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OLDER ADULTS CAPITALIZE ON CONTEXTUAL INFORMATION TO GUIDE SEARCH

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Much has been learned about the age-related cognitive declines associated with the attentional processes that utilize perceptual features during visual search. However, questions remain regarding the ability of older adults to use scene information to guide search processes, perhaps as a compensatory mechanism for declines in perceptual processes. The authors had younger and older adults search pseudorealistic scenes for targets with strong or no spatial associations. Both younger and older adults exhibited reaction time benefits when searching for a target that was associated with a specific scene region. Eye movement analyses revealed that all observers dedicated most of their time to scanning target-consistent display regions and that guidance to these regions was often evident on the initial saccade of a trial. Both the benefits and costs related to contextual information were larger for older adults, suggesting that this information was relied on heavily to guide search processes towards the target.

Searching for an object, be it as a precursor to action or an end unto itself, is a behavior that we engage in regularly. Although we perform such tasks with relative ease, the perceptual and cognitive processing necessary to complete them successfully are quite remarkable. To

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better understand these underlying processes, a large body of research has focused on visual search behavior, with the typical paradigm having an observer search for a target object among some number of distractor objects (e.g., a target letter among some number of distractor letters). Performance is typically measured in terms of the time taken to find the target (reaction time), and how this time changes as the number of items in the display are increased (set size). Much of this work has focused on understanding the visual features (e.g., color, line orientation) that guide search processes in both a bottom-up (e.g., Julesz, 1981; Treisman & Gelade, 1980; Treisman & Gormican, 1988) and a top-down (e.g., Motter & Belky, 1998; Wolfe, Cave, & Franzel, 1989; Wolfe, 1994; Zelinsky, 1996) manner. From these studies we have learned that visual search for objects defined by a feature singleton, or unique visual feature, is typically highly efficient; reaction time does not increase as items are added to the display (e.g., Treisman & Gelade, 1980). In contrast, search for targets defined by two features, commonly referred to as a conjunction search, among similar distractor objects is rather inefficient, resulting in increased reaction times with increasing set size (see Wolfe, 1998, for a review). The former singleton search is thought to be reflective of a search mechanism acting in a parallel processing manner, whereas the latter conjunction search task is thought to be reflective of a task requiring the serial allocation of attention to each item in the display (e.g., Treisman & Gelade, 1980; Wolfe et al., 1989). However, it should be noted that significant debate continues regarding the efficacy of the serial/parallel processing framework within the attentional literature (e.g., Wolfe, 1998).

To better understand the cognitive declines that accompany aging, a number of studies have examined how search behavior, and by proxy the related underlying attentional mechanisms, differs in older adults as compared to younger adults. Similar to young adults, older adults are able to locate a singleton target quickly and efficiently (Whiting, Madden, Pierce, & Allen, 2005). However, search for conjunction targets is less efficient for older adults than it is for younger adults (e.g., Folk & Lincourt, 1996; Madden, Pierce, & Allen, 1996); although both age groups suffer a performance cost when searching for a conjunction target, that cost is larger for older adults. In theoretical terms, these findings have been interpreted as evidence that the extraction of featural information is relatively age invariant (singleton search), whereas the ability to integrate features is vulnerable to age-related decline (conjunction search; Foster, Behrmann, & Stuss, 1995; Plude & Doussard-Roosevelt, 1989). Interestingly, in search for the conjunction of three visual features both older (Humprey & Kramer, 1997) and younger (e.g., Quinlan & Humphreys, 1987; Wolfe et al., 1989) adults exhibit an *increase* in search efficiency when compared to performance during conjunction search, perhaps due to the availability of additional top-down information (see Kramer & Madden, 2008, for a review of attentional mechanisms in older adults). More recently, it has also been shown that the importance of certain types of information might be dependent on the complexity of the search objects. For instance, in search for images of real-world objects, such as a drill, older adults appear to depend less on low-level perceptual information, such as color, than when searching for complex shapes (Williams, Zacks, & Henderson, 2009).

Although perceptual features undoubtedly play a prominent role in shaping search behavior, real-world environments provide an additional source of guidance in the form of context. Context, broadly defined, can be thought of as a representational attribute developed over time of objects and environments from which cues can be drawn as to where a given object might appear in a given environment. Because the general layouts of many of the environments we interact with remain generally stable over time (Henderson, Weeks, & Hollingworth, 1999), previous experience can often be recruited to inform action in different instances of similar environments. For instance, although we see many different parking lots over the course of our lives, we always know that they are likely to contain cars, regardless of whether the parking lot is novel or has been previously seen. Similarly, we know that those cars are going to appear on the ground rather than floating in the sky. What's more, we know that a car will appear on a surface without necessarily seeing a car on a surface; we do not need a scene in order to know that one of the characteristics of a car is that it is constrained to the ground. Memories of previous encounters with an object or scene provide us with information that can be used in subsequent encounters with similar objects or scenes.

In terms of visual search, this contextual information can provide cues related to where items are likely to appear in a scene. Early work exploring contextual guidance by Chun and Jiang (1998) showed that when searching through arrays of simple items (e.g., Ts and Ls), observers become more efficient at searching repeated arrays over time, despite the fact that they were unaware that the displays were in fact repeated, indicating that contextual learning, at least in simple displays, involves implicit memory (also see Chun & Jiang, 1999; Jiang & Chun, 2001; Peterson & Kramer, 2001). A number of studies have also examined this phenomenon in naturalistic scenes. Brockmole and Henderson (2006a) found that observers learn target positions in repeated real-world scenes and use that learned information to improve search efficiency over time. Interestingly, learning in naturalistic scenes occurs much faster than in non-scene displays, the benefits are much larger, and explicit memory seems to play a role (also see Brockmole & Henderson, 2006b; Ehinger & Brockmole, 2008). Contextual learning in naturalistic scenes also appears to be more dependent upon global context than on local context (Brockmole, Castelhano, & Henderson, 2006). This dependence upon global information might be attributed to the fact that human are remarkably efficient at extracting information related to a scene's gist (e.g., Potter, 1976; Schyns & Oliva, 1994). Because global gist information is quickly available, cognitive processes make use of that information to form object-scene associations, and perhaps even guide initial eye movements within scenes. Along these lines, recent work has explored the oculomotor behavior associated with contextual guidance in visual search. For example, observers searching realistic displays are likely to examine ground regions when searching for a target jeep object and sky regions when searching for a target blimp object, a pattern reflecting the spatial locations typically associated with those objects. Moreover, these regional preferences are often reflected in the initial fixation following display onset, and result in a reaction time benefit when compared to search for objects that are not typically spatially constrained (Neider & Zelinsky, 2006). Similar fixational preferences and reaction time benefits for spatially constrained objects have been shown in a number of other studies utilizing a wide range of realistic stimuli (e.g., Biederman, Glass, & Stacy, 1973; Brockmole & Henderson, 2006b; Henderson, Weeks, & Hollingworth, 1999; Hollingworth, 2009; Neider & Zelinsky, 2008; Oliva & Torralba, 2007; Torralba, Oliva, Castelhano, & Henderson, 2006; Zelinsky & Schmidt, 2009; see Henderson & Hollingworth, 1999, for a review).

Unfortunately, whereas search behavior in older adults has been well explored in the context of traditional feature-based search paradigms, questions related to high-level scene-based guidance in older populations remain largely unanswered. Do older adults still possess the ability to use preexisting spatial associations inherent to the target object and search scene in order to augment their search performance, and if so, are performance benefits similar to those shown by younger adults? On the one hand, it is possible that age-related cognitive decline might impair the ability of older adults to utilize contextual information as efficiently as younger adults. More specifically, older adults have shown impaired performance in tasks requiring explicit memory, whereas implicit memory processes appear to be spared from age-related cognitive decline (e.g., Light & Singh, 1987; see Old & Naveh-Benjamin, 2008, for a review of age-related changes in memory).

