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Age-Related Decline of Visual Processing Components in Change Detection

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Abstract

Previous research has suggested that an age-related decline in change detection may be due to older adults using a more conservative response criterion. However, this finding may reflect methodological limitations of the traditional change detection design, in which displays are presented continuously until a change is detected. Across two experiments, adult age differences were assessed in a version of change detection that required a response after each pair of pre- and post-change displays, thus reducing the potential contribution of response criterion. Older adults performed worse than younger adults, with greater errors and requiring a greater number of display cycles for correct detection. These age-related performance declines were substantially reduced after controlling statistically for elementary perceptual speed. Search strategy was largely similar for the two age groups, but perceptual speed was less successful in accounting for age-related variance in detectability when a more precise spatial localization of change was required (Experiment 2). Thus, the negative effect of aging in the present tasks lies in a reduction of detection efficiency due largely to processing speed, though some strategy-level effects may also contribute.

Keywords

aging; cognition; attention; change detection; processing speed

The change detection paradigm has revealed that our capacity to detect changes to visual scenes can be surprisingly limited (O'Regan, Rensink & Clark, 1999; Rensink, 2000; Simons & Ambinder, 2005). This insensitivity, or *change blindness*, occurs whenever the transient signal that normally accompanies visual changes is either missing or otherwise unattended (Simons & Rensink, 2005). The canonical change detection design is the 'flicker' task, in which participants are shown repeating cycles of a pre-change display and a post-change display, with a brief blank screen mask interposed between (e.g., Rensink, O'Regan, & Clark, 1997). After multiple display repetitions, participants indicate whether the changed item is present or absent

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from the displays. The mask interposed between the pre-change and post-change displays effectively eliminates transient signals identifying the changed item and results in greater difficulty in detection. Understanding when, how, and what changes are detected (or not detected) offers an especially powerful tool for examining issues of visual attention, memory, and perception. For example, change detection tasks have been used to examine the content of visual representations (e.g., Rensink, 2002; Simons, 1996), the role of focused attention in visual representations (e.g., Rensink et al., 1997; Scholl, 2000), the nature of visual memory (e.g., Hollingworth & Henderson, 2004), and the role of awareness in visual processing (e.g., Mitroff, Simons, & Franconeri, 2002). There are likely several underlying causes for change blindness (see Simons & Rensink, 2005 for a recent review), including failures of encoding or representation (e.g., O'Regan & Noe, 2002), overwriting of the pre-change display with the post-change display (e.g., Beck & Levin, 2003; Levin, Simons, Angelone, & Chabris, 2002), and failures of comparison between the pre-change and post-change displays (e.g., Angelone, Levin, & Simons, 2003; Hollingworth, 2003; Mitroff, Simons, & Levin, 2004).

Despite the broad utility of the change detection paradigm in visual information processing research, it has been used relatively sparingly in the study of aging. A few studies used change detection to examine age-related differences specifically for automobile driving (Caird, Edwards, Creaser, & Horrey, 2005; McCarley et al., 2004; Pringle, Irwin, Kramer, & Atchley, 2001) and found that older adults missed more changes than younger adults and required greater presentation time for correct detection. Another study measured eye movements during a change detection task in which older and younger participants were to detect an orientation change in alternating displays of vertical and horizontal bars (Veiel, Storandt, & Abrams, 2006). In the Veiel et al. (2006) study, two key findings emerged, beyond an overall age-related decline in change detection performance. First, the age-related differences in change detection could be substantially eliminated when controlled statistically for an independent measure of processing speed (digit symbol) and measures of eye movement behavior. This age-related decline is consistent with a decline in the speed of sensory-level feature extraction, leading to a noisier visual representation for older adults relative to younger adults (Madden, 2001; Salthouse & Madden, 2007; Schneider & Pichora-Fuller, 2000; Scialfa, 2002). Second, the eye movement patterns of the older adults were indicative of an overall less efficient search strategy, with older adults differing from younger adults in saccade patterns (greater numbers and longer lengths), longer duration periods, and increased returns to previously viewed areas. Veiel et al. speculated that these eye movement patterns were suggestive of an age-related increase in cautiousness, which accords with similar findings in psychophysical studies of visual discrimination (Ratcliff, Spieler, & McKoon, 2004; Ratcliff, Thapar, Gomez, & McKoon, 2004) and in visual search (Hommel, Li, & Li, 2004; Kramer, Martin-Emerson, Larish, & Andersen, 1996; Scialfa & Thomas, 1994).

A common feature of these previous change detection experiments is that they have used a continuous flicker design, in which the pre-change and post-change images continuously cycle until a detection response is made (Caird et al., 2005; Hoffman, McDowd, Atchley, & Dubinsky, 2005; McCarley et al., 2004; Pringle et al., 2001; Veiel, Storandt, & Abrams, 2006). A limitation of this design is that it can potentially conflate detectability with search strategy (e.g., response criterion). Older adults, for instance, may have comparable access to bottom-up information of the changed item across cycles compared to younger adults, but they may require a greater number of cycle repetitions to attain sufficient confidence for the detection decision. In this case, age group differences in the number of cycles for detection might reflect cautiousness rather than detectability. Furthermore, the traditional flicker design typically features a simple binary detection response (yes/no), which may also incorporate the effects of response criterion. For instance, older adults may display improved detectability if given a third response option to express indefinite but possible detection.

In these experiments we used a change detection paradigm (first used by Mitroff & Simons, 2002) that addressed these limitations in two ways. First, after each presentation of the pre-change and post-change displays, participants were required to make a detection response (Experiment 1) or a mouse-click on the probable location of the changed item (Experiment 2). Thus, change detection was measured across a series of discrete responses to individual display-pairs, rather than as a single response following a display presentation cycle. Second, our design provided an additional category of a third detection response, beyond the binary yes/no responses, with a *verify* option. With the latter response, participants indicated that they perceived some evidence of change but that additional verification was needed. Thus, increased cautiousness would be reflected in increased use of the *verify* response. We believe that changing these two features of the traditional flicker design allows for a cleaner separation of change detection efficiency (measured in cycles-to-detection and hits minus false alarms) from response criterion (measured in use of *verify* response option).

