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Visual Search for Change in Older Adults

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Previous research has demonstrated that younger adults are surprisingly poor at detecting substantial changes to visual scenes. Little is known, however, about age differences in this phenomenon. In the 2 experiments reported here, older adults were slower than younger adults in detecting changes to simple visual stimuli. This age difference was beyond what would be expected given known age-related changes in processing speed. Examination of eye movement behavior during the search for change suggested that age-related changes in the useful field of view and degree of cautiousness play a significant role. Speed of processing and 3 age-related eye movement behaviors explained 85% of the variance in change detection latency, eliminating the effect of age.

Keywords: attention, eye movements, change blindness, vision, aging

When something in a person's visual world changes it is usually accompanied by a transient that can facilitate detection of the change. In the absence of such a transient, changes are often surprisingly difficult to detect. In the extreme, some substantial changes may go completely undetected, a phenomenon known as *change blindness*. Although there is a commonly held belief that humans maintain a rich mental representation of the visual world around them, research on change blindness suggests otherwise. This phenomenon has been demonstrated for changes to stimuli including photographs, computer-generated natural scenes, artificial displays, motion pictures, and even people during interpersonal interactions (for reviews, see Rensink, 2002, and Simons & Ambinder, 2005). Driving provides a modern-world example of a situation in which change detection is crucial for survival. The ability to notice a car stopping ahead or a pedestrian crossing the street is necessary to avoid potentially fatal accidents. Despite the importance of the ability to detect changes, very little is known about it in older adults. Only one prior study could be located: Pringle, Irwin, Kramer, and Atchley (2001) found that older adults required more time than younger adults to detect changes to photographs of driving scenes. These researchers, however, did not control for known age differences in processing speed. As a result, it is not known whether the decline in change detection ability differs from the age-related changes that have been observed in other tasks.

The search for change has been compared with visual search tasks more generally (e.g., Rensink, 2000; Zelinsky, 2001). Previous research has demonstrated that older adults' performance on visual search tasks is differentially slowed compared with that of young adults as the number of distractors increases (Humphrey & Kramer, 1997; Kramer & Atchley, 2000; Plude & Doussard-Roosevelt, 1989). Older adults also demonstrate poorer spatial localization of targets (Scialfa & Kline, 1988), especially with increased distractor set size (Sekuler & Ball, 1986). Although there are a number of obvious differences between change detection and visual search, both tasks rely on some processes in common. For example, visual search for a specified target (*visual search*) and visual search for some unspecified change (*change detection*) both require movements of overt or covert attention from one location to another. A reduction in the speed of search, as noted earlier (e.g., Humphrey & Kramer, 1977), might thus be expected to also be reflected in a reduced speed of change detection. Additionally, change detection requires a comparison of information obtained in one frame with information obtained in a preceding one, and as a result, impaired spatial localization, as has been noted above for visual search tasks (Scialfa & Kline, 1988), may also be expected to impact change detection.[1] Thus, to the extent that change detection relies on some of the same mechanisms that support visual search more generally, these results suggest that older adults may indeed be especially impaired in change detection tasks.

In order to gain more insight into the age-related changes that affect visual search, several investigators have recorded eye movements during search tasks. Scialfa, Thomas, and Joffe (1994) reported that older adults took longer to locate targets than did younger adults, made more eye movements than did the young,

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[1] At this point, it is also worth noting that there are considerable differences between change detection and visual search, although the two tasks may rely on a number of processes in common. For example, during visual search, the participant typically has the goal of finding a particular prespecified target or targets in the scene. In contrast, in a change detection task, the participant may know only that something changes from one moment to the next in the scene, but they typically do not know anything about the identity of the item that is likely to change. Additionally, in a standard visual search task, the visual display is static and any part of the scene may be inspected and then dismissed when the participant decides to move on to inspect another part of the scene. In change detection however, two displays typically alternate with each other (along with a blank screen interposed between the two displays). A changing item cannot be detected on the basis of information in any one display—instead it is necessary for the participant to encode and remember the information in one display and then to compare that memory with information obtained in the second display. These additional memorial demands are not required in visual search.

and tended to recheck previously inspected areas of the display slightly more often. Maltz and Shinar (1999) also noted that older adults were more likely to examine an area repeatedly and made more fixations, although average fixation duration did not differ across age groups. The tendency of older adults to examine areas repeatedly during visual search may reflect age-related declines in visual working memory (Laberge & Scialfa, 2005, reported a connection between working memory and search through World Wide Web pages), although the relationship between visual working memory and visual search is not well defined and is currently under debate (Woodman, Vogel, & Luck, 2001).

Consistent with other research, Ho, Scialfa, Caird, and Graw (2001) found that speed of target identification in a visual search task declined with increasing age and that older adults made more eye movements and tended to fixate areas for longer durations, particularly during the final fixation. They suggested that the age-related increase in final fixation duration might be related to differences in decision processes and a more cautious response criterion adopted by the older adults. Taken together, these results demonstrate that older adults exhibit different patterns of eye movement behavior during visual search tasks.