If explicit memory processes are important for employing contextual guidance during search through naturalistic scenes (Brockmole & Henderson, 2006a), then it is possible that for older adults the benefits of using contextual information to restrict search to relevant scene regions might be outweighed by the costs of employing explicit memory processes. On the other hand, it is also conceivable that older adults might capitalize on the availability of semantic information in order to compensate for age-related perceptual deficits previously associated with search (see Dennis & Cabeza, 2008, for a review of compensatory accounts of age-related cognitive decline), which might result in older adults achieving a larger overall reaction time benefit than younger adults. Recent work has shown that the experience obtained over many years can preserve the performance of older adults in complex tasks such as air traffic control (Nunes & Kramer, 2009). A similar mechanism might engender enhanced contextual guidance during search, as older adult have had numerous years to gain experience with objects and their contextual spatial associations. Previous work by Scialfa and colleagues has also shown that foreknowledge of a target's color can help older adults guide search processes towards a target as efficiently as younger adults (e.g., Scialfa, Jenkins, Hamaluk, & Skaloud, 2000); however, whether contextual information can be used in similar manner is unknown.

Furthermore, if older adults prove able at using contextual information, what is the time course of such usage? Whereas it has been shown that younger adults use contextual information to guide their initial eye movement, it is unclear whether older adults have access to such information as quickly, perhaps due to the general slowing of overall cognitive function (e.g., Salthouse, 2003, 2006). In the current study, we begin answering these questions by comparing search performance through realistic scenes in older and younger adults.

EXPERIMENT 1

In Experiment 1 we directly compared the behavior of younger and older adults during visual search for contextually constrained and unconstrained targets. The search task was similar to that used by Neider and Zelinsky (2006). Observers searched for a blimp, jeep, or oleh object in a computer-generated mountain scene. Consistent with the real world, blimps appeared only in the sky and jeeps only on the ground. The oleh was a novel object, intended to have no preexisting object-location association, and appeared at chance in either the sky or on the ground. Neider and Zelinsky (2006) found that when searching for an oleh target, observers displayed no discernable restriction of search processes to a display region (i.e., neither the ground nor sky was preferentially searched).

Methods

Participants

Twenty-four undergraduate students (mean age 20.67; 15 male, 9 female) from the University of Illinois at Urbana-Champaign and 24 high-functioning older adults (mean age 69.52; 11 male, 13 female; recruited from the community) participated in the study. All participants had normal or corrected-to-normal color vision and were paid $8 per hour for their participation. Visual acuity was assessed with a Snellen chart and color vision with Ishihara's test for color blindness (24 plates).

Apparatus, Stimuli, and Design

Search displays were created using Autodesk's 3d Studio Max and were similar to those used in previous work by Neider and Zelinsky (2006). Each scene subtended $34^\circ \times 25^\circ$ and depicted a pseudorealistic desert landscape containing a clear sky region and desert ground region separated by a mountainous region (see Figure 1). On each trial observers searched for one of three object types: a blimp, a jeep, or an oleh (each $\sim 1.3^\circ$). Consistent with typical real-world experience, the blimp (associated with the sky) and jeep (associated with the ground) served as scene-constrained objects. These scene-constrained objects only appeared in their scene-consistent region. The oleh, which was a fictional object composed of the rearranged components of a helicopter object, served as a scene-unconstrained object and appeared equally often in the sky and on the ground. No object ever appeared in the neutral mountain region. There were six objects per scene, with at least one of each object type present in each scene. Object color was manipulated as well in order to avoid object duplication (green, blue, red, and yellow). One of the objects in one of the four colors served as the target in each trial. The target was present on 50% of the trials and absent on the remaining 50% of trials. All experimental factors were randomly interleaved across 90 experimental trials.

Eye movements were recorded throughout the experiment using an EyeLink II eye tracker sampling at 500 Hz. All displays were presented in color on a 19-inch color CRT (cathode ray tube) monitor. Response times and accuracy were recorded through a gamepad, with the left trigger indicating the target as present, and the right trigger indicating

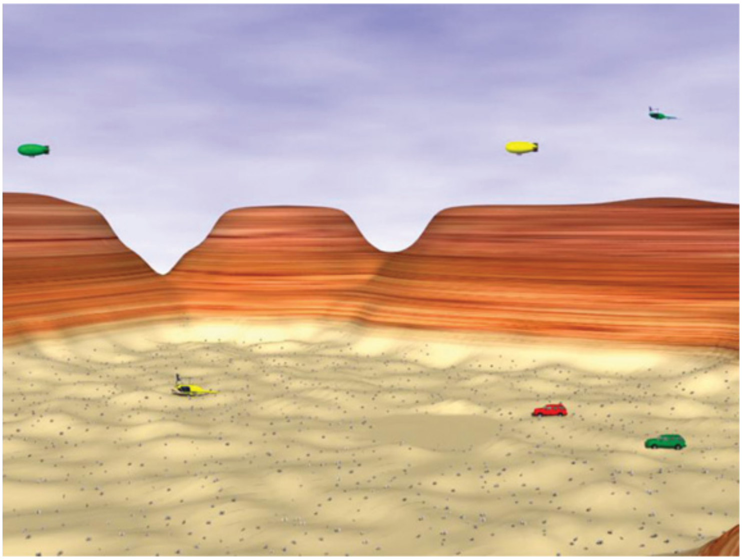


Figure 1. A sample search display from Experiment 1. Note that in the actual experiment all scenes were displayed in full color. (Color figure available online.)

the target as absent. All eye movement measures were calculated using the default EyeLink II algorithms. In accordance with these algorithms, an eye movement was classified as a saccade if it exceeded 2° and its velocity reached 30°/s or its acceleration 9500°/s^2. Detailed descriptions of the EyeLink algorithms can be found at www.sr-research.com.

Procedure

Each trial began with a fixation dot presented in the center of the screen. A fixation on the dot accompanied by a button-press caused the fixation dot to be replaced by a centrally located semantic description of the target (i.e., Blue Jeep, Yellow Blimp, Green Oleh). After 1 s the target description was replaced by the search scene. Observers were told that their task was to locate the target object as quickly as possible while maintaining high levels of accuracy, and were not instructed or trained as to the spatial contingencies associated with each target object. Each trial was terminated by a button-press response after which the search display was immediately replaced by a central fixation dot indicating the start of the next trial.

Results and Discussion

All measures, unless otherwise noted, were entered into an analysis of variance (ANOVA) with age (young and old) submitted as a between-subjects measure and target type (constrained and unconstrained, where the blimp and jeep targets were constrained and the oleh target was unconstrained) as a repeated measure. Because target presence was an important factor in differentiating whether behavior was diagnostic of guidance from context or guidance from target-related visual properties, target-present and target-absent trials were analyzed separately.

Error Rates

Error rates, presented in Table 1, differed as a function of age in target-present trials, $F(1, 46) = 4.43$, $p < .05$, but not in target-absent trials, $F(1, 46) = .37$, $p = .55$. Additionally, ANOVAs performed on each individual age group revealed that error rates for younger adults differed significantly as a function of target type (constrained = 3.29%; unconstrained = 7.18%) in target-present trials, $F(1, 23) = 4.97$, $p < .05$, but not in target-absent trials, $F(1,23 = .1.21$, $p = .28$. Similarly, for older adults error rates varied as a function of target type (constrained = 4.67%; unconstrained = 16.87%) in target-present trials, $F(1,23) = 12.39$, $p < .005$, but not in target-absent trials, $F(1,23) = 2.89$, $p = .10$. Although error rates varied in target-present trials for both younger and older adults, a significant Age $\times$ Target interaction indicates that older adults were more heavily affected by the availability of contextual guidance information, $F(1, 46) = 4.60$, $p < .05$.