Experiment 1

Experiment 1 tested two hypotheses. First, assuming that previous findings of age-related reduction in change detection (Caird et al., 2005; Hoffman et al., 2005; McCarley et al., 2004; Pringle et al., 2001; Veiel et al., 2006) reflect the actual quality of detection, and not just response-level effects, we expected that older adults would require a higher number of presentation cycles for correct detection and exhibit reduced hits minus false alarms, relative to younger adults. Thus we expected that older adults would display reduced detectability for changed items, and that this age difference, in turn, should be related significantly to elementary perceptual speed. Second, if the age-related decline in change detection is influenced by a more cautious search strategy (Veiel et al., 2006), then older adults should respond more frequently with the *verify* response option than the definite rejection option, compared to younger adults.

Method

Participants—Twenty-four older adults (12 female) between the ages of 63 and 84 years of age (*M* = 72.21 years, *SD* = 5.67) and 24 younger adults (12 female) between the ages of 18 and 25 years of age (*M* = 19.75 years, *SD* = 1.75) participated. The research procedures were approved by the Institutional Review Board of the Duke University Medical Center, and all participants provided written, informed consent. All the testing took place in one session of approximately one hour. Participant characteristics are presented in Table 1. All participants possessed distance visual acuity (corrected) of at least 20/40 (Bach, 1996), normal color vision (at least 12/14 on the Dvorine color plates (Dvorine, 1963), and at least 27 out of 30 points on the Mini-Mental State Exam (MMSE) (Folstein, Folstein, & McHugh, 1975). The two age groups were comparable in their performance on the Vocabulary subtest of the Wechsler Adult Intelligence Scale-Revisited (WAIS-R) (Wechsler, 1981). Participants also completed a computer-administered digit-symbol coding test (Salthouse, 1992a) as a measure of elementary perceptual motor speed. Across 72 trials, participants determined whether a centrally presented digit-symbol test pair corresponded to one of nine digit-symbol pairs listed at the top of the screen. Participants made a same/different keypress response regarding whether the central pair corresponded to one of the nine standard pairs (which remained constant). Older adults exhibited slower performance on this task, relative to younger adults, $t(46) = 2.63$, $p < .05$.

Stimuli, Design, and Procedure—The stimuli consisted of 40 digitized photographs of natural scenes used in previous change detection experiments (e.g., Mitroff & Simons, 2002; Simons, Franconeri, & Reimer, 2000). The photographs were relatively complex scenes (e.g., shoppers at a market) composed of numerous individual items (shopping bags, cash registers, individual shoppers, etc.). The changes consisted of one clearly identifiable item within a scene that was deleted from the original digitized photograph, with the relevant region filled in with similar context. During the task, the scenes were presented as pairs (e.g., the original scene and its changed version, separated by a brief mask). Thus, depending on whether this changed display was presented as the first or second item within the display pair, the change trials consisted of either deletions (i.e., an object removed from the scene) or additions (i.e., an object added to the scene). For additional details on the stimuli set, see Simons et al. (2000). The images were approximately 32.5° horizontal by 25.8° vertical at a viewing distance of 48 cm and were surrounded by a black frame. Stimulus presentation and response measurement were controlled by Matlab 7 software (MathWorks, 1994), running on a 2.0 GHz processor, Pentium 4 microcomputer with a 20-in. flat panel monitor. The monitor was set to an 1152×864 pixel resolution with a screen refresh rate of 60 Hz.

The task was based on that of Mitroff and Simons (2002). Each trial began with a 500 ms presentation of a red fixation cross in the center of the screen. After this delay, the first display was presented for 500 ms, followed by a 250 ms gray screen mask, then the second display for 500 ms, and finally a blank gray response screen (see Figure 1). The 500 ms display duration was chosen based upon earlier pilot testing that found that the typical ~250 ms duration was unsuitable for older adults and resulted in unacceptable dropout rates. Participants were instructed to press one of three keys on the computer keyboard to indicate their confidence level of change detection: *Z*-key (definitely did not detect a change), *X*-key (possibly saw a change but require additional verification), or /-key (definitely saw a change). We will henceforth refer to these response key options as *didn't see*, *verify* and *saw*. With selection of either the *didn't see* or *verify* responses, the presentation cycle of pre-change, mask, post-change, and response displays would be repeated, up to a limit of 15 cycles. Following a *saw* response, the cycle presentation ended, and participants made an additional two-choice localization judgment (with key press response), reporting whether the changed item appeared on the left or the right side of the image and thereby ensuring that the participant's detection response was accurate. For change trials, if participants failed to make a *saw* response after 15 repetitions, then the changed item would be revealed to participants (the two displays would alternate, without the gray screen mask, for 5 s), and a new trial would begin. For no-change trials, if participants did not report seeing a change after 15 repetitions, a message appeared stating, “Correct, there was no change.” After successful completion of a change trial, the changed item flickered for 2 s as a form of feedback.

There were 40 trials (i.e., display-pairs) total, comprised of 33 change trials and 7 no-change trials (i.e., the same display presented twice). Of the 33 change trials, change type (addition versus deletion) was distributed in approximately half of the trials (16 vs. 17). The assignment of particular changes as additions or deletions was counterbalanced across participants. Changed items were distributed evenly among four display quadrants of upper left, upper right, lower left, lower right locations.

Prior to testing, participants were instructed on the task purpose and requirements. They were informed that, in a majority of the trials, one item within each pair of displays would change (either added to, or deleted from, the first display), and that in a minority of trials there would be no changes. After task instruction, participants completed four practice trials that simulated the actual testing. One participant, an older adult, was excluded prior to testing, due to an inability to complete any practice trials correctly. Data were also eliminated post-testing from six participants, five younger adults and one older adult, because they exhibited either a change detection hit rate of less than 40% or a false alarm rate greater than 60%. These dropped participants were then replaced to reach the 48 participant total. Presentation order, change item location, and change type were balanced across participants.

