictive contexts, M (SD) = 187.00 (117.07). There were no significant interactions, Age × Congruency: $F(1, 46) = 0.13$, $p = .72$; Age × Context: $F(1, 46) = 2.5$, $p = .12$; Congruency × Context: $F(1, 46) = 0.17$, $p = .68$; Age × Congruency × Context: $F(1, 46) = 0.07$, $p = .80$.

Given older adults' tendency to overrely on schemas, we subsequently examined whether prior knowledge interfered with location memory for targets in incongruent locations. For each

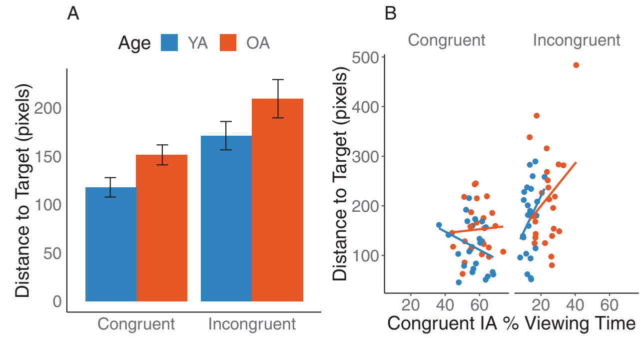

Figure 6. (A) Target location performance (pixel distance from the center of the target) by Age and Congruency. (B) Correlation between target location performance (distance to target in pixels) and Congruent IA % Viewing Time by Age and Congruency. See the online article for the color version of this figure.

incongruent location memory test trial, we coded the location of the participant's mouse press as either falling within or outside of the congruent IA for that image. We then conducted an ANOVA on the proportion of location memory test trials on which the mouse press fell within a congruent IA as a function of Age and Context. Two subjects (1 YA, 1 OA) were removed prior to analysis on the basis of mean scores >2.5 standard deviations from their respective group means. Results of the ANOVA revealed a marginally significant effect of Age, $M_{OA} = 22.83\%$, $M_{YA} = 17.25\%$; $F(1, 44) = 3.70$, $p = .06$, $\eta_p^2 = .08$, and a significant effect of Context, $M_{predictive} = 5.86\%$, $M_{unpredictive} = 34.22\%$; $F(1, 44) = 77.82$, $p < .0001$, $\eta_p^2 = .64$. The interaction of Age × Context was nonsignificant, $F(1, 44) = 0.00$, $p > .05$, $\eta_p^2 < .001$. These findings suggest that older adults' overreliance on schemas has detrimental effects on memory for incongruent search targets, and further, that nesting incongruent information in a predictive context may support spatial memory by protecting against interference from prior knowledge.

To better understand the relationship between schema guidance during search and subsequent performance on the location memory task, we ran bootstrapped Pearson correlations ($n = 5000$) of Congruent IA % Viewing Time averaged across all search blocks (excluding unsuccessful trials) with performance on the location memory task (distance to target) for younger and older adults on congruent and incongruent search arrays (see Figure 6B). Results of the bootstraps revealed a robust relationship between schema-driven viewing during incongruent search trials and location memory performance for younger adults ($r = .32$, 95% CI [.01, .65]), suggesting that failure to inhibit prior knowledge when encoding schema-incongruent associations has consequences for subsequent memory. No such effects were observed for congruent trials (YA: $r = -.29$, 95% CI [−.63, .05]; OA: $r = .06$, 95% CI [−.30, .42]) nor for older adults on incongruent trials ($r = .28$, 95% CI [−.25, .92]).