Although younger and older adults both exhibited increased error rates in target-present trials when the target object was unconstrained,

Table 1. Mean reaction times (ms) and percent error for younger and older adults by target type in Experiment 1

	Younger adults		Older adults	
	Present	Absent	Present	Absent
Constrained	986 (81)	1259 (92)	1256 (50)	1719 (71)
	3.29%	1.94%	4.67%	3.98%
Unconstrained	1305 (67)	1402 (84)	1935 (74)	2058 (106)
	7.18%	2.77%	16.87%	3.06%

Note. Values in parentheses indicate 1 standard error of the mean. Error rates are presented below the reaction time for the corresponding condition.

it is interesting to note that this effect was larger for older adults. This difference was largely driven by a ~17% miss rate for the scene-unconstrained oleh target (compared to ~7% for younger adults), suggesting that older adults relied more extensively than younger adults on the contextual information associated with a given target in order to guide their search processes to that target.

Manual Reaction Times

Mean reaction times for older and younger adults in correct target-present and target-absent trials are displayed in Table 1. Overall, younger adults were faster to respond than older adults in both target-present, $F(1, 46) = 30.39$, $p < .001$, and target-absent, $F(1, 46) = 21.71$, $p < .001$, trials, as indicated by significant main effects of age. This pattern is consistent with a number of previous findings showing that older adults search more slowly than younger adults (e.g., Folk & Lincourt, 1996; Madden et al., 1996); however, overall cross-group reaction time differences do not tell us whether observers were able to use contextual information within the scene to guide search processes, and whether older and younger adults utilized such information in a differential manner. To answer this question, we examined reaction times for scene-constrained targets compared to scene-unconstrained targets across age groups.

If observers were able to use contextual information from the targets and scene to restrict search processes to target-consistent regions, then we would expect to find faster reaction times when observers searched for the scene-constrained targets compared to the scene-unconstrained target. Overall, a main effect of target in target-present, $F(1, 46) = 195.91$, $p < .001$, and target-absent, $F(1, 46) = 50.01$, $p < .001$, trials suggests that search performance was somewhat dependent on the search target. Additional ANOVAs performed on each age group individually revealed that this target-dependent pattern was borne out for both younger and older adults. Replicating the findings of Neider and Zelinsky (2006), when searching for the blimp or jeep, younger adults were faster (320 ms) to locate the target than when searching for the oleh, $F(1, 23) = 85.96$, $p < .001$. Older also adults also enjoyed a benefit, locating the blimp and jeep an average 678 ms faster than the oleh, $F(1, 23) = 118.16$, $p < .001$. It is particularly interesting that the overall scene-constrained target benefit for older adults was more than twice that of the younger adults (Target × Age interaction in all target-present trials), $F(1, 46) = 25.37$, $p < .001$, indicating that older adults gained a larger absolute benefit (with a 35% relative benefit for the old and a 24% relative benefit for the young) from the availability of spatially specific contextual information (i.e., when searching for the blimp or jeep) than did younger adults, and incurred a larger cost when that information was not available (i.e., when searching for the oleh target).

A similar pattern of results was observed in target-absent trials. Both younger (143 ms; $F(1, 23) = 31.55$, $p < .001$) and older (340 ms; $F(1, 23) = 28.76$, $p < .001$) adults benefited from the availability of contextual information, with older adults again displaying a larger benefit than younger adults (in all target-absent trials), $F(1, 46) = 8.27$, $p < .01$. Importantly, our observation of similar patterns of results in both target-present and target-absent trials suggests that our findings can be attributed to contextual guidance mechanisms as opposed to target-specific featural information, because in target-absent trials the target object was not present in the display.

To account for general slowing in older adults (e.g., Cerella, 1990; Faust, Balota, Spieler, & Ferraro, 1999), we submitted the reaction time data to a logarithmic transform (e.g., Lindholm & Parkinson, 1983). Findings that remain significant following such a transform can be considered task dependent; findings that are insignificant following the transform are typically attributed to general age-related slowing of perceptual processes. Following transformation, the Target $\times$ Age interaction in target-present trials remained significant, $F(1, 46) = 9.11$, $p < .005$, indicating that the disproportionate reaction time benefit for constrained targets displayed by older adults was not due wholly to a general slowing in processing speed. In target-absent trials, the Target $\times$ Age interaction was not significant following transformation, $F(1, 46) = 1.68$, $p = .20$. Although this suggests that general slowing alone could explain context-related differential performance across age groups in target-absent trials, it is also not altogether surprising. Given that the target was absent in these cases, it is possible that all participants may have resorted to an exhaustive search once it was realized that target was not in its appropriate scene region, resulting in a more perceptually reliant search strategy. Hence, any benefit that older adults might have gained from the availability of contextual information would be less valuable.

Regional Dwell Time

The reaction time data clearly show that observers benefited when searching for a scene-constrained target compared to a scene-unconstrained target, indicating that contextual information can be used to guide search processes. To examine the extent to which search processes were restricted to the target-consistent region, we analyzed, for each observer, the proportion of time that observers spent, as measured by fixations, in a given region of the display on each trial (saccades are excluded from this measure). To do so, we divided the display into three interest areas (sky, ground, and mountains). If observers used contextual information to restrict their search, then we would expect a large proportion of search time to be spent in the target-consistent region of the display (i.e., the sky when searching for the blimp and the ground when searching for the jeep). Time spent in the neutral mountain region was excluded from the analysis.

The data were entered into an ANOVA for each age group with target (blimp, jeep, and oleh) and fixation region (ground and sky) entered as repeated measures. The proportion of dwell time spent in each region is shown as a function of target object and age group in Figure 2a (target present) and b (target absent). When searching for a scene-constrained target, both younger and older adults spent the majority of their search time in the target-consistent region of the display, as indicated by the Target $\times$ Region crossover interactions in both target-present ($F(2, 46) = 378.56$, $p < .001$, for younger adults, and $F(2, 46) = 362.26$, $p < .001$, for older adults) and target-absent ($F(2, 46) = 63.39$, $p < .001$, for younger adults, and $F(2, 46) = 18.09$, $p < .001$, for older adults) trials. Search for the scene-unconstrained oleh target produced an intermediate result, with both older and younger adults searching both the sky and ground regions.