Results

Change Detection Accuracy—For each participant, we obtained the percentage of change trials with correct detection (i.e., hit rate), the mean number of cycles required for correct detection, and the percentage of incorrect responses to no-change trials (i.e., false alarm rate). Within each age group, on approximately 3% of the change trials, the detection response was correct but the left-right location response was incorrect; these trials were consequently removed from analyses. Mean false alarm rates did not differ statistically between the age groups (younger = 11.2%; older = 10.7%; $t(46) = -0.13$, *n.s.*). To assess overall detectability in the task, we calculated two variables. First, we calculated hits minus false alarms for each participant. Mean values are presented in Figure 2. Older adults yielded lower hits minus false alarms compared to younger adults, $t(46) = 3.09$, $p < .01$). Second, we calculated the number of cycles required until a positive and correct change detection response (henceforth called *cycles-to-detection*), which was higher for older adults than for younger adults, $t(46) = 9.66$, $p < .0001$.

Response Preference—To assess response preference (*didn't see* vs. *verify*), we derived mean percentages for each participant in the relative contributions of both responses in correctly identified change trials. Mean percentage for *verify* key usage in change trials that led to correct detection was equivalent between the two age groups, with 52.6% of the responses for older adults ($SD = 46.6$) and 51.9% of the responses for younger adults ($SD = 36.7$), being associated with *verify* responses. An additional analysis examined whether response type preference may have altered across the course of the testing session. We derived response preference averages in the first, second, third and fourth quarters of the testing session. However, an ANOVA of these values, with age group as a between-subjects variable and quarter (1 – 4) averages as a within-subjects variable yielded no significant effects.

Effects of Perceptual Speed—Following Veiel et al (2006), we conducted hierarchical regression analyses to assess the contribution of elementary perceptual speed in the age-related differences on the cycles-to-detection and hits minus false alarms variables. The perceptual speed measure was the median response time (RT) for correct trials in the digit symbol task (Table 1). First, age group was entered as the sole predictor of each of the two dependent variables. Second, median RT in the digit symbol task was entered into the model before age group. The relative change in age-related variance between these two types of regression models is an estimate of the degree to which age-related variance in the dependent variable is shared with perceptual speed (Salthouse, 1992a). That is, when age-related variance in perceptual speed is shared with the age-related effect in the dependent variable, the unique effect of age will be attenuated when covaried for speed (i.e., speed entered before age in the model). The results of these analyses are presented Table 2. The unique age-related variance in the second model (age covaried for speed) was subtracted from the age-related variance in the first model (age alone), and the result was divided by the age-related variance in the first model. This calculation revealed that speed of processing accounted for most of the age-related variance (70.90 %) in cycles-to-detection, although the unique effect age group, following speed, remained significant ($p < .0001$). Speed of processing also accounted for most of the hits minus false alarms variance (72.64 %) and in this case the age group effect was not significant following the speed variable.

Discussion

As expected, older adults performed worse in the task compared to younger adults, displaying lower accuracy for changed items and requiring greater cycle repetitions for correct detection. Both of these measures of detection efficiency were heavily influenced by perceptual speed, which had a substantial role in older adults' change detection performance, a finding similar to that of Veiel et al. (2006). Covarying digit symbol RT led to a substantial attenuation of the age-related variance in both the hits minus false alarms and cycles-to-detection variables (Table 1). Note that Veiel et al. also included several measures of eye movement behavior in their regression model predicting change detection performance. It is consequently possible that including additional variables related to eye movements would completely eliminate the effects of age group in our measures. However, mediation models require that the predictor variables have a degree of independence from the criterion variables (Salthouse, Atkinson, & Berish, 2003), which may not be the case for measures of eye movements during change detection.

Contrary to Veiel et al. (2006), we found little evidence of an age-related increase in cautiousness. First, there were no age group differences in false alarm rates, and if older adults were more cautious in the task we would expect them to have fewer false alarms compared to younger adults. Second, there was age equivalence in response preference (*didn't see* vs. *verify*), indicating that the two age groups were registering similar degrees of confidence in their detection response. Thus, although age-related changes in response criterion or cautiousness may exist, they were not evident in the participants' explicit categorization of their visual representation. One limitation of this type of response preference analysis is that it reflects conscious appraisals of confidence but does not address whether the age groups differ in the amount of perceptual evidence required prior to explicit detection. That is, age-related change may occur in the preattentive accumulation (across multiple display cycles) of target evidence, prior to explicit recognition of change. This issue is addressed in Experiment 2, which explored whether age-related differences in response criterion and/or search strategies will be apparent in the preattentive buildup of the changed signal.

Experiment 2

The results of Experiment 1 indicate that age-related decline in change detection efficiency is driven substantially by processing speed, with no evidence of increased cautiousness on the part of older adults. Yet Experiment 1 was limited insofar as the response criterion analyses consisted primarily in explicit detection appraisals (i.e., *didn't see* vs. *verify*). It is possible that the more conservative older adults may be gathering greater perceptual-level pickup of the changed item across cycle repetitions, as they would require a greater degree of evidence prior to explicit detection. Cautiousness, in other words, was analyzed in Experiment 1 as an overt and explicit judgment by the participant, yet age group differences in response criterion might nevertheless exist within the display cycles leading up to explicit detection.

In Experiment 2, participants also responded following each pair of displays, and the *verify* option was available for each response. In this version, however, participants were also required to make a mouse-click on the screen after every cycle repetition indicating exactly where they think the changed item might be, even if they did not see the change and were guessing its location. The x and y coordinates of this localization response were then subtracted from the x and y location coordinates of the changed item, with the resulting Euclidian distance providing a measure of localization error across display cycles. The resulting measure provides some indication of the gradual accumulation of information of the changed target on correctly performed trials, allowing us to better assess age group differences in response criterion or search strategy that may manifest prior to explicit detection. If older adults are more cautious than younger adults, then they will require greater evidence of the changed item's location or identity prior to making an explicit detection judgment, evident as a drop of localization error across cycles leading up to correct detection. Thus, a greater influence of cautiousness, for older adults, would be expressed as greater decline in localization error, across display cycles, for older adults than for younger adults.