In the present research, we examined a task that relies on visual search processes: the detection of change in a visual display. To study this, we used a version of the flicker paradigm (Rensink, O'Regan, & Clark, 1995) in which two display frames are presented alternately with a blank screen in between. The two frames contain many objects and are identical with the exception of one element (on the trials when a change is present). If older adults indeed use less efficient visual search strategies as suggested by the studies cited earlier, then it would be expected that they might be less efficient at detecting changes in visual scenes. However, the detection of change in the flicker paradigm involves more than a simple visual search. For example, in a visual search task the target is defined on the basis of its appearance—an object is either a target or it is not. For example, a participant might be asked whether a display of letters contains the letter *H*. However in change detection, the target cannot be distinguished from nontargets on the basis of physical appearance. Rather, the target is the item that changes from one frame to another. Any object in the display has the potential to be the changing item. Because of this feature of the change detection task, change detection requires additional memory and comparison processes beyond those required by visual search in general. Thus, it is necessary for participants not only to remember where they have searched (memory that would also be required in a standard visual search task) but also to remember the identities of the elements recently inspected in order to compare them with the elements visible in the next frame, and then they must perform such a comparison. Age-related changes in the ability to track this information might lead to greater deficits in change detection abilities than those that have been observed in visual search more generally. Alternatively, it is possible that older adults typically use strategies that reduce the impact of age-related changes. Furthermore, it may be the case that efficient change detection requires effective visual search strategies that may differ from the search strategies that are most appropriate for standard searches. As a result, age-related differences in strategic aspects of search may impact change detection in a manner that is different from the impact on standard search.

The purpose of the experiments reported here was to address two questions. First, do older adults demonstrate poorer change detection abilities relative to younger adults beyond their known slower speed of processing? Second, is the expected age-related decrement in change detection ability related to less efficient visual search strategies in the change detection task? That is, do patterns of visual search as revealed by eye movement behaviors provide insight into the mechanisms underlying age-related differences in change detection abilities?

Experiment 1

Method

Participants

The younger adult participants (21 women, 19 men) ranged in age from 18 to 30 years ($M = 21.18$, $SD = 2.36$). The older adults (21 women, 19 men) ranged in age from 66 to 86 years ($M = 75.90$, $SD = 4.28$). The younger adults were recruited from the Washington University community, and the older adults were recruited from the Washington University Department of Psychology's Older Adult Volunteer Pool. Older participants were administered the Blessed Orientation-Memory-Concentration Test during the initial telephone contact (Katzman et al., 1983); those with scores of 5 or more were excluded. Older adults were paid $10; younger adults were paid $10 or given course credit for their participation.

Static visual acuity was measured at a distance of 14 in. (35.56 cm) while participants wore any prescribed corrective device. Individuals with acuity poorer than 20/40 were excluded. Median visual acuity was 20/20 ($SD = 3.75$) for the younger adults and 20/25 ($SD = 5.49$) for the older adults.

Materials and Procedure

All procedures were approved by the university's human studies committee. Two tasks (a visual detection task and a change detection task) were administered in a single 1-hr session in a testing room with dimmed lighting to increase the prominence of the visual display. The ambient illumination consisted of a single overhead 40-W light bulb. The brightness of the monitor was adjusted to values typically used for comfortable reading. Viewing distance was 21 in. (53.34 cm). Effort was made to minimize potential auditory distraction. The order of administration of tasks was counterbalanced across participants.

Visual detection task. A visual detection task served as a measure of simple reaction time. The task was included as a potential covariate in the subsequent analysis. On each trial of this task participants saw a black fixation cross on a white background at the center of a CRT display for 1,000 ms. A delay of 500, 650, 800, or 1,000 ms followed disappearance of the cross after which a black rectangle was presented at the center of the display. The rectangle occupied approximately $0.5° \times 1.5°$ of visual angle. Participants were asked to press a single response key as quickly as possible upon detection of the rectangle. The display was cleared when the participant responded, after which a 1,000 ms intertrial interval ensued. There were 10 practice trials followed by 200 test trials (50 at each of four interstimulus intervals [ISIs]). Trials of various ISIs occurred in a random order. The summary measure for this task was the median reaction time from the 200 test trials.

Change detection task. We also studied a change detection task using the flicker paradigm (Rensink et al., 1995). The stimuli that we used were selected by first considering some of the age-related changes that occur in basic visual functions. In particular, older adults are known to have reduced contrast sensitivity (Schefrin, Tregear, Harvey, & Werner, 1999). As a result, stimuli that include low-contrast information might place additional demands on the older adults beyond those required for simple change detection. Additionally, Ho et al. (2001) found that increased visual clutter led to a difference in the pattern of eye movements made during search: Younger adults fixated longer on highly cluttered scenes, but older adults did not adjust the duration of their fixations. This difference also suggests that complex scenes may introduce additional challenges for the older adults. We did not want our study of change detection to be contaminated by these and other age-related differences in visual processes and processes involved in simple searches. Thus, to minimize the contribution of such factors to our results, we used simple uncluttered displays containing high-contrast geometric shapes.

Figure 1 shows an example of the stimuli used and illustrates the sequence of events in a trial. Participants were instructed to begin each trial by fixating on a cross in the center of the display. After 1,000 ms, the cross disappeared, and an array of 12 black rectangles on a white background appeared. Each rectangle occupied approximately 0.5° × 1.5° of visual angle and appeared in 1 of 12 randomly selected locations within an imaginary 6 × 8 grid. Each rectangle was randomly placed in either a horizontal or vertical orientation.