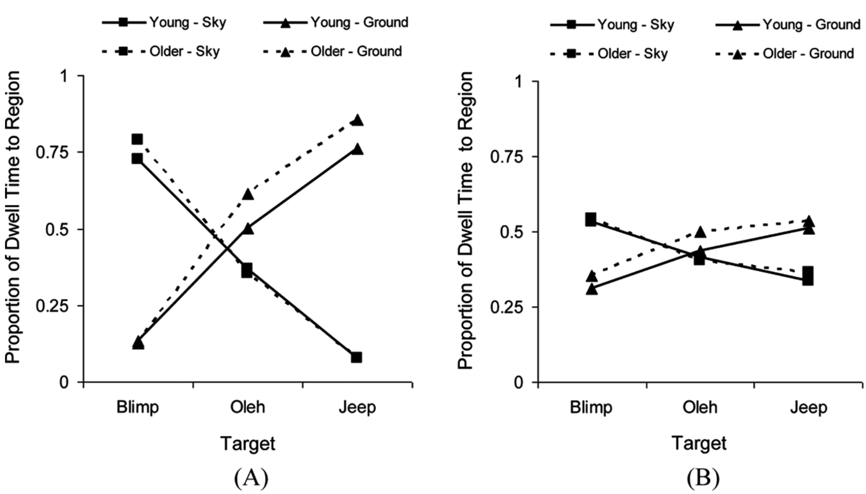
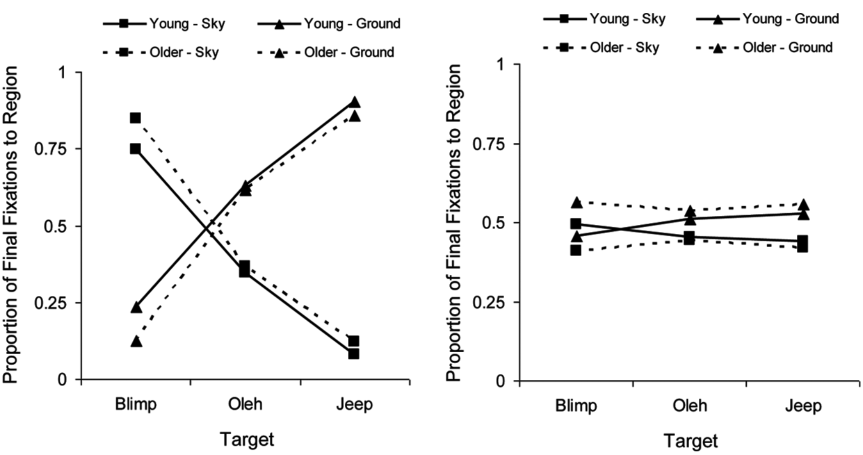


Figure 2. The proportion of time in each trial spent searching a given scene region as a function of target type and age in (*A*) target-present and (*B*) target-absent trials in Experiment 1.

Proportion of Final Fixations to Region

Although the reaction time and regional dwell time data clearly suggest that both younger and older adults utilize and enjoy a benefit from the availability contextual information, it is also evident that the restriction of search processes to target-consistent regions is not absolute, particularly in target-absent trials. In these trials, younger adults spent 32% of their search time in the *target-inconsistent* region. Similarly, older adults spent 36% of their search time in the inconsistent region. To examine the nature of these inconsistent region inspections, we analyzed the proportion of final fixations (the last fixation in a trial) to scene regions as a function of target type and age (target-present trials in Figure 3a; target-absent trials in Figure 3b). As would be expected from our analysis of regional dwell time, both younger and older adults made the overwhelming majority of their final fixation in target-present trials to the target-consistent region. However, a somewhat different pattern emerges in the target-absent trials. In this case, younger adults showed no significant regional preference on their final fixation when searching for the blimp, $t(23) = .47$, $p =$ .64, or jeep, $t(23) = .1.34$, $p = .19$, target. Older adults showed a significant final fixation preference towards the target-inconsistent ground region when searching for the blimp, $t(23) = 2.25$, $p < .05$, and no regional preference when searching for the jeep, $t(23) = 1.93$, $p = .07$.



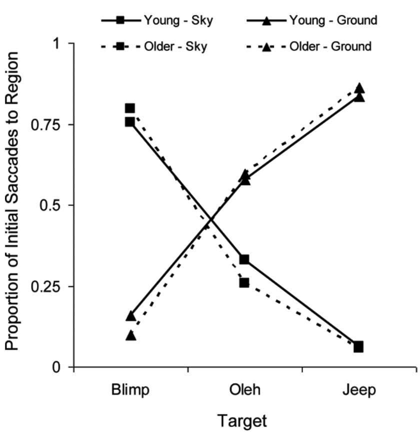
(A) (B)

Figure 3. The proportion of final fixations located in each scene region as a function of target type and age in (*A*) target-present and (*B*) target-absent trials in Experiment 1.

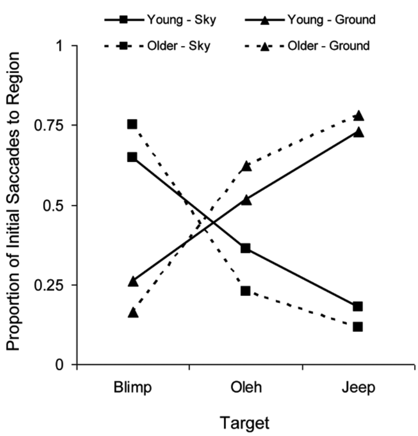
These data suggest that prior to making a target-absent response, observers sometimes engaged in an inspection of the target-inconsistent region, a finding consistent with previous work by Neider and Zelinsky (2006).

Direction of Initial Saccades

It is apparent that both younger and older adults can use contextual information to restrict search processes to target-relevant scene regions, but how quickly is this information available to search processes after display onset? Previous work has shown that younger adults have access to contextual information early enough to guide the initial saccade in a trial towards the target region (Neider & Zelinsky, 2006), but do older adults enjoy the benefits of contextual information in the same timescale? To answer this question, we analyzed the region to which the initial saccade of each trial was directed. Trials with initial saccadic amplitudes of less than 1° were omitted from the analysis, with over 95% of trials meeting the inclusion criteria. The results of the analysis for each age group were entered into individual ANOVAs with target and saccade direction (toward sky or ground) entered as repeated measures, and are displayed in Figure 4a (target-present trials) and b (target-absent trials). In target-present trials, a significant Target $\times$ Direction interaction indicates an initial saccadic preference towards the target-consistent region. When



(A)



(B)

Figure 4. The proportion of initial saccades directed towards each display region as a function of target type and age in (*A*) target-present and (*B*) target-absent trials in Experiment 1.

searching for the blimp, younger adults directed their initial saccade towards the target-consistent sky region 75% of the time; when searching for the jeep, the initial saccade was directed at the ground 83% of the time, $F(2, 46) = 169.86$, $p < .001$. Older adults showed a similar pattern of results, directing their initial saccade towards the sky 79% of the time when searching for the blimp and 86% of the time towards the ground when searching for the jeep, $F(2, 46) = 174.87$, $p < .001$. Omnibus analysis of target-present trials indicated that these effects did not differ as a function of age (Age × Target × Direction interaction), indicating that both younger and older adults were equally able to utilize contextual information in order to guide their initial eye movements $F(2, 92) = 1.59$, $p = .21$. In target-absent trials, the Target × Direction interactions were significant as well, for both younger, $F(2, 46) = 89.93$, $p < .001$, and older, $F(2, 46) = 115.69$, $p < .001$, adults, suggesting that initial saccades were guided by contextual information rather than target-specific featural information. Unlike target-present trials, in these trials a significant Age × Target × Direction interaction indicated that older adults were more likely to initially direct their gaze towards the target-consistent region than younger adults, even in the absence of target-specific featural information, $F(2, 92) = 8.41$, $p < .001$. This differential restriction of initial eye movements in target-absent trials could suggest that older adults might have been somewhat more reliant on contextual guidance information than younger adults.

Interestingly, both younger and older adults displayed a preference to initially move their gaze towards the ground region when searching for the oleh object, with this trend observed in both target-present and target-absent trials. It is possible that because the oleh was inherently devoid of any contextual constraints, observers chose to initially direct their search towards a surface area, in this case the ground, as objects are more readily known appear on surfaces than in the air.

EXPERIMENT 2

In Experiment 1, observers, both older and younger, were clearly able to restrict search processes towards regions of the display where the target was most likely to appear, with this restriction resulting in a reaction time benefit during search for scene-constrained targets (i.e., the blimp and jeep targets). What's more, this restriction of search processes, as measured by eye movements, was often evident on the first fixation during search. When observers were searching for the blimp, their initial eye movement was often made towards the sky; when searching for the jeep, the initial eye movement was typically made towards the ground. Although this biasing of search processes could be considered as evidence of observers utilizing preexisting contextual knowledge of the search objects and their likely spatial associations, there is an alternate possibility. More specifically, observers may have recognized the probabilistic regional associations of the search objects during the experiment and then simply matched their search behavior to these probabilities. Recent work by Williams, Pollatsek, Cave, & Stroud (2009) has in fact shown that, at least in the case of younger adults, observers are remarkably adept at matching their initial eye movements to the probabilistic spatial associations of the target.