These hypothesized differences between the age groups accord closely with two detection models discussed by Mitroff and Simons (2002). In the *temporal integration model*, the buildup of evidence regarding change, across display presentation cycles, leads to explicit detection once the evidence exceeds an observer's threshold. The temporal integration model would therefore be a reasonable fit for the hypothesized older adult performance, assuming that older adults would gather greater evidence of the changed item prior to explicit detection. Younger adults' data, in contrast, would be more likely consistent with a *focused attention model*, in which the detection decision is made with little or no featural information gathered across display cycles. In this case, the repetitions of the display assist detection only insofar as attention can focus on new items within the display for comparison. The two models can be quantitatively distinguished by the expected decrease in localization error across successive localization guesses within a trial, as illustrated in Figure 5. Mitroff and Simons (2002) found that younger adult performance yielded a consistent degree of localization error across display cycles leading up to detection, suggesting that their performance was unaffected by the preattentive accumulation of bottom-up signals of the changed item. As such, their performance was most indicative of the focused attention model, although it is unknown whether this would hold true for older adults.

A further goal of Experiment 2 was to examine group differences in search strategy. As mentioned in the Introduction, older adults have shown differing eye movement patterns while performing change detection tasks, with a greater number of saccades, shorter length saccades and a greater number of returns to previously viewed areas (Veiel et al., 2006). With only a single detection response per trial, however, the relation between eye movement pattern and eventual detection of change is difficult to determine. In this experiment, we analyzed two strategic properties of the localization response. First, we examined the average distance between consecutive localization responses, providing an index of how widely or narrowly participants were placing their localization responses across cycles. Second, we examined group differences in the total area covered by the mouse-click localizations across the multiple cycles within a trial, providing an index of overall spatial extent of localization. These two measures serve as an estimation of strategy, as they quantify how the localization responses relate to one another across multiple cycles, rather than in relation to the target (which the localization error analyses, detailed above, indicate). If older adults are more cautious than younger adults, and perform the task with a less efficient search strategy, then we should expect their area and distance measures across cycles to be greater than those of younger adults.

Method

Participants—Twenty-four older adults (12 female) between the ages of 60 and 82 years of age (*M* = 68.29 years, *SD* = 5.2) and 24 younger adults (12 female) between the ages of 18 and 28 years of age (*M* = 20.25 years, *SD* = 2.3) participated. Participant recruitment, payment and informed consent procedures were identical to Experiment 1. None of the participants for Experiment 2 had participated in Experiment 1. Twelve participants, evenly divided by gender (6 males) and by age (6 older, 6 younger), were tested at Washington and Lee University, and the remaining participants were tested at the Duke University Medical Center. The two sites featured comparable testing environments, with equivalent viewing distance, monitor display size and screen resolution, and participant demographic equivalence. Total testing time was approximately 1.5 hours. Participant characteristics, including vocabulary and digit symbol performance, are presented in Table 3. The exclusionary criteria were identical to Experiment 1. One participant, an older adult, tested positive for color blindness and was excluded. Data were eliminated from four participants (one younger and three older adults) because they exhibited either a change detection hit rate of less than 40% or a false alarm rate greater than 60%. Two younger adults were excluded from testing based on low vocabulary scores. All excluded participants were later replaced.

Stimuli, Design, and Procedure—The stimuli were the same as those used in Experiment 1 (cf. Mitroff & Simons, 2002; Simons et al., 2000), although for Experiment 2 the number of images increased to 46 and the location of changed items included the center of the display. Each pair of displays (separated by a gray-screen mask) was presented up to 15 times, and participants made detection responses following each presentation (see Figure 3). As in Experiment 1, changed items could occur as either additions or deletions. There were a total of 46 trials (i.e., display-pairs), comprised of 40 change trials and 6 no-change trials.

The sequence of events was comparable to Experiment 1, although with an important modification in the response mode. Each trial began with a 500 ms red cross fixation placed in the center of the screen, followed by a 500 ms presentation of the pre-change display, then a 250 ms gray screen mask, then the post-change display for 500 ms, and finally a localization response screen. The localization response screen was a gray screen into which participants were instructed to make a mouse-click on the localization response screen to indicate the location of the changed item. This localization judgment was mandatory, even when participants had no knowledge of a change or its possible location. After making the mouse-click, a black screen appeared with instructions for a response categorization. The three response options were identical to those in Experiment 1 (*didn't see, saw, verify*).

For change trials, the image-cycle would cease after a correct mouse click on the changed item and the subsequent *saw* response selection. Correct change detection was defined as 1) a mouse-click falling within the boundary box (set at 35 pixels, or 1°) of the changed item; and 2) a *saw* detection selection indicating positive detection.[1] For localization calculation purposes, each changed item was defined through the coordinates of the outer extremities (lower left, lower right, upper left, upper right boundaries) of the changed item. Localization error was calculated as the Euclidian distance between the mouse click and the nearest pixel of the changed item coordinates. In cases of correct detection, feedback was provided with the changed item flashing onscreen for 3 seconds. In cases of failed detection (a *saw* response with a mouse-click localization response outside of the boundary box), similar feedback was provided and the next trial of images proceeded. As in Experiment 1, no-change trials were performed correctly with consistent rejection (no *saw* responses) over the 15-repetition cycle. In cases of correct rejections, the feedback was, “Correct, there were no changes”. In cases of false alarms, the feedback was, “Incorrect, there were no changes”.

Task instructions and practice session were comparable to those of Experiment 1. Two run lists of 46 trials were administered to participants (40 change trials and 6 no-change trials), with the presentation order of the display-pairs reversed between the two run lists. Both the change and no-change trials were evenly distributed (20 change and 3 no-change trials) across the two run lists. The same no-change trials were used across participants. Targets were located at one of four display quadrants (upper left, upper right, lower left, lower right), with an even distribution of 10 samples per quadrant across the change trials.