After 250 ms, the array of rectangles disappeared and a blank (white) screen appeared for an ISI of 50, 100, 200, or 400 ms. Longer ISIs require that participants maintain a representation of the scene for longer periods of time and have been associated with increased change detection latencies in young adults (Rensink, O'Regan, & Clark, 2000). We manipulated ISI here to compare effects of increased memory demands across the two age groups. Immediately following this blank screen, a second array of rectangles was presented for 250 ms. On 80% of the trials, the second array of rectangles consisted of an identical arrangement of rectangles except that one of the rectangles selected at random had changed orientation (horizontal to vertical or vice versa). On the other 20% of the trials, an array completely identical to the first appeared. Following the second array another blank screen was presented for the same duration as the first blank screen on that trial (50, 100, 200, or 400 ms). This cyclical presentation of stimuli (original image, blank screen, second image, blank screen) continued for 60 s or until participants responded.

Participants were told that a change would occur on most trials and were instructed to respond as quickly and as accurately as possible by pressing a single response button when they detected a change in orientation of one of the rectangles or were certain that nothing was changing. After the button press, participants saw a display identical to the first array of that trial with 9 of the 12 items numbered. The numbers were placed in a pseudo-random fashion (with the constraint that any changed item must be numbered) on 9 of the items. Younger adults at that point pressed the

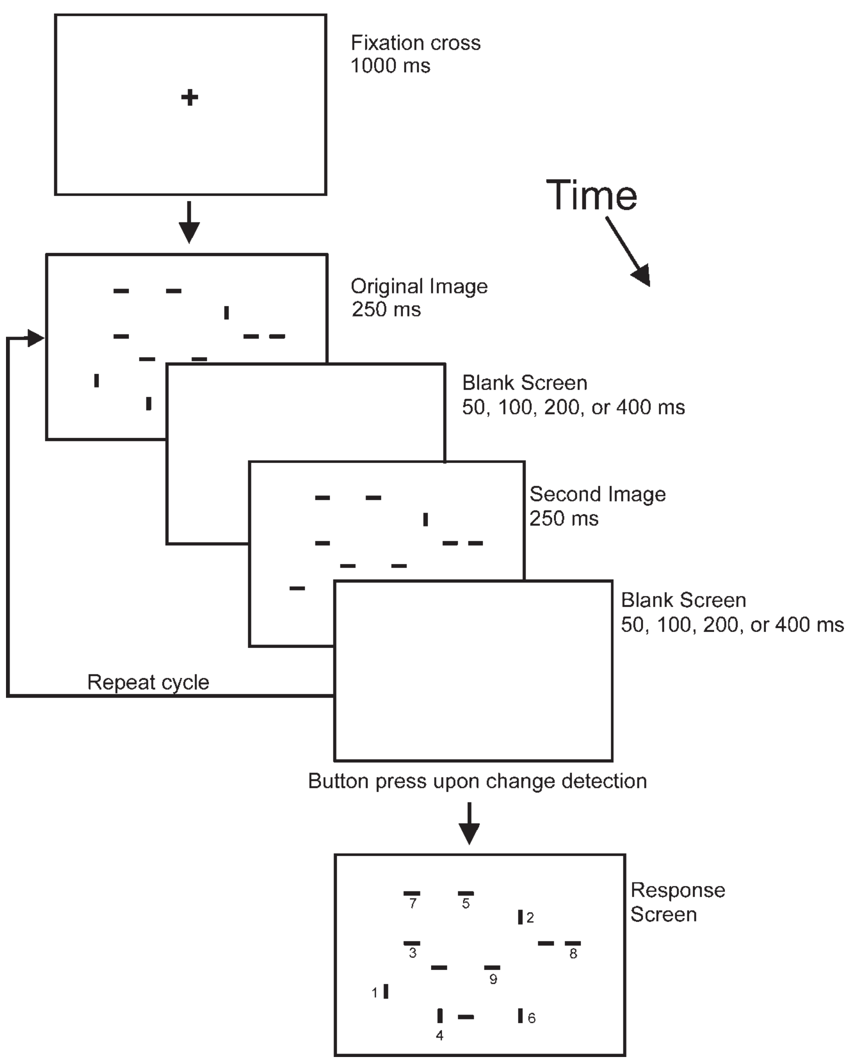

Figure 1. Sequence of events on a change detection trial in Experiment 1.

number on the keyboard that corresponded to the item they thought had changed. If they believed that no change occurred they pressed the zero key. Older adults said the number aloud or stated that they felt that no change had occurred, and the examiner recorded the response. This difference in procedure across age groups was introduced to more closely equate the duration of the experiment for younger and older adults. The numbered screen remained visible until the participant responded.

Participants completed 10 practice trials followed by 200 test trials (50 at each of four ISIs) of the change detection task. Trials of various ISIs occurred in a random order. The summary measure from this task was the time spent viewing images before responding for all correct trials. The time measure included only the time spent viewing the objects in the display; the duration of the blank screens was not included.

Results and Discussion

Alpha was set at .05 for all statistical tests. When the sphericity assumption was not met in the mixed analyses, the Greenhouse–Geisser correction was used.