To directly test whether observers were restricting their search in Experiment 1 based on preexisting contextual knowledge of the search objects or probability matching, in Experiment 2 we had observers search scenes similar to Experiment 1 with the caveat that all objects were devoid of preconceived spatial associations. Specifically, observers searched for colored rectangles, ovals, and trapezoids in the same desert-mountain scene as Experiment 1. Rectangles appeared only in the sky and ovals only on the ground, thus resulting in a 100% probabilistic region association for each of those objects (identical to the blimps and jeep objects in Experiment 1). The trapezoid object was equally likely to appear in the sky or on the ground. Critically, whereas blimps are typically associated with the sky and jeeps with the ground, rectangles and ovals should engender no such expectations. Hence, if observers were searching based on probability matching in Experiment 1, we would expect a similar pattern of results in Experiment 2, a reaction time advantage when searching for the rectangle or oval targets compared to the trapezoid target. If observers in Experiment 1 were using preexisting contextual expectations of the blimp and jeep targets to guide search, then we would expect that observers in Experiment 2 would display little or no reaction time advantage for the rectangle or oval targets compared to the trapezoid target, because they are devoid of any preexisting contextual region associations.

Methods

Participants

Twelve undergraduate students (mean age 22.75; 5 male, 7 female) from the University of Illinois at Urbana-Champaign and 12 high-functioning older adults (mean age 76; 5 male, 7 female; recruited from the community) participated in the study. All participants had normal or corrected-to-normal color vision and were paid $8 per hour for their participation.

Apparatus, Stimuli, and Design

Search scenes were identical to those used in Experiment 1 with the exception of the search objects. Rather than searching for blimps, jeeps, and olehs, observers searched for shapes in a desert-mountain scene. Specifically, targets and distractors were composed of colored rectangles, ovals, and trapezoids ($\sim 1.3^\circ$ in size and identical in color to the search objects in Experiment 1). To create probabilistic spatial contingencies, rectangles appeared only in the sky, ovals only on the ground, and trapezoids were equally likely to appear in the sky or on the ground. As in Experiment 1, the target cue was presented semantically (e.g., Yellow Rectangle, Blue Oval, etc.), and observers were given no instructions or training related to the target-location contingencies. All other aspects of the experiment were identical to Experiment 1.

Results and Discussion

Unless otherwise noted, the procedure and parameters for all analyses were identical to those used for the corresponding analyses in Experiment 1.

Error Rates

Error rates are shown in Table 2 and did not vary as a function of age ($F(1, 22) = .96$, $p = .34$, in target-present trials; $F(1, 22) = .05$, $p = .83$, in target-absent trials) or target type ($F(1, 22) = .01$, $p = .95$, in target-present trials; $F(1, 22) = .08$, $p = .79$, in target-absent trials).

Manual Reaction Times

If the effects of target type (constrained vs. unconstrained) observed in Experiment 1 were the result of observers learning and matching target-region probabilities rather than utilizing preexisting contextual

Table 2. Mean reaction times (ms) and percent error for younger and older adults by target type in Experiment 2

	Younger adults		Older adults	
	Present	Absent	Present	Absent
Constrained	969 (72)	990 (90)	1300 (79)	1431 (93)
	5.35%	2.89%	8.57%	2.09%
Unconstrained	1048 (95)	1028 (83)	1310 (94)	1427 (86)
	4.86%	2.77%	8.83%	3.03%

Note. Values in parentheses indicate 1 standard error of the mean. Error rates are presented below the reaction time for the corresponding condition.

associations relating the given target to scene likely locations, then we would expect to find a similar reaction time advantage when the target was either a scene-constrained rectangle (100% in the sky) or oval (100% ground) compared to the scene-unconstrained trapezoid (50% sky; 50% ground); reaction times for rectangles and ovals should be faster than reactions times for trapezoids. The data, shown in Table 2, do not bear this prediction out. Although older adults were slower to find the target than younger adults ($F(1, 22) = 12.80$, $p < .005$, in target-present trials; $F(1, 22) = 6.53$, $p < .05$, in target-absent trials), no significant effects of target type were observed ($F(1, 22) = .27$, $p = .61$, in target-present trials; $F(1, 22) = 1.39$, $p = .25$, in target-absent trials); observers did not benefit when searching for a target that was probabilistically constrained to a particular scene region.

Although the evaluation of overall reaction times did not indicate a search advantage when searching for scene-constrained targets, it is possible that given the novel nature of the object-region constraints in Experiment 2 observers might have required some time to learn the probabilistic contingencies associated with the scene-constrained rectangle and oval. That is, early trials in the experiment may have been used primarily to learn the target-region contingencies, with these learned contingencies then used in later trials to guide search processes. To explore this possibility, we analyzed performance in the first half of trials (initial 45 trials) compared to that in the second half of trials (final 45 trials). ANOVAs were conducted for target-present and target-absent trials with half (first 45 trials compared to final 45 trials) and age entered as between-subjects measures and target entered as a repeated measure. The data are shown in Table 3. In target-present trials, performance varied as a function of age, $F(1, 44) = 10.59$, $p < .001$, reflecting the fact that younger adults were generally faster to locate the target than older adults. In addition, there was also a significant Half $\times$ Target Type interaction, $F(2, 44) = 4.15$, $p < .05$. Performance in target-absent trials also varied with age, $F(1, 44) = 21.93$, $p < .001$. No other statistical effects in target-absent trials were significant, indicating that performance was similar in both the first and second half of the experiment. Although the significant Half $\times$ Target Type interaction in target-present trials might appear consistent with some sort of probabilistic learning, this possibility seems lees likely when considered in combination with the lack of such an effect in target-absent trials. If subjects were truly learning to associate specific targets with specific spatial locations, then we would expect this restriction to occur the majority of the time, regardless of whether the target was present

Table 3. Mean reaction times (ms) for younger and older adults by target type for first half of trials and second half of trials in target-present (tp) and target-absent (ta) trials in Experiment 2

	First half				Second half			
	Younger adults		Older adults		Younger adults		Older adults	
	TP	TA	TP	TA	TP	TA	TP	TA
Rectangle	998 (70)	902 (75)	1423 (81)	1462 (105)	952 (71)	1045 (145)	1189 (86)	1420 (97)
Trapezoid	1010 (75)	1018 (78)	1315 (82)	1445 (84)	1091 (135)	1047 (108)	1267 (106)	1344 (82)
Oval	1054 (109)	1023 (73)	1296 (80)	1440 (80)	919 (67)	944 (83)	1213 (76)	1294 (82)

Note. Values in parentheses indicate 1 standard error of the mean.

or absent. This was clearly not the case. Instead, it seems likely that over time observers became better acquainted with the visual features associated with each target, with this information helping to guide search when the target was present. When the target was absent, observers were left to rely on other means to guide search processes.

Overall, the reaction time data suggest that the target type differences observed in Experiment 1 were not due to simple probability matching. Rather, it seems likely that observers were able to bias search processes towards regions where the target was likely to appear based upon some preexisting target-associated spatial contingencies of the type generally associated with context.

Regional Dwell Time

Although observers did not display an overall reaction time benefit for scene-constrained targets in Experiment 2, it is still possible that they used the probabilistic target-region relationships to guide eye movements. To examine whether this was the case, we again analyzed the proportion of time that observers spent in each scene region of the display on each trial. If observers based their search on learned target-region probabilities, then we would expect that when searching for the rectangle target, the majority of search time would be spent searching the sky, and that when searching for the oval target, the majority of search time would be spent searching the ground region. Search time for the unconstrained trapezoid target would be evenly distributed across both regions. Additionally, we would expect these patterns to persist in both target-present and in target-absent trials, as was the case in Experiment 1.