Following the completion of the change detection task, participants were also administered the digit symbol task used in Experiment 1, to be used as a covariate for the regression analyses on the change detection measures.

Results

Change Detection Accuracy Analyses—We derived for each participant the following dependent measures: 1) the percentage of change trials with correct detection (i.e., hit rate); 2)

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[1] The boundary box was used to minimize any age group differences in the role of spatial memory in the localization judgment. Excluding the boundary box from the analyses did not significantly alter the group comparison of either hits, misses, or hits minus false alarms, although the cases of localization errors increased by 7% in older adults and 3% in younger adults.

the percentage of no-change trials in which participants responded with positive detection (i.e., false alarms; 3) the mean number of cycles required for correct detection (i.e., cycles-to-detection); and 4) two miss rate measures that are described below. A hit was defined as both a *saw* detection response and an accurate localization placement (within 1° of changed item) for the final trial within a cycle repetition sequence. As in Experiment 1, we calculated hits minus false alarms and cycles-to-detection for each participant (see Figure 4). Older adults displayed lower hits minus false alarms values compared to younger adults, $t(46) = 6.66$, $p < .0001$. The number of cycles-to-detection was higher for older adults than for younger adults, $t(46) = 6.39$, $p < .0001$. False alarms were infrequent, with older adults at 4% and younger adults with no false alarms. Age group comparisons for false alarms are not statistically plausible as younger adults have no variability with a zero mean. For Experiment 2, misses were separated into two different types. A *failure-to-see miss* occurred when participants registered either the *didn't see* or *verify* selections for every change trial up to the maximum of 15 cycle repetitions. A *localization miss* occurred when participants selected *saw* on change trials but failed to click accurately within the boundary box of the changed item. There were significant age group differences for both failure-to-see misses, $t(46) = 6.69$, $p < .0001$, and false localization misses, $t(46) = 2.40$, $p < .05$, with older adults showing greater likelihood of errors, in both cases (mean failure-to-see = 19%, mean localization miss = 3%), compared to younger adults (mean failure-to-see = 8%, mean localization miss = 1%).

Effects of Perceptual Speed—As in Experiment 1, we conducted regression analyses for Experiment 2 that analyzed the relative contribution of elementary perceptual speed (mean RT for correct trials in the digit symbol task) in the age-related differences on the cycles-to-detection variable and hits minus false alarms. The results of these regressions, detailed in Table 4, found broad replication of the key findings from Experiment 1. The effect of age was substantially reduced (64 – 79%) after processing speed was included in the model. Yet despite this strong attenuation, age remained a significant predictor for both variables.

Localization Error Analyses—The distinguishing feature of Experiment 2 is that participants were required to make a localization judgment after each image-pair display. To analyze the localization responses, we derived the mean error (in cm) for each participant for each localization attempt prior to correct detection. Excluded from these analyses were failure-to-see trials (never selecting *saw* across 15 cycles) or miss trials (bad localization responses with *saw* selection) from the change trials, as well as all no-change trials. Due to the relatively small number of *verify* responses, these trials were excluded from the slope analyses, and therefore only the *didn't see* localization responses were included. Because our interest for these analyses lay in how the two age groups were accumulating bottom-up information of the changed item across cycle repetitions, we binned the localization error data from 10 - 1 according to their relative position within a cycle sequence, sorted from early (the tenth trial prior to correct detection) to latest (the last trial prior to correct detection). We excluded the earliest trial attempts (i.e., > 10 trials prior to eventual detection) from these analyses because there were relatively few such trials.[2] These localization data are presented in Figure 6.

We first analyzed these data by calculating regression slopes derived from the 2-10 positions, for each participant. The slope of these localization attempts represents the rate of change in localization errors across successive display cycles, leading up to correct detection. Position 1 was excluded from these slope analyses because of the obviously sharp difference from the

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[2] For the first ten bins that were included in these analyses, the total number of trials contributing were distributed as follows; for older adults: 51, 67, 86, 125, 156, 211, 277, 351, 448, 435 trials (respectively, bins 10 – 1); for younger adults: 34, 51, 80, 111, 148, 198, 259, 329, 433, 388 trials (respectively, bins 10 – 1). These values represent only *didn't know* responses leading to correct detection. Including both the *didn't know* and *verify* responses, the distribution is as follows; for older adults: 57, 77, 98, 141, 177, 242, 322, 402, 517, 639 (bins 10 – 1); for younger adults: 42, 59, 98, 137, 175, 232, 305, 393, 535, 728 (bins 10 – 1).

preceding positions. The slopes were not significantly different between the age groups (mean slope for older = -0.02 (*SD* = .39); for younger = 0.30 (*SD* = .84), and neither of the mean slope values was statistically different from zero. Therefore, across the 10 trials prior to correct detection, neither age group showed gradual improvement in localizing the changed item. However, the slope analyses do not reveal potential differences between pairs of adjacent points along the line. This is especially important because, as evident in Figure 6, the localization responses immediately prior to explicit detection show marked improvement in localization accuracy. Accordingly, we conducted repeated measures ANOVA on the localization data leading up to correct detection, with the 10 pre-detection trials entered as separate levels of an independent variable (within-subjects), with age group as the between-subject variable. Thus, each trial position was contrasted with its neighboring position (1 vs. 2, 2 vs. 3, etc). Eight participants (3 older adults and 5 younger adults) were removed from these analyses, because they did not have data at one or more trial positions. For the attempts that were more distant from the eventually correct detection (i.e. positions 3 - 10) there were no statistical differences in localization error between adjacent positions, a result that coheres well with the slope analysis: These early attempts at localization show no improvement across display cycles. However, the positions closest to correct detection (positions 1, 2 and 3) show a more complex pattern. The transition from position 3 to position 2 showed a significant lowering of localization error (i.e., more accurate localization), $F(1, 38) = 24.07$, $p < .0001$, with no significant age group effect. The transition from position 2 to position 1 also showed a significant improvement in localization, $F(1, 38) = 85.00$, $p < .0001$, as well as a significant age difference in the magnitude of improvement, $t(46) = 2.03$, $p < .05$, with younger adults showing greater localization improvement compared to older adults.