There was a significant difference between the age groups in the median reaction times on the visual detection task, $t(78) = 2.98$, $p < .01$, $\omega^2 = .09$. As expected, the older adults' median reaction times ($M = 336.96$ ms, $SD = 177.39$) were longer overall than the younger adults' reaction times ($M = 251.63$ ms, $SD = 36.38$). Performance on the visual detection task, however, was not correlated with performance on the change detection task for either group at any ISI (*r*s ranged from .05 to .23). Therefore it was not possible to control for age-related processing speed differences on the change detection task with the reaction time measure from the visual detection task.

Performance on the change detection task was analyzed with an Age (young, older) × ISI (50 ms, 100 ms, 200 ms, 400 ms) mixed analysis of variance (ANOVA). The upper portion of Table 1 shows median reaction times and standard deviations on the change detection task for correct trials during which a change occurred. There was a significant main effect of age group, $F(1, 78) = 189.83$, $p < .001$, $\omega^2 = .70$. Overall, older adults spent more time viewing the images before responding that they had detected a change ($M = 2144.62$ ms) than did the younger adults ($M = 1030.31$ ms). The main effect of ISI approached significance, $F(3, 78) = 2.28$, $p = .08$. The interaction between age and ISI was not significant, $F(3, 78) = 0.94$, $p > .05$.

Table 1
Performance of Two Age Groups at Each Interstimulus Interval (ISI) on the Change Detection Task in Experiment 1

ISI	Younger *M*	Younger *SD*	Older *M*	Older *SD*
Median reaction times (ms)				
50 ms	985.39	151.49	2,160.58	583.94
100 ms	972.54	176.40	2,108.49	507.67
200 ms	1,057.58	214.48	2,145.34	505.80
400 ms	1,105.75	257.16	2,164.09	606.15
Standardized reaction times (*z* scores)				
50 ms	$-.10_{a,b}$	.15	.03	.22
100 ms	$-.10_{c,d}$	.19	.00	.15
200 ms	$.09_{a,c}$	.19	.01	.16
400 ms	$.13_{b,d}$	.24	−.03	.24

Note. Means sharing subscripts in columns are significantly different.

Given the significant effect of age, we conducted a second mixed ANOVA on standardized reaction times to examine the effects of ISI in the two age groups with individual reaction times transformed to a common scale. Faust, Balota, Spieler, and Ferraro (1999) suggested using this method as a way to examine effects across groups known to have different overall information-processing rates (e.g., younger and older adults). Standardized reaction times were calculated by first computing each participant's mean reaction time and standard deviation for all correct responses across all ISIs. Individual trial reaction times were then converted to *z* scores using the person's grand mean and standard deviation. This transformation standardized each participant's reaction times to a mean of 0 and a variance of 1 and permitted comparison of effects across age groups. Mean *z* scores at each ISI are shown for each age group in the lower portion of Table 1. As expected, because of the standardization, there was no main effect of age, $F(1, 78) < 1.0$. Both the main effect of ISI, $F(3, 78) = 4.59$, $p < .01$, partial $\eta^2 = .15$, and the interaction of age and ISI, $F(3, 78) = 7.56$, $p < .001$, $\eta^2 = .15$, were significant. This interaction is driven by the fact that the younger adults demonstrated a dramatic increase in reaction time with increasing ISI. Post hoc simple effects tests indicated that the younger adults exhibited significantly faster reaction times on the 50-ms ISI trials than on the 200-ms and 400-ms ISI trials, $t(39) = 4.15$, $p < .001$, and $t(39) = 4.63$, $p < .001$, respectively. They were also faster on the 100-ms ISI trials than on either the 200-ms or 400-ms ISI trials, $t(39) = 4.02$, $p < .001$, and $t(39) = 3.66$, $p = .001$, respectively. The older adults' reaction times did not differ across ISI.

Table 2 contains the mean error rates at each ISI for the two age groups. Almost all of the errors for both age groups were changes that were not detected. A mixed ANOVA revealed significant main effects of age, $F(1, 78) = 27.27$, $p < .001$, $\omega^2 = .25$, and ISI, $F(3, 78) = 128.69$, $p < .001$, partial $\eta^2 = .62$, that were qualified by their interaction, $F(1, 78) = 10.61$, $p < .001$, partial $\eta^2 = .12$. Error rates increased with increasing ISI for both groups, but the interaction appears to be the result of a more dramatic increase in error rate at the longest ISI for the older adults. As shown in Table 2, age group accounted for a larger portion of the variance at the longest ISI than it did at the shorter ones. This higher error rate at the longest ISI demonstrated by the older adults may have influenced the interaction between age group and ISI on change detection latency. In other words, if the older adults were somehow prevented from making more errors on trials with the longest ISI, they might show an increase in reaction time with increasing ISI.

In summary, the older adults were slower to detect changes than were the younger adults. The younger and older adults also demonstrated different patterns of performance across ISI. The younger adults exhibited a fairly consistent increase in response time with increasing ISI. This pattern of performance in the younger adults is similar to that found by Rensink et al. (2000) in that the time to detect changes increased with increasing ISI. The older adults, however, demonstrated no increase in reaction time with increasing ISI. This pattern suggests that the limiting factor responsible for the age-related differences in overall performance may involve a process other than those that are affected by the increased demands of longer ISIs. However, as noted earlier, the

Table 2
Comparisons of Number of Errors Made by Two Age Groups at Each Interstimulus Interval (ISI) in Experiment 1

	Younger		Older			
ISI	*M*	*SD*	*M*	*SD*	$t(78)$	ω^2
50 ms	0.80	0.79	1.83	1.65	3.55**	.13
100 ms	1.10	0.96	2.15	1.90	3.12**	.10
200 ms	2.75	1.90	5.23	3.93	3.58**	.13
400 ms	6.00	4.14	11.08	5.62	4.60***	.20

** $p < .01$. *** $p < .001$.

lack of an effect of ISI in the older adults may be related to their increased error rate at the longest ISI.