The proportion of dwell time in each region is shown in Figure 5a (target present) and b (target absent) as a function of target object and age. Independent ANOVAs conducted on each age group revealed significant Target $\times$ Region interactions in target-present trials for both older ($F(2, 22) = 104.99$, $p < .001$) and younger ($F(2, 22) = 219.62$, $p < .001$) adults, indicating that when the target was present in the display, observers spent a larger proportion of their search time in the target-consistent scene region. Analysis of target-absent trials, however, produced a different pattern of results. In target-absent trials, younger adults did not preferentially allocate their search time to target-consistent scene regions, $F(2, 22) = .71$, $p = .50$. Rather, they appeared to favor searching the sky region of the display regardless of the target (44%, 45%, and 48% of their search time for the sky-constrained rectangle, unconstrained oval, and ground-constrained oval target, respectively), with the only $\sim$24% of search time spent on the ground region for any target.

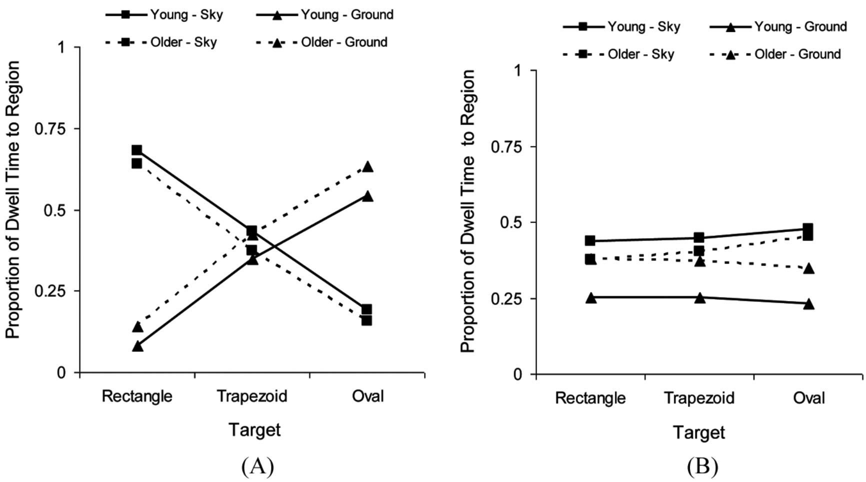


Figure 5. The proportion of time in each trial spent searching a given scene region as a function of target type and age in (*A*) target-present and (*B*) target-absent trials in Experiment 2.

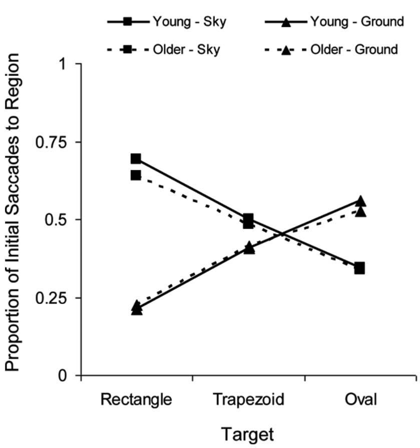
Despite the fact that older adults did show a significant Target $\times$ Region interaction in target-absent trials ($F(2, 44) = 5.70$, $p < .05$), their pattern of data was much the same as that of the younger adults, with search time divided slightly more evenly across scene regions and the sky region favored. Omnibus analyses indicated that the overall allocation of search time did not differ as a function of age in either target-present or target-absent trials.

Overall, the data patterns related to regional dwell time do not provide clear evidence that observers were able to use learned target-region relationships in order to restrict gaze to target-consistent regions in Experiment 2. Although observers did in fact spend the majority of their search time in the target-consistent region in target-present trials, in target-absent trials this was not the case. In the latter, all observers seemed to prefer to search the sky region of the display regardless of the target being search for. This is a stark contrast to Experiment 1, where all subjects spent the majority of their search time in the target-consistent display region in both target-present and target-absent trials. Taken together, it seems likely that the regional preference in search time observed in target-present trials in Experiment 2 is more likely the by-product of target-specific featural guidance than of target-region probability matching. When the target was present in the display, observers were able to use the featural information associated with the target to guide search processes. When the target was absent, that information was no longer available to guide search, and as such search time was distributed more evenly across the search display.

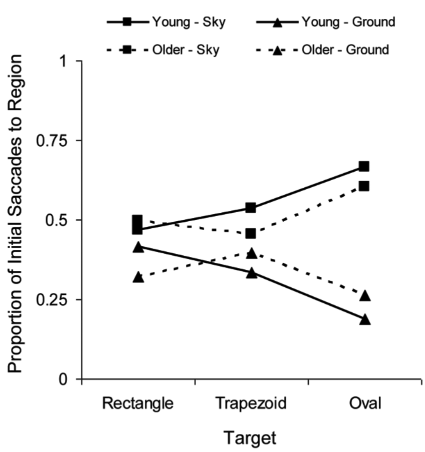
Direction of Initial Saccades

The lack of reaction time benefits for scene-constrained targets in Experiment 2 suggests that observers did not utilize probabilistic target-region relationships to restrict their search to regions of the display where a given target was likely to appear. However, it remains possible that observers might have utilized such probability matching to guide the initial eye movement of their search before engaging in a more exhaustive search strategy for the remainder of the search task. To assess this possibility, we again analyzed the region to which the initial saccade in each trial was directed. The parameters of the analysis were identical to those used in Experiment 1. If observers used a probability matching strategy to guide their initial eye movements, then we would expect a disproportionate number of those initial eye movements to land in the target-consistent scene region when searching for the scene-constrained rectangle and oval targets.

The results of the analysis are shown in Figure 6a (target present) and b (target absent). Overall, in target-present trials both younger ($F(2, 22) = 20.21, p < .001$) and older ($F(2, 22) = 20.64, p < .001$) adults preferentially directed their initial eye movement towards the target-



(A)



(B)

Figure 6. The proportion of initial saccades directed towards each display region as a function of target type and age in (*A*) target-present and (*B*) target-absent trials in Experiment 2.

consistent scene region; gaze was initially directed towards the sky when searching for the rectangle (69% for younger adults; 63% for older adults) and towards the ground when searching for the oval (55% for younger adults; 52% for older adults). Search for the trapezoid produced an intermediate effect. Target-absent trials were somewhat different, however. As in target-present trials, both younger ($F(2, 22) = 8.62$, $p < .005$) and older ($F(2, 22) = 9.35$, $p < .005$) adults displayed significant Target × Direction interactions; however, inspection of the data shows that these effects were not driven by the preferential deployment of initial saccades towards target-consistent scene regions. Rather, in target-absent trials observers preferred to deploy their initial eye movements towards the sky region regardless of the target they were searching for. Younger adults did so 47%, 54%, and 67% of the time when searching for the scene-constrained rectangle, scene unconstrained trapezoid, and scene-constrained oval, respectively. Older adults exhibited a similar pattern, directing their initial eye movement towards the sky 50%, 45%, and 60% of the time when searching for the rectangle, trapezoid, and oval, respectively. On average, younger adults made their initial eye movement towards the ground on only 31% of trials; older adults did so on only 33% of trials. Taken together, the pattern of consistent target-region initial saccades in target-present trials and the lack there of in target-absent trials make it seem unlikely that the initial saccades in target-present trials were driven by any learned relationships between the scene-constrained targets and the regions they were bound to. Rather, it seems more likely that these saccades were driven by target-specific feature guidance. When the target is absent such target-specific information is absent from the display, and as a result initial saccades were directed in a more random manner regardless of target type.