Object memory task. For the object memory task, participants were shown half of the scenes presented at study and were required to select the associated target object from an array of lures (taken from other scenes in the same category, chance = 1/6). Results of the ANOVA on object recognition performance revealed a significant effect of Congruency, $F(1, 45) = 10.5$, $p =$

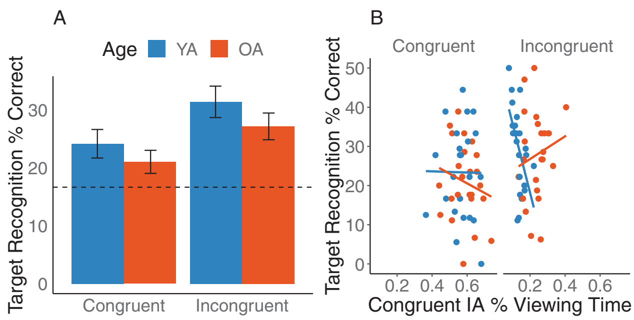

Figure 7. (A) Target object recognition performance (% correct) by Age and Congruency. (B) Correlation between object recognition performance (% correct) and Congruent IA % Viewing Time by Age and Congruency. See the online article for the color version of this figure.

.002, η_p^2 = .19, with higher accuracy on incongruent relative to congruent trials (see Figure 7A). Notably, we did not observe a significant effect of Age on object recognition performance, $F(1, 45) = .95$, $p = .33$, $\eta_p^2 = .02$, although younger adults performed numerically better than older adults. All other effects were nonsignificant, Age × Congruency: $F(1, 45) = 0.02$, $p = .88$, Context: $F(1, 45) = 0.67$, $p = .42$, Age × Context: $F(1, 45) = 3.24$, $p = .08$, Congruency × Context: $F(1, 45) = 0.28$, $p = .60$, Age × Congruency × Context: $F(1, 45) = 0.9$, $p = .35$. To ensure that the recognition benefit for target objects in incongruent locations was not a result of viewing of those objects for longer compared with target objects in congruent locations, we compared the mean proportion of total viewing time (over the full 3-s trial) spent on the target object for congruent and incongruent trials. A paired samples *t* test of the difference in mean proportion of viewing time for congruent and incongruent trials was significant, $t(46) = 8.89$, $p < .001$, $d = .91$. On average, participants spent a greater proportion of total viewing time on targets located in congruent locations ($M = 15.591\%$) compared with targets located in incongruent locations ($M = 11.164\%$), suggesting that the recognition benefit for targets in incongruent locations cannot be attributed to greater viewing of those targets during search. Indeed, viewing of targets in incongruent locations was not significantly correlated with object recognition performance, $r = .051$, $p = .735$.

Similar to the findings from the location memory task, schema-guided viewing during incongruent search trials was robustly associated with performance on the object memory task for younger adults ($r = -.54$, 95% CI [−.80, −.28]; see Figure 7B), suggesting that greater reliance on schemas during search has negative consequences for subsequent memory. This effect was not observed for congruent targets in younger ($r = -.01$, 95% CI [−.44, .42]) or older adults ($r = -.19$, 95% CI [−.57, .18]), nor for incongruent targets in older adults ($r = .16$, 95% CI [−.20, .54]).

Discussion

Healthy aging has been associated with several cognitive changes including declines in episodic memory (Craik, 1986; Rönnlund et al., 2005) and inhibition (Hasher & Zacks, 1988; for review, see Lustig et al., 2007) and a corresponding increased reliance on prior knowledge (for review, see Umanath & Marsh, 2014). Although the outcomes of these age-related changes for memory have been extensively studied and modeled, their effects on active vision remain less well understood. In the present study, we used eye movement monitoring to investigate age differences in visual search and memory for search targets whose locations were either congruent or incongruent with prior knowledge. In line with our predictions, older adults were disproportionately impaired on searches for target objects located in schema-incongruent locations as evidenced by longer search times and greater viewing of congruent regions relative to younger adults. Moreover, in younger adults, engagement of prior knowledge during search predicted poor memory for target objects located in incongruent locations, suggesting that prior knowledge effects on active vision can have downstream consequences for memory.