Strategy Analyses—To determine age group differences in localization response strategy, we analyzed 1) the distance between successive mouse-click localization responses prior to detection; and 2) the total area of localization responses covered across display cycles. We also examined (as in Experiment 1) age group response criterion differences, in terms of the *verify* and *didn't see* response options.

For the distance calculation, we determined the Euclidian distance of each localization response from the previous localization response within every trial that contained multiple cycles, separately for both the change and no-change trials. The individual display-pairs associated with positive detection (*saw* responses) were removed from these analyses, and thus the remaining trials were deliberative localization (either *didn't see* or *verify*) responses. There were no age group differences in the distance measure for either change trials (older adults *M* = 7.64 cm, *SD* = 2.27; younger adults *M* = 8.16 cm, *SD* = 1.2) or no-change trials (older adults *M* = 7.91 cm, *SD* = 2.69; younger adults *M* = 8.07 cm, *SD* = 1.44). For the area measure, we calculated for every participant the total area covered across successive mouse-clicks prior to detection, based upon the lowest and highest x and y localization coordinates across cycles, separately for both change and no-change trials. As before, cycles with positive detection (*saw* responses) were removed from these analyses. As with the distance calculation, there were no statistical differences in the area measure for either change trials (older adults *M* = 130.06 cm^2, *SD* = 49.69; younger adults *M* = 131.18 cm^2, *SD* = 30.68) or no-change trials (older adults *M* = 209.31 cm^2, *SD* = 85.51; younger adults *M* = 230.68 cm^2, *SD* = 48.97).[3] The two age groups were also equivalent in the use of the verify response option on correctly

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[3] These analyses were collapsed across all cycle counts, and it is possible that differences in scan area may be evident in trials with few cycles to detection compared to many cycles to detection. Accordingly, we binned the area dataset for correctly detected trials into easy (2 – 3 cycles required for detection), medium (4 – 5 cycles), and difficult (6 – 7 cycles) change trials. However, there was no Age Group by Bin interaction, indicating that regardless of change detection difficulty the two age groups were placing localization responses within an equivalent area.

identified change trials, with older adults selecting *verify* on 16% of the trials and younger adults on 21% of the trials, a non-significant difference.

Discussion

The results of Experiment 2 replicated many of the findings from Experiment 1. Older adults performed worse in change detection when compared to younger adults, displaying lower hits minus false alarms values and requiring greater image-pair cycles for correct detection. Also as in Experiment 1, the age-related variance in change detection was shared substantially with elementary processing speed (Table 4), although some unique effects of age remained following the statistical control of speed.

The age-related reduction in detection efficiency, however, did not translate into group differences in the overall detection model. For both age groups, localization attempts showed no improvement in target accuracy across viewing cycles until the two trials prior to correct detection, indicating group equivalence in the role of bottom-up information as attentional guidance. Therefore, although older adults were less efficient than younger adults in change detection (fewer hits, greater errors, and more cycles needed for correct detection), they exhibited comparable influence of bottom-up information across cycles for correctly detected trials. A more conservative response criterion would require greater evidence prior to positive detection, and in the context of Experiment 2 this would be manifest as a steeper and more extended reduction in localization error across cycles (compared to a more liberal setting). Yet the group equivalence in detection model (Figure 6) suggests, to the contrary, that the age-related reduction in detection efficiency is not driven by response criterion differences.

Furthermore, the strategy analyses indicated the two age groups conducted their searches in a strategically similar manner, with no group differences in either the distance or area calculations. An earlier eye tracking study found that older adults were using different search strategies compared to younger adults, with increased saccades and longer fixation durations, perhaps indicative of increased cautiousness in older adults (Veiel et al., 2006). Although a qualitatively different measure from eye tracking, the localization responses in our task offer a quantifiable measure of the target search across cycles, and group difference in search strategy should be expressed in the localization patterns across display cycles. In Experiment 2, we found no significant group differences in the distance between localization attempts, the average area covered across cycles, or in the use of the *verify* detection response. However, the fact that there remained significant group differences in both detectability measures (beyond the contribution of speed of processing) indicates that age-related change may occur in strategic aspects of performance not captured by our measures of response key preference and spatial localization.

These strategic aspects are illustrated by the direct comparison between Experiments 1 and 2. In Experiment 2, both age groups exhibited increased detectability (hits minus false alarms), $F(1, 92) = 43.51$, $p < .0001$, and an increased number of cycles for correct detection, $F(1, 92) = 26.47$, $p < .0001$, relative to Experiment 1. There was no Age Group × Experiment interaction for either variable ($F < 1.0$ in each case). Thus, adding the more precise localization response in Experiment 2 led both age groups to use more detection cycles before responding, but also to be more accurate in their eventual response. Participants were also more confident of their responses in Experiment 2, as reflected in the decreased use of the *verify* key. This more cautious accumulation of display information, before responding, in Experiment 2, appears to represent something beyond simply responding more slowly, because perceptual speed was less successful in capturing the age-related variance in detectability in Experiment 2 than in Experiment 1.

Neither of the theoretical models of change detection, the *temporal integration* and *focused attention* models (Mitroff and Simons, 2002), provides a complete account of performance in Experiment 2. For both age groups, localization error was a (statistically) flat line across 3-10 trials prior to detection, indicating, as in the focused attention model, no gradual accumulation of evidence. Between 1 and 3 trials before detection, however, localization improved significantly, and this improvement was greater for younger adults (Figure 6). Mitroff and Simons (2002) noted a similar improvement in the localization response immediately prior to correct detection for younger adults. Thus, evidence regarding change may accumulate somewhat gradually across the most recent few cycles, prior to detection, and this evidence accumulation appears to be more efficient for younger adults than for older adults. We will discuss possible explanations for this age-related difference in the General Discussion.