The older adults were also slower on the visual detection task, but performance on this task was not correlated with performance on the change detection task. This suggests that the processes involved in change detection are more complex than those involved in simple visual detection. In other words, although change detection necessarily involves visual perception and response, it also includes other functions such as visual comparison and decision making, the speeds of which are not accounted for by a simple visual detection task such as the one used in the present experiment.

Experiment 2

The second experiment was conducted to investigate age differences in change detection ability for visually simple stimuli with a more comprehensive control for age differences in response time than that examined in Experiment 1. Further, eye movements made during the change detection task were recorded, and we examined patterns of eye movements to investigate possible underlying mechanisms for successful change detection and to learn more about age-related changes in visual search.

Method

Participants

Younger adults (16 women, 14 men) ranged in age from 19 to 26 years ($M = 20.63$, $SD = 1.50$). Older adults (22 women, 8 men) ranged in age from 66 to 83 years ($M = 74.28$, $SD = 5.50$). Participants were recruited, excluded, and paid in the same manner as for Experiment 1; none had participated in Experiment 1. In addition, 6 younger adults and 2 older adults were excluded because of technical difficulties that prevented accurate calibration of eye position. The 30 younger participants had a median visual acuity of 20/20 ($SD = 2.52$). The 30 older participants had a median visual acuity of 20/30 ($SD = 6.15$).

Materials and Procedure

Participants completed two tasks for Experiment 2 in a single 1-hr testing session conducted in a testing room with dimmed lighting to increase the prominence of the visual display. Effort was made to minimize potential auditory distraction. Administration of the two tasks was counterbalanced across participants. All procedures were approved by the university's human studies committee.

Visual same–different judgment task. In an attempt to measure and control for age differences in the speed of some additional processes that may be involved in performing a change detection task other than simple visual detection, we had the participants perform a visual same–different judgment task as a measure of simple decision-making and manual response time (Scialfa & Thomas, 1994, have also studied same–different judgments in older adults.). This task served as a measurement of age differences in processing speed. Participants saw a fixation cross in the center of a computer monitor followed 500, 650, 800, or 1,000 ms later by two rectangles that each occupied approximately 0.5° × 1.5° of visual angle. The two rectangles were presented side by side in the center of the monitor. Both were oriented horizontally, both were oriented vertically, or one was oriented horizontally and one was oriented vertically. Participants were instructed to respond as quickly and accurately as possible by pressing the *M* key on a standard computer keyboard if the rectangles shared the same orientation or pressing the *Z* key if the rectangles were of different orientations. The *M* and *Z* keys were marked with blank labels.

The visual same–different judgment task included 10 practice trials followed by 200 test trials (50 at each of four ISIs). Trials of various ISIs occurred in a random order. The summary measure for each participant was the median reaction time for all correct trials.

Change detection task with eye movement monitoring. Participants performed a change detection task while eye movements were monitored. The change detection task was identical to the change detection task in Experiment 1 with two exceptions. First, this task was conducted with only the ISI at which participants were slowest to detect changes in Experiment 1 (400 ms). This was done to maximize the duration of the search for change on each trial in order to allow more time to observe the eye movement behavior. Second, the change detection task in the second experiment differed in that a change occurred on every trial. Given that most errors in the first experiment were false negatives, we eliminated the catch trials in this experiment in order to remove the option of denying the occurrence of a change and therefore to obtain more detailed eye movement data on those trials. Participants completed 10 practice trials followed by 96 test trials.

Monitoring of eye movements was conducted with an eye position tracking system (ISCAN RK 426-PC, Iscan Inc., Cambridge, MA). The device records the position of the pupil and that of the corneal reflection from a reference light source at a rate of 60 Hz. Gaze direction is given by the difference between these two positions and is unaffected by head movements in the range studied. Eyeblinks have a characteristic signature and were filtered prior to analysis. A chin rest was used to help keep the head still. Accuracy was approximately 0.5° of visual angle. The system was calibrated at the beginning of each experimental session and at later points in the session as needed. Calibration was conducted by having the participant fixate each of nine crosses placed in an imaginary 3 × 3 grid on the display screen.

Following the calibration of the eye movement monitor, participants were instructed to begin each trial by fixating on a cross in the center of the monitor. The cross was displayed for 1,000 ms, after which the participant's gaze position was checked. If the participant was fixating within 2.5° of the fixation cross then the cross disappeared and the trial began in the same manner as in Experiment 1. Participants were given 5s to acquire fixation—otherwise the eye movement monitor was recalibrated and the trial was restarted from the beginning. Participants were instructed to maintain a stable head position aided by the use of a chin rest, but they could move their eyes freely about the display until locating the changing object. Eye position recording continued until participants responded that they had located the changing object by pressing a response button.