The results of the present study suggest that in real-world scenes, older adults rely on schemas to guide object search to a greater extent than do younger adults. Although both younger and older adults located targets in congruent locations more quickly than targets in incongruent locations during novel search (i.e., block 1), older adults were disproportionately impaired at detecting targets in incongruent locations relative to younger adults, and this effect persisted across repeated search blocks (2–4) for older adults, but not for younger adults. That is, when episodic memory guidance was available (blocks 2–4), younger adults no longer relied on prior knowledge to guide search, while older adults continued to do so. These findings are consistent with previous research showing that in the face of cognitive declines, older adults rely on other forms of top-down viewing guidance, and in some cases, even show a greater effect than younger adults of such guidance on gaze behavior (Madden, Whiting, Cabeza, & Huettel, 2004; Madden, Whiting, Spaniol, & Bucur, 2005). For example, a study by Neider and Kramer (2011) found that compared with younger adults, older adults showed a greater search time benefit for scene-constrained (e.g., a blimp, which could only reasonably appear in the sky) relative to unconstrained (e.g., a novel abstract object, which could appear anywhere) targets, suggesting that contextual guidance plays a particularly salient role in the visual search of older adults. Controlling for general age-related slowing did not abolish this effect, further suggesting that age-related impairments in visual search for unconstrained (by schemas) targets cannot be attributed to general slowing of perceptual processes. Other work has further suggested that older adults can use compensatory eye movement strategies to support visuospatial relational memory performance (Wynn et al., 2019; for review, see Wynn et al., 2019). Taken together, these findings suggest that older adults' overreliance on prior knowledge and other forms of top-down viewing guidance might compensate for age-related cognitive declines, including declines in episodic memory and inhibition.

Although search times can help to elucidate age differences in reliance on prior knowledge, a particular goal of the present study was to probe the extent to which older adults' overreliance on prior knowledge biases their encoding of novel and well-known associations. Eye movement monitoring allowed us to address this question by providing a reliable and indirect index of cognitive biases in real time, while circumventing the stereotype threat associated with explicit memory reports (Rahhal, Colcombe, & Hasher, 2001; see Hannula et al., 2007). Results of the viewing analysis revealed that relative to younger adults, older adults spent more time viewing congruent regions during search for targets located in incongruent locations, and this effect (schema-driven viewing) was negatively correlated with search performance for targets in incongruent locations in older adults. In addition, although we did not see a significant interaction of age and congruency on either of the memory tasks, older adults were marginally more likely than younger adults to incorrectly select a schema-congruent location as the location of a schema-incongruent target on the location memory task. In line with the search results, these findings suggest that older adults may rely on a strategy based on prior knowledge to support search and memory performance to compensate for age-related declines in episodic memory and inhibition.

Interestingly, for both younger and older adults, schema effects on viewing emerged early in the search process, with a significantly greater proportion of initial fixations landing in congruent regions on congruent relative to incongruent trials. In line with previous findings of early conceptual processing of scenes (Castelhano & Henderson, 2007; Henderson & Hayes, 2017; Neider & Zelinsky, 2006), this result suggests that the processing of schema congruency occurs early and is age-invariant. Taken together with the observed age difference in viewing, this finding further suggests that older adults' disproportionate slowing in locating targets in schema-incongruent locations cannot be explained by age differences in the initial activation of prior knowledge. Rather, these age differences might be attributed to a number of possible factors including deficient inhibition and impaired episodic memory resulting from a deficit in relational binding. Thus, age-related differences in our study may have resulted from older adults' failure to inhibit prior knowledge from biasing visual attention toward schema-congruent regions in addition to, or as a result of, age-related declines in episodic memory and inhibition. Indeed, previous work suggests that relative to younger adults, older adults have concurrent deficits in both binding and inhibition. A study by Ryan et al. (2007) showed that older adults directed more viewing to a to-be-ignored abrupt onset item than younger adults, reflecting a deficit in inhibition. However, when that item was subsequently manipulated, only younger adults directed increased viewing to the changed region, indicating that older adults, despite viewing the manipulated item, failed to bind it together with the other encoded items into a lasting memory trace. Although it is unclear whether deficits in relational binding underlie deficits in inhibition or visa versa, our results suggest that as a result of these deficits, older adults rely on other available cognitive mechanisms, in this case, prior knowledge, to support performance.