One difference between the current task design and the Mitroff and Simons design is the display duration: Our display durations were extended to 500 ms in comparison to their 250 ms durations. At 500 ms, participants may have encoded multiple items within a single fixation, and accordingly may have required extra viewings to double check their eventual decision. If each encoded item requires a recheck, then the 500 ms duration may have encouraging rechecking not only in the first position prior to detection, but in the second position as well. Rechecking, however, would appear to benefit focused attention and temporal integration equally. For the focus of this study, the primary finding was the more unambiguous result of broad age group equivalence in the change detection search process. Note that while our display duration of 500 ms is nearly twice as long as the prior 250 ms designs, it is well within the normal range of durations used in the change detection literature.

General Discussion

The goal of the current experiments was to examine the effect of aging on change detection, using a task that did not limit the detection response to a single, binary outcome following display presentation. Overall, the results support the following conclusions: 1) change detection efficiency was worse for older adults compared to younger adults, with lower detectability and greater cycles required for correct detection; 2) speed of elementary perceptual processing significantly reduced, although did not eliminate, the age-related decline in most measures; 3) there was no evidence of age group differences in strategy or response criterion; and 4) the role of gradually accumulated bottom-up evidence of the changed target across cycles (i.e., the overall detection model) was similar for the two age groups. The age effect in our change detection experiments is best characterized as impacting detection efficiency but not task strategy or response criterion.

Across both experiments, older adults had lower hits minus false alarms values compared to younger adults and required a greater number of cycle repetitions prior to correct detection. This age-related reduction in detection efficiency supports previous studies, which similarly suggest decreased change detection performance by older adults (Caird et al., 2005; Hoffman et al., 2005; McCarley et al., 2004; Pringle et al., 2001; Veiel et al., 2006). Processing speed was an important variable in the age effect in both experiments, as it strongly attenuated the age effect in all of our detectability measures. Given that the change detection paradigm involves speeded presentations of displays, the significant role of processing speed is not surprising (Madden, 2001; Salthouse & Madden, 2007; Schneider & Pichora-Fuller, 2000; Scialfa, 2002). Attenuation of age effects by processing speed is exacerbated in time-limited display durations and can occur even in self-paced testing setups (Salthouse, 1996), such as those used in the current studies. Yet successful change detection performance requires relatively complex processing demands, featuring not only speeded visual processing but also a cognitive comparison between pre-change and post-change displays (Mitroff et al., 2004). Note that this attenuation did not entirely eliminate the age effect on most of the key variables, and the remaining age effect may be due to the memory demands inherent in change detection (e.g., Henderson et al., 2004), or to the comparison of pre-change and post-change displays (e.g., Mitroff et al., 2004). The latter possibility appears a likely candidate to age-related differences in change detection considering the increase in residual age effects in Experiment 2 relative to Experiment 1. Experiment 2 required two response types (localization and detection responses) whereas Experiment 1 required only one (detection response); this increased response demand may have consequently increased the difficulty in the pre-change and post-change display comparisons. Furthermore, the more precise localization of change required by Experiment 2, relative to Experiment 1, led both age groups to use a more cautious response strategy, which in turn decreased the degree to which speed accounted for age-related variance in detectability. Although speculative, our results lend support for the possibility that the age effect in change detection may be directed to the pre-change and post-change comparison requirement.

We found no evidence of an age-related difference in response criterion. We provided an additional measure of cautiousness, in terms of a *verify* response, beyond the standard binary yes/no option used in most other change detection tasks. Across both experiments, however, older and younger adults showed comparable use of the *verify* detection response, indicating comparable levels of cautiousness. We also found no evidence of age group differences in either the distance or area calculations of the localization responses, suggesting that across cycles the two age groups were localizing targets with similar coverage and spatial extent. These results cannot be explained as an artifact of low statistical sensitivity, as power analyses (Cohen, 1988) indicated that, in the present design, with 24 participants per group, there was .92 power to detect a significant effect (alpha = .05) when the effect size is .25 or greater. Previous evidence of more cautious search strategies in change detection (Veiel et al., 2006) may therefore have reflected the demands of the continuous flicker design, rather than a necessary consequence of change detection per se.

The similarity in how the two age groups approached the task was also evident in the time course of change localization in Experiment 2. These analyses revealed that the two age groups exhibited similar reductions in localization error, at least across cycles 3-10 before detection, indicating that the accumulation of evidence regarding change is no more gradual for older adults than for younger adults. Thus, although older adults took longer to acquire this evidence (i.e., exhibit higher cycles-to-detection values compared to younger adults), both age groups appear to rely primarily on focused attention (Mitroff & Simons, 2002), in which change is detected when it occurs within a spatially limited, attended area. Previous work has shown that the perceptual salience of changed items can effectively draw attention during change detection, perhaps more so for older adults (Pringle et al., 2001). Yet we found little evidence indicating group differences in bottom-up attentional guidance in the tasks, as the two age group exhibited largely equivalent detection models. Our results suggest that change detection strategy is age invariant, despite the significant age-related decline in overall detectability. The exception to this finding was that immediately prior to correct detection (position 1, Figure 6) younger adults had reduced localization errors compared to older adults. The attended area at this critical point, just prior to detection, may be more information-rich for younger adults than for older adults.

There are at least two ways to interpret the age-related reduction in localization accuracy on the trial immediately prior to correct detection. First, compared to younger adults, older adults have a reduced useful field of view (UFOV; Ball, Roenker, & Bruni, 1990) which can negatively correlate with RT in change detection (Pringle, 2001) and thus may have impacted the detection capacity of older adults immediately prior to correct detection. Second, the trial immediately prior to correct detection might draw on memory of the target to a greater degree than the earlier, more deliberative, localization attempts. Older adults may have reduced explicit memory for target location at this critical juncture. Explicit memory for previously identified targets decays quickly after an intervening trial (Maljkovic & Nakayama, 2000), and such decay may be exacerbated with aging (Chiarello & Hoyer, 1988; D'Eredita & Hoyer, 1999; Howard & Howard, 1989, 1992). However, these possibilities should be approached with caution, given the relatively minor statistical effect ($p < .05$) at the -1 position.