As was the case with reaction times, it is possible that observers needed some time to learn the region associations for scene-constrained targets before they were able to guide initial eye movements. To assess this possibility, we again did a split-half analysis to examine initial saccade direction in early trials compared to late trials. The data are shown in Tables 4 (younger adults) and 5 (older adults). A significant Target × Direction × Half interaction was observed in target-present trials ($F(2, 88) = 10.71$, $p < .001$); however, the interaction did not quite reach significance in target-absent trials ($F(2, 88) = 2.69$, $p = .07$). Inspection of the data suggests that the significant Target × Direction × Half interaction in target-present trials, and the trend towards a similar interaction in target-absent trials, was not driven by an increase in initial saccades towards the target-consistent region in later trials. As Tables 4 and 5 show, in target-present trials both younger and older

Table 4. Proportion of initial saccade to scene region (SKY = sky; GRD = ground; NEU = neutral) for younger adults by target type for first half of trials and second half of trials in Experiment 2

	First half						Second half					
	Target present			Target absent			Target present			Target absent		
	GRD	SKY	NEU	GRD	SKY	NEU	GRD	SKY	NEU	GRD	SKY	NEU
Rectangle	.23 (.04)	.72 (.04)	.05 (.02)	.34 (.10)	.55 (.07)	.11 (.05)	.18 (.07)	.66 (.08)	16 (.04)	.46 (.06)	.41 (.05)	.13 (.04)
Trapezoid	39 (.06)	.51 (.05)	.10 (.04)	.40 (.06)	.48 (.05)	.12 (.04)	.43 (.07)	.48 (.05)	.09 (.04)	.14 (.07)	.71 (.08)	.15 (.06)
Oval	60 (.10)	.29 (.08)	.11 (.05)	.23 (.05)	.66 (.06)	.11 (.04)	.54 (.05)	.37 (.06)	.09 (.03)	.12 (.05)	.68 (.05)	.20 (.06)

Note. Values in parentheses indicate 1 standard error of the mean.

Table 5. Proportion of initial saccade to scene region (SKY = sky; GRD = ground; NEU = neutral) for older adults by target type for first half of trials and second half of trials in Experiment 2

	First half						Second half					
	Target present			Target absent			Target present			Target absent		
	GRD	SKY	NEU	GRD	SKY	NEU	GRD	SKY	NEU	GRD	SKY	NEU
Rectangle	.18 (.04)	.63 (.06)	.19 (.05)	.15 (.05)	.63 (.07)	.22 (.07)	.28 (.08)	.65 (.09)	.07 (.03)	.41 (.05)	.43 (.05)	.16 (.05)
Trapezoid	.42 (.07)	.49 (.08)	.09 (.03)	.39 (.06)	.45 (.06)	.16 (.07)	.42 (.07)	.47 (.08)	.11 (.04)	.41 (.08)	.47 (.07)	.12 (.05)
Oval	.63 (.07)	.19 (.06)	.18 (.06)	.27 (.04)	.59 (.06)	.14 (.05)	.48 (.07)	.40 (07)	.12 (.04)	.26 (.06)	.62 (06)	.12 (.04)

Note. Values in parentheses indicate 1 standard error of the mean.

adults generally made fewer initial saccades towards the target-consistent scene region when searching for the scene-constrained rectangle and oval targets in the second half of the experiment than they did in the first. This is the opposite of what we would expect had observers been learning probabilistic target-region associations in early trials and then using those associations to guide eye movements in later trials. In target-absent trials, observers showed a general preference to direct their initial saccade towards the sky region regardless of the target or half of the experiment. Combined, these data make it seem unlikely that observers matched their initial eye movements to probabilistic target-region associations at any point in the experiment.

GENERAL DISCUSSION

Previous studies of visual search behavior in older adults have focused on the attentional guidance afforded by low-level visual features in simple geometric objects or letters, and the differences that arise between younger and older adults in the featural extraction and integration (e.g., Foster et al., 1995; Humphrey & Kramer, 1997; Plude & Doussard-Roosevelt, 1989) components of a search task. However, additional sources of guidance, such as the relationship between objects and the spatial locations in a scene where they are likely to occur, have received little consideration. Studies in younger adults have shown that observers quickly gather information related to the spatial configuration of objects in simple displays, and subsequently use that information to guide search to the target more efficiently (e.g., Chun & Jiang, 1998), a phenomenon called contextual cueing. Similarly, it has been found that observers can use preexisting knowledge of real-world objects and their related spatial associations to guide search process towards target-associated spatial regions within a display (e.g., Neider & Zelinsky, 2006; see Henderson & Hollingworth, 1999, for a review). Our study extends these findings to older adults. We found that older adults locate targets with strong spatial associations more quickly than targets that are not constrained to a specific scene region, and enjoy larger reaction time benefits for scene-constrained targets than younger adults. What's more, older adults are seemingly able to use spatial context information as efficiently as younger adults, restricting the majority of their search time to target-consistent regions and often moving their eyes towards those regions on the initial saccade of a trial.

The argument could be made that the benefits we observed when participants were searching for scene-constrained targets were not due to the availability of contextually based spatial information, but rather a simple by-product of object familiarity. Whereas the scene-constrained blimps and jeeps were familiar objects to the observer, the oleh target was fictional, and hence novel. However, based on past research, it seems likely that familiarity was not the determining factor in our data. In a study similar to the current one, Neider and Zelinsky (2006; Experiment 1) had young adults search through scenes for blimp, jeep, and helicopter objects. Similar to the current study, blimps and jeeps were constrained to the sky and ground regions, respectively. However, instead of an oleh serving as the scene-unconstrained target, a helicopter was used and was equally likely to appear in the sky, or on the ground. Hence, all objects were familiar to the observer. Their findings were similar to ours; observers enjoyed a reaction time advantage when searching for the scene-constrained blimp and jeep objects compared to the scene-unconstrained helicopter object. Because all objects were familiar to the participants, the observed effects could not have been due to familiarity. Furthermore, a nearly identical pattern of results was observed in a follow-up experiment in which younger adults searched identical scenes where the helicopter was replaced with a fictional oleh object (Neider & Zelinsky, 2006; Experiment 2). Based on these previous findings, and our current replication of those findings, it seems highly likely that our data patterns are reflective of guidance from contextually based spatial information, and not the result of object familiarity. Still, this previous study did not include any examination of age-related differences in the experimental paradigm. Hence, any extension of this previous work to the current study must be made cautiously. Thus, although the previous study would suggest it unlikely, some effect of object familiarity cannot be entirely ruled out in our Experiment 1 data. That is, the age-related differences observed in Experiment 1 may have reflected some contribution of object familiarity despite previous findings to the contrary in younger adults. Future work will examine this issue further.