Results and Discussion

Same–Different Judgment Task

The older adults were slower on this task ($M = 617.27$ ms, $SD = 103.23$) than were the younger adults ($M = 452.77$ ms,

$SD = 44.29$), $t(58) = 8.02$, $p < .001$, $\omega^2 = .51$. The younger adults made more errors ($M = 4.53$, $SD = 3.47$) than did the older adults ($M = 1.70$, $SD = 1.51$), $t(58) = 4.09$, $p < .001$, $\omega^2 = .21$. This indicates that at least some of the age difference in latency could be accounted for by a speed–accuracy trade-off. More important for the purposes of this investigation, reaction time on correct trials of the same–different judgment task was related to performance on the change detection task for both the younger ($r = .32$) and older adults ($r = .46$).

Change Detection Task

Participants' performance on the change detection task was examined with analysis of covariance (ANCOVA) with age group as the independent variable, median reaction time on the same–different judgment task as the covariate, and median time spent viewing images before locating the changing object as the dependent variable. There was a significant main effect of age, $F(1, 57) = 21.26$, $p < .001$, $\omega^2 = .25$. The interaction between age and reaction time on the same–different task was not significant, $F(1, 56) < 1$, thereby satisfying the assumption of homogeneity of regression. The older adults spent more time viewing images before responding (estimated $M = 2{,}002.38$ ms, $SE = 77.46$) compared with the younger adults (estimated $M = 1{,}414.11$ ms, $SE = 77.46$). The corresponding raw means were 2,171 ms and 1,245 ms.

Error rates on the change detection task were low for both age groups. The older adults did make statistically more errors ($M = 2.47$, $SD = 2.16$) than did the younger adults ($M = 1.40$, $SD = 1.52$), $t(58) = 5.45$, $p < .05$, $\omega^2 = .32$. The direction of this difference is not consistent with a differential speed–accuracy trade-off for the two age groups.

The presence of a speed–accuracy trade-off in performance of the same–different judgment task, however, suggests that the reaction times on it might differ if both groups had adopted similar criteria for acceptable levels of error on this covariate task. In other words, had the error rates been similar across age groups, the younger adults would have been slower or the older adults would have been faster in performing the same–different judgment task. Therefore, a second ANCOVA was conducted on the change detection latencies, examining the performance of the subset of participants who made between one and five errors on the same–different judgment task (i.e., 22 younger adults and 23 older adults) and who therefore presumably adopted similar response criteria. As expected, the number of errors were then equal across age groups within this subset (younger $M = 2.77$, $SD = 1.38$; older $M = 2.22$, $SD = 1.35$), $t(58) = 1.37$, $p > .05$. Again there was a significant effect of age, $F(1, 42) = 14.00$, $p < .01$, $\omega^2 = .18$, on the change detection latencies. The older adults in this subset spent more time viewing images prior to detecting the change (estimated $M = 1{,}998.85$ ms, $SE = 90.83$) compared with the younger adults in this subset (estimated $M = 1{,}445.32$ ms, $SE = 93.47$).

Eye Movement Behavior

Saccade starting and ending points were identified as the velocity zero crossings that preceded or followed runs in which the velocity of the eye exceeded 40°/s for at least three consecutive samples, respectively. Seven quantitative measures of the eye movement behavior were examined. These included the number of saccadic eye movements on each trial, the length of each saccade, the median duration of periods of fixation between saccades, the latency of the first saccade (measured from the appearance of the initial stimulus array), the duration of the final fixation on each trial, the distance of the final fixation from the changing object, and the number of times the participant's gaze left a quadrant of the visual scene and then subsequently returned to that same quadrant. A total of 25,563 eye movements were examined. Summary scores for each participant on each measure are median values on correct trials.

The means and standard deviations of each age group as well as the results of independent groups t tests on each measure of eye movement behavior are shown in Table 3. The older adults made more eye movements per trial. Recall that older adults spent more time viewing the image and thus had longer recordings of eye movement behavior. To determine if the apparent age-related increase in number of saccades was a function of the longer duration of eye movement recording, the rates of saccade production (in units of number of eye movements per second) for the younger and older adults were compared. The two groups tended to make eye movements at similar rates (younger $M = 2.16$, $SD = 0.95$; older $M = 2.11$, $SD = 0.59$), $t(58) = 0.23$, $p = .82$. Therefore, the age difference in number of saccades reflects the longer overall time older adults spent viewing the array, not a different saccade production rate.

The older adults also made shorter eye movements but were similar to the younger adults in overall fixation duration. Two specific fixations were of particular interest: the first and the last. The two age groups spent a similar amount of time fixating prior to beginning the first eye movement, but older adults spent more

Table 3
Age Group Differences in Eye Movement Behavior in Experiment 2

	Younger adults		Older adults				
Eye movement behavior	M	SD	M	SD	$t(58)$	p	ω^2
Number of saccades per trial	2.72	1.15	4.53	1.41	5.46	<.0001	.32
Saccade length (degrees)	5.14	.95	4.50	.89	2.68	.009	.09
Fixation duration (ms)	966.69	302.57	1066.78	279.66	1.33	.189	
First saccade latency (ms)	653.90	495.83	521.95	300.19	1.21	.219	
Final fixation duration (ms)	880.57	185.28	1385.31	304.43	7.76	<.0001	.50
Distance of final fixation from changing object (degrees)	3.79	.91	3.23	.82	2.51	.015	.08
Number of returns to previously viewed areas	0.00	0.00	0.52	0.68	4.19	<.0001	.22