Notably, although the search cost for incongruent target locations was increased for older adults relative to younger adults, older adults derived a greater performance benefit from predictive context cues than younger adults, consistent with findings of reduced age-related inhibitory deficits with environmental support (repetition: Ryan et al., 2007; predictive cues: Madden et al., 2004; Ryan et al., 2006). Notably, unlike the congruency manipulation (which was made immediately obvious during the practice trials), participants were not made explicitly aware of the context manipulation, and did not become explicitly aware, as indicated by postexperiment interviews. Thus, age differences in the context effect suggest that in addition to explicit top-down knowledge (e.g., prior knowledge), older adults can utilize implicit knowledge (e.g., contextual cues) to support visual search for targets in real-world scenes. Indeed, evidence of contextual cueing (decreased reaction time (RT) with repeated search configurations) in older adults suggests that implicit learning of spatial context is preserved with age (Howard, Howard, Dennis, Yankovich, & Vaidya, 2004; Madden et al., 2005), and other work suggests that it may even be enhanced (Campbell, Zimerman, Healey, Lee, & Hasher, 2012). For example, whereas both younger and older adults show implicit learning of statistical regularities in attended streams of information, only older adults show learning of regularities embedded in unattended streams (Campbell et al., 2012). Moreover, older adults not only encode environmental regularities and item co-occurrences, but can also use this information to boost task performance (for review, see Amer et al., 2018). Consistent with these findings, we observed a significant interaction of context and congruency on both the search task and the location memory task, suggesting that contextual support during perception can modulate encoding and benefit later memory.

Although the primary objective of the present study was to investigate the effects of prior knowledge on the visual search strategies of older adults, our findings are additionally informative to an understanding of the effects of prior knowledge on memory more generally. Research on the effects of schema congruency on memory has been mixed, with some studies reporting mnemonic benefits for schema-congruent information (Amer et al., 2018; Castel, 2005, 2007) and others reporting benefits for schema-incongruent information (Greve, Cooper, Kaula, Anderson, & Henson, 2017; Mäntylä & Bäckman, 1992). In the present study, both younger and older adults showed a benefit for schema-congruent locations relative to schema-incongruent locations on the location memory task (select the location of the associated target object), suggesting that prior knowledge can support performance that relies on knowledge of expected object locations. In contrast, performance on the object memory task (select the associated target object from an array of lures, which were target objects from other scenes in the same category) was better for targets located in incongruent locations, suggesting that schema violations (i.e., novelty) might benefit performance on tasks that rely on retrieval of detailed memory representations (see also, Van Kesteren et al., 2012). Younger adults outperformed older adults on both tasks, but only performance on the location memory task showed significant age differences. Given the difference in performance measures across the two tasks (distance to target vs. target recognition % correct), further work will be required to elucidate age differences in schema effects on memory.

In summary, the results of the present study demonstrate that age-related declines in episodic memory, and inhibition, and increased reliance on contextual cues and prior knowledge, have consequences for both active vision and memory. In line with our predictions, older adults' search performance benefitted more from schema congruency than did that of younger adults, who were able to use episodic memory to guide target detection on repeated search arrays. Moreover, older adults showed disproportionate viewing of congruent image regions during incongruent search trials relative to younger adults, despite showing similar facilitation of initial fixations by prior knowledge, and this resulted in poor search performance, suggesting that prior knowledge guides online visual processing by older adults. Lastly, both younger and older adults demonstrated superior performance on the location memory task for targets in congruent locations, and on the object memory task for targets in incongruent locations, indicating that schemas can both help and hinder memory, depending on task conditions. Taken together, the present findings provide novel evidence that the age-related shift from reliance on episodic memory to reliance on prior knowledge extends to visual search, with immediate and persistent consequences for both active vision and memory. Moreover, these findings advance a critical role for eye movement monitoring at the intersection of vision and memory research (see also Ryan et al., 2018; Shen, McIntosh, & Ryan, 2014). Future work should continue to explore the relationship between active vision and memory, and in particular, how attentional biases associated with healthy aging modulate memory encoding and retrieval.

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