Another alternative explanation for our findings could be that the reaction time and associated oculomotor benefits observed during search for the blimp and jeep targets may have reflected the ability of observers to recognize and match oculomotor behavior to target-location probabilities. For example, a recent study by Williams, Pollatsek, et al. (2009) found that when searching for a randomly rotated red or blue T amongst randomly rotated red and blue Ls, eye gaze was preferentially guided towards clusters of search items that were known to contain a higher percentage of target color items. Our findings from Experiment 2 indicate that in our study such an account seems unlikely. When asked to search for simple shapes that were probabilistically constrained to given scene regions, observers demonstrated no reaction time benefit; performance was similar regardless of whether the target was constrained to a given scene region 100% of the time or unconstrained. Additionally, analyses of regional dwell time and initial saccade direction did not produce any clear evidence of probabilistic matching in the oculomotor domain. This absence of evidence for probabilistically guided search endured even when comparing performance in later experimental trials to earlier experimental trials; observers did not learn target-region associations early in the experiment and then use them to guide search behavior later in the experiment. In contrast, in Experiment 1 observers showed a clear restriction of search to target-relevant regions, and enjoyed a substantial reaction time benefit (231 and 509 ms for young and older adults, respectively, in all trials combined) for scene-constrained search targets. The contrasting data patterns observed in Experiments 1 and 2 are likely representative of the presence (in Experiment 1) and absence (in Experiment 2) of contextual information related to the search objects. Whereas the objects in Experiment 1 were somewhat typical of objects normally encountered in real-world environments, the search objects in Experiment 2 were much more abstract. That is, although rectangles and ovals are common, they are not typically associated with a spatial location in the same manner as blimps and jeeps. It is this additional information relating known objects to likely scene locations that represents guidance from context. It should, however, be noted that although observers did not show a reaction time benefit for region-constrained targets in Experiment 2, we do not consider probabilistic learning of target-region locations to be unrelated to contextual guidance. In fact, it is likely that probability learning serves as the basis upon which spatial context is established in real-world environments. For example, if asked to search for a plane, one is likely to look towards the sky, but this behavior is predicated upon the countless instances during the course of every day life in which the observer has previously witnessed a plane in the sky. Such probabilistic learning has formed the basis for some models of contextual guidance during visual search in the form of Bayesian frameworks (Eckstein, Drescher, & Shimozaki, 2006; but also see Torralba et al., 2006, for an alternative technique). Hence, the time course over which probability learning takes place and is consolidated to form contextual type spatial characteristics associated with most objects remains a fertile area for future research. Although observers did not appear to learn the probabilistic positioning of objects in Experiment 2, it is certainly possible that with additional trials observers might learn and utilize probabilistic information in a manner similar to that demonstrated by Williams and colleagues with simpler stimuli (Williams, Zachs, & Henderson, 2009).

The current findings broaden our understanding of visual search in older adults, and the associated attentional mechanisms that support search processes, in three key respects. First, our findings confirm that older adults are able to use the contextual information related to an object and scene in order to guide search processes to a target more effectively. Furthermore, it appears that older adults are even more reliant on this type of top-down guidance information than are younger adults. In our experiment, older adults showed nearly twice the reaction time benefit when searching for scene-constrained targets than did younger adults; when searching for the scene-unconstrained target, they incurred nearly twice the cost. This pattern can be interpreted in the context of compensatory functioning. Previous studies have shown that older adults perform poorly when searching for a conjunction target (e.g., Foster et al., 1995; Plude & Doussard-Roosevelt, 1989), but improve when searching for a triple-conjunction target (Humphrey & Kramer, 1997). It has been argued that this improvement in performance is due to the increased top-down guidance information afforded by the additional visual feature inherent to the target, which can be used by older adults in a compensatory manner. Neuroimaging studies of cognition and aging have provided converging evidence for this account. Older adults have been shown to display increased activation compared to younger adults in the frontal and parietal regions thought to reflect top-down attentional control when engaged in a number of cognitive tasks, including visual search (e.g., Cabeza, 2002; McIntosh et al., 1999; see Dennis & Cabeza, 2008, and Madden, 2007, for reviews). For example, Madden and colleagues (Madden et al., 2007) recently found that frontal and parietal region activation was correlated with search performance in older adults, whereas occipital lobe activation was correlated with search performance in younger adults. Contextual information can be thought of in a similar vein as the additional featural information available during triple-conjunction search. Using contextual information, older adults can restrict the space through which they must search for a target in a top-down manner, with this spatial restriction compensating for age-related declines in other attentional mechanisms, such as those related to featural integration (e.g., Foster et al., 1995; Plude & Doussard-Roosevelt, 1989). Because this information is being used to compensate for other degradations, when it is available it results in a large benefit, with the cost of its absence equally large.

Second, our findings shed interesting light on the memory mechanisms underlying contextual guidance in realistic scenes. Previous demonstrations of contextual cuing in simple displays have suggested that contextual guidance is largely associated with implicit memory processes (Chun & Jiang, 1998, 1999; Jiang & Chun, 2001). In contrast, studies of contextual cuing in real-world scenes have indicated that under real-world conditions, explicit memory underlies contextual learning (e.g., Brockmole & Henderson, 2006a). Previous work with older adults has shown that explicit memory tends to suffer from age-related declines, whereas implicit memory is often spared (e.g., Light & Singh, 1987; see Old & Naveh-Benjamin, 2008, for a review of age-related changes in memory). Hence, if explicit memory is important in utilizing context in real-world environments, we might have expected that older adults would have been less efficient when searching for scene-constrained targets in our task than younger adults. Our data from Experiment 1 clearly indicated that this was not the case. Not only did older adults benefit during search for scene-constrained targets, but they also appeared to benefit even more from the availability of contextual information than younger adults. Given the declines typically associated with explicit memory in older adults, this finding suggests that the differentiation between implicit and explicit memory processes in relation to utilizing contextual information in real-world environments might be less clearly defined than previously thought.

Furthermore, it should be noted that the previous studies implicating implicit and explicit memory in contextual learning involved objects that did not possess strong spatial associations (such as Ts and Ls). Hence, it is quite possible that older adults might perform well in learning contextual associations with simple stimuli (in which implicit memory has been implicated), but poorly in learning contextual associations for novel objects in realistic scenes (in which explicit memory has been implicated), yet their ability to utilize such information once learned might be comparable to younger adults. Future work will focus on continuing to tease apart the contributions of implicit and explicit memory to contextual learning and utilization in older adults.

Third, our study provides us with insight as to the time course of contextual guidance information in older adults. Based on general slowing accounts of cognitive aging (see Salthouse, 2003, 2006), we might expect older adults to require more processing time before being able to access contextual guidance information compared to younger adults. This was not the case in our study. Similar to younger adults, older adults were able to utilize contextual information quickly, usually in time to direct the initial eye movement in a trial towards the target-consistent region. Given this similarity, it appears that older adults process contextual information quickly, with this fast access helping to compensate for slower perceptual processes that might suffer from age-related decline.

Even though older adults are able to use contextual information to improve their search performance, it is apparent from our reaction time data that some age-related declines are still present. Although older adults enjoyed nearly twice the benefit from contextual information in both target-present and target-absent conditions than did younger adults, overall they were still substantially slower to locate the target. We speculate that this reaction time difference can be attributed to a reduced useful field of view (UFOV) or attentional window in older adults (Ball, Beard, Roenker, Miller, & Griggs, 1988). Although older adults were able to restrict gaze to target-consistent regions, they required more fixations than younger adults within those regions to locate the target, indicating that less featural information was processed on a fixation by fixation basis than younger adults.[1] This account is consistent with previous research examining the effect of aging on singleton and conjunction search (Scialfa & Joffe, 1997) that suggested that older adults process information less efficiently than younger adults on a fixation-by-fixation basis.

A limitation of our study is that it does not allow us to make a direct comparison relating the effects of guidance from low-level visual features to guidance from high-level contextual information, or to clearly investigate the interaction that undoubtedly takes place between the two. This is due in large part to the realistic nature of our displays. Although using realistic displays allowed us to investigate contextual influences on search behavior, they also forced us to give up some measure of control, making it very difficult to assess search performance in the same terms as more traditional studies of search and aging (e.g., conjunction search). Future work will attempt to combine realistic displays with traditional experimental controls in order to examine how high-level contextual information might affect different types of traditional search tasks, such as search for conjunction targets.

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[1]On average, in Experiment 1 older adults made more fixations than younger adults in both target-present (5.7 compared to 4.8; $F(1, 46) = 13.13$, $p < .005$) and target-absent (8.6 compared to 6.5; $F(1, 46) = 18.90$, $p < .001$) trials.

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