Table 4
Intercorrelations of Eye Movement Behaviors and Latencies on the Change Detection and Same–Different Tasks in Experiment 2

Variable	1	2	3	4	5	6	7	8	9
1. Number of saccades	—	−.08	−.50**	−.63**	.43**	.72**	−.09	.71**	.55**
2. Saccade length		—	−.23	−.05	−.26*	.13	.36**	−.25	−.23
3. Fixation durations			—	.67**	.23	.14	−.14	.16	.11
4. First saccade latency				—	−.25	−.22	.15	−.25	−.14
5. Final fixation duration					—	.41**	−.28*	.78**	.60**
6. Number of returns						—	−.12	.69**	.54**
7. Distance between final fixation and change							—	−.20	−.07
8. RT on the change detection task								—	.75**
9. RT on the same–different judgment task									—

* $p < .05$. ** $p < .01$.

time fixating after the last eye movement and prior to responding. In addition to the longer duration of the final fixation, older adults exhibited final fixation positions closer to the changing object than did the younger adults. Finally, the younger adults did not return their eyes to previously viewed areas. Therefore, a one-sample *t* test was conducted to test whether the frequency of returns to previously viewed areas demonstrated by the older adults was significantly more than zero; it was.

Table 4 contains the correlations of the eye movement measures and latencies on the change detection and same–different tasks for all participants in Experiment 2. Three of the eye movement measures (number of saccades, final fixation duration, and number of returns) were strongly correlated with latencies on the change detection task. A hierarchical regression analysis was conducted to determine how much of the age difference in change detection latency could be explained by age differences in eye movement behavior (see Table 5). Latencies from the same–different task were entered at the first step to control for age differences in processing speed. The three eye movement behaviors that were correlated with reaction times on the change detection task were entered at the second step. Finally age group was entered at the third step. As seen at the second step, after we controlled for reaction time on the same–different judgment task in the first step, number of saccades, duration of final fixation, and number of returns to previously viewed areas accounted for an additional 28% of the variance in change detection latency. There was no increment in explained variance when age was added at the third step. To say it in another way, the zero-order correlation of .78 ($p < .0001$) between age and change detection latency was reduced to .52 ($p < .0001$) after we controlled for processing speed and to a nonsignificant .13 after we controlled for the three eye movement variables.

General Discussion

In the present experiments, older adults were slower to detect changes in visual scenes, even after we accounted for age differences in processing speed. Three types of eye movement behaviors explained this age difference: Older adults made more eye movements, returned more frequently to previously viewed areas, and fixated longer before responding. These three variables along with a measure of processing speed account for 85% of the variance in change detection latency.

The older adults in our experiments made more eye movements on each trial than did younger adults, but because the older adults spent more time searching, both groups produced saccades at similar rates. The older adults, however, made shorter saccades, perhaps because they were not able to gather as much information per fixation. This might occur if older adults have a reduced useful field of view (UFOV) as suggested by Pringle et al. (2001); larger distances between fixations would result in missing visual information.[2] The finding of an age-related decrease in saccade size is consistent with previous research on age differences in eye movement behavior during other types of visual search (Maltz & Shinar, 1999).

Older adults exhibited significantly longer final fixations than did younger adults. This finding is also consistent with previous research on age differences in other types of visual search tasks (Ho et al., 2001). Perhaps older adults adopt a more cautious response bias and spend more time prior to responding in order to be certain that their response is correct. Consistent with this, the older adults made fewer errors than did the younger adults on the same–different judgment task in Experiment 2. Additionally, some previous research suggests that older adults tend to be more cautious, particularly when risk taking is not rewarded (see Botwinick, 1984, for review). Given the lack of incentive to take risks in the present experiments, it is plausible that the older adults were more cautious in responding. In contrast, other research, specifically cued recall and recognition memory studies, suggests that older adults are sometimes less cautious than younger adults (e.g., Jacoby, 1999). Older adults' degree of cautiousness may vary across cognitive domains.

[2] We conducted some additional regression analyses order to examine the possibility that a reduced UFOV played a role in the age-related changes in change detection latency that we have reported. First we considered the possibility that reduced saccade amplitudes might reflect a reduced UFOV, and we examined the role of amplitude in explaining the changes in behavior. Nevertheless, as seen in Table 4, saccade amplitude was not correlated with the dependent variable. When amplitude was included after the first step in the hierarchical regression analysis shown in Table 5, it did not alter the pattern of results (its beta weight was not significant at that step or any thereafter). We also considered the possibility that the number of returns might be an index of the UFOV. We repeated the hierarchical regression analysis shown in Table 5 and included only the number of returns at Step 2. Age remained significant at Step 3 under those circumstances, indicating that number of returns is insufficient by itself to eliminate age differences. Because saccade amplitude and rechecking rates are only indirect measures of the UFOV, the results of these analyses do not rule out a reduced UFOV as a partial explanation of the age-related changes in behavior reported here.

Table 5
Hierarchical Regression Analysis Predicting Change Detection Latency in Experiment 2

Predictor	*B*	*SE B*	β	R^2	ΔR^2	*F* for increment	*df*s
Step 1				.57	.57	76.35***	1, 58
RT on same–different judgment task	3.93	0.45	.75***				
Step 2				.85	.28	33.00***	3, 55
RT on same–different judgment task	1.27	0.39	.24**				
Number of saccades	86.77	30.52	.23**				
Final fixation duration	0.76	0.11	.45***				
Number of returns	230.77	87.82	.21*				
Step 3				.85	.00		
RT on same–different judgment task	0.96	0.42	.19*				
Number of saccades	72.10	31.34	.19*				
Final fixation duration	0.65	0.13	.39***				
Number of returns	243.41	86.82	.22**				
Age group	−179.99	109.23	−.15				

* $p < .05$. ** $p < .01$. *** $p < .001$.

Perhaps also related to age-related increases in cautiousness, previous research has demonstrated that during visual search tasks, older adults tend to recheck areas of the visual display more often (Maltz & Shinar, 1999; Scialfa et al., 1994). Although the number of returns to previously viewed areas of the visual display was low for all participants in the present investigation, approximately half of the older adults exhibited this behavior, whereas none of the younger adults did. This is consistent with previous research (Scialfa et al., 1994) and may indicate that some older adults use a less organized strategy for visual search, that they are not as confident in their initial conclusion about an area of the visual display, that they are more cautious about responding, or perhaps that they forget where they have already looked.

It is also possible that the increased rechecking is related to a change in the mechanisms underlying the attentional phenomenon known as inhibition of return (IOR). IOR refers to the finding that people are often slower to detect targets appearing at recently cued locations. Many researchers have suggested that IOR might help to bias visual searches toward fresh sources of input (e.g., Klein & MacInnes, 1999). Older adults, however, have a magnitude of inhibition that is equal to that of young adults (Hartley & Kieley, 1995), although they differ in terms of the spatial reference frame in which it occurs (McRae & Abrams, 2001). Nevertheless, IOR also develops more slowly in older adults (Castel, Chasteen, Scialfa, & Pratt, 2003). As a result, a delay in the onset of the inhibition could lead to an increased frequency of rechecking—exactly as we have reported. Of course, more work is needed to determine the extent to which the changes that we observed can be attributed to IOR or to other mechanisms.

It is worth considering the extent to which the present findings extend our knowledge beyond what is already known on the basis of traditional visual search experiments. As noted earlier, the change detection task that we studied requires many processes that are also required during visual search as well as additional processes needed for change detection that are not part of search. Indeed, in some ways our findings are similar to results that have been reported earlier for search, yet other aspects of our findings differ from past reports. For example, older adults in our study made more saccades than did younger adults, similar to findings from search research (e.g., Ho et al., 2001; Watson, Maylor, & Bruce, 2005). Older participants in the present study also had longer final fixation durations as has been observed in search research (Ho et al., 2001) and a greater frequency of rechecking (Watson et al., 2005). Unlike some tasks involving solely visual search, we found no age-related differences in the durations of the fixations (Ho et al. 2001; Scialfa & Joffe, 1997; Watson et al., 2005, reported age-related fixation duration differences in a search task). Older adults also made smaller saccades in our change detection task compared with younger adults, but no differences in saccade size during visual search have been reported. Note that in the present investigation, we have explicitly assessed age-related changes in performance after removing all contributions from changes in processing speed (as indexed by the same–different judgment task). In much of the earlier work on age-related changes in visual search, processing speed changes remain a viable explanation for the changes that were observed. Finally, when taking into account the observed changes in eye movement behavior and processing speed, we completely accounted for all age-related differences in change detection performance.

An important question for future research is whether older adults' change detection performance can be improved with training. The results of the present study suggest two aspects of change detection performance that may be amenable to training. First, in Experiment 2, a pattern of eye movement behavior associated with more successful change detection was identified: longer saccades and shorter final fixation durations. If the older adults' tendency to make shorter saccades compared with younger adults is due to an unnecessarily conservative search strategy, it may be that they can be taught to make eye movements similar to those made by younger adults and thereby improve their change detection performance. If the decreased saccadic amplitude exhibited by the older adults is a necessary product of a reduced UFOV, however, training them to make larger eye movements is unlikely to have a beneficial effect. Therefore, the effects of such training might also provide a way to examine the cause of age-related reductions in saccadic amplitude (i.e., cautiousness vs. reduced UFOV). Similarly, if the older adults' longer final fixation durations reflect a cautious response bias, it may be that specific response criteria training could decrease their final fixation durations and thus improve their change detection performance. It would be important to examine error rates under such training conditions; task complexity may preclude older adults from responding more quickly without increasing their error rates.

One question that remains unanswered involves the extent to which the age-related differences observed in eye movement behavior also occur in tasks or situations other than the ones that we studied. For example, a reduced UFOV might be expected to lead to shorter eye movements in a range of tasks that require acquisition of visual information. One interesting avenue for future research would be to examine eye movement behavior of younger and older adults during the search for change in more complex natural scenes (e.g., photographs as used by Pringle et al., 2001, or in real-world scenes). It is possible that older adults exhibit similar eye movement behavior while searching real-world scenes as they do while searching simple object arrays. On the other hand, the visual complexity of a natural scene might differentially affect their eye movement behavior. The practical implications of change detection in real-world scenes make this an important area for future research.

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