We do not regard our lack of evidence for age group differences in response criterion as necessarily conflicting with the Veiel et al (2006) study that found eye movement patterns indicative of increased cautiousness in older adults during change detection. Our task design was intended to decrease the role of response criterion in task performance by requiring detection responses after each display presentation and by offering a third response option (*verify*) beyond the binary yes/no typical of the continuous flicker design. These design modifications served the purpose of alleviating group differences in response criterion in our tasks. It is likely that age group differences would be more pronounced in a continuous flicker design than in the interrupted design we used in our two tasks. Note that an important consistency between our two studies is the influence of processing speed in the group comparison: For both the present study and Veiel et al. there was substantial reduction in the age effect after inclusion of processing speed into the regression models. This suggests that the age effect in change detection is heavily influenced by processing speed across differing versions of the task, even when (as in the current research) group differences in response criterion have been reduced.

In conclusion, we found an age-related decline in change detection performance that represented primarily a decline in detection efficiency. Regression models indicated that this age effect was substantially decreased after controlling for processing speed, although in most measures the reduced age effect remained significant. The two likely candidates to explain the remaining age effect were strategy differences and/or response criterion differences. Yet we found no indication of group differences in our measures of these variables: There was broad group equivalence in the response key (*verify*) use, in the accumulation of display information across presentation cycles, and in the strategic placement of localization responses. Thus, in a task that does not rely entirely on a single detection response, age-related differences in change detection efficiency are closely associated with elementary perceptual processing, but not with differences in response criterion or search strategy.

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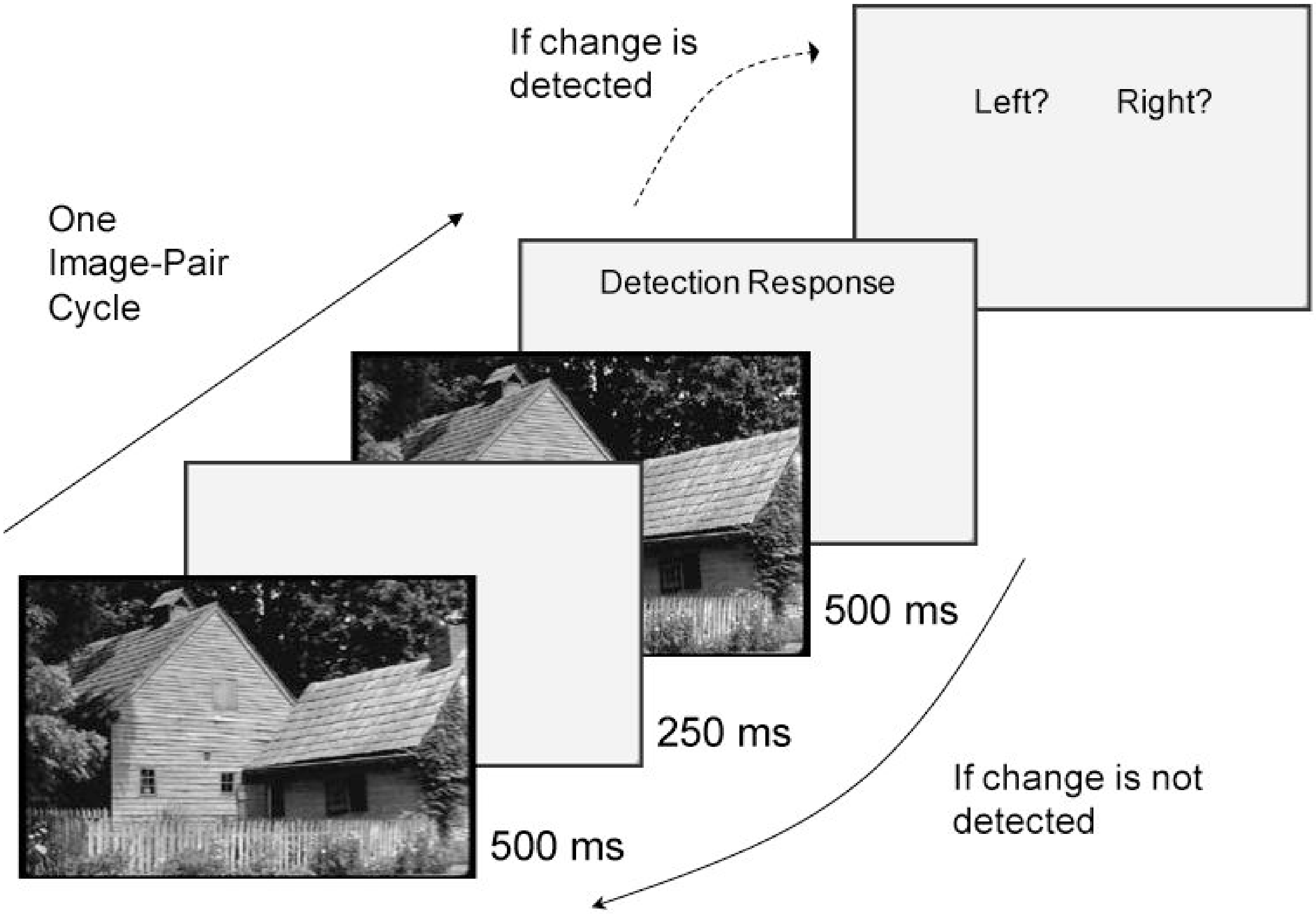

Figure 1.

Stimuli and course of events in a typical trial of Experiment 1. After each display of the image-pairs, participants gave their detection response: *didn't see*, possibly saw but needing to *verify*, and *saw*. The image-pairs were repeatedly shown when participants indicated a negative detection response. When participants responded with positive detection, they were prompted to indicate whether the changed item was located on the left or right side of the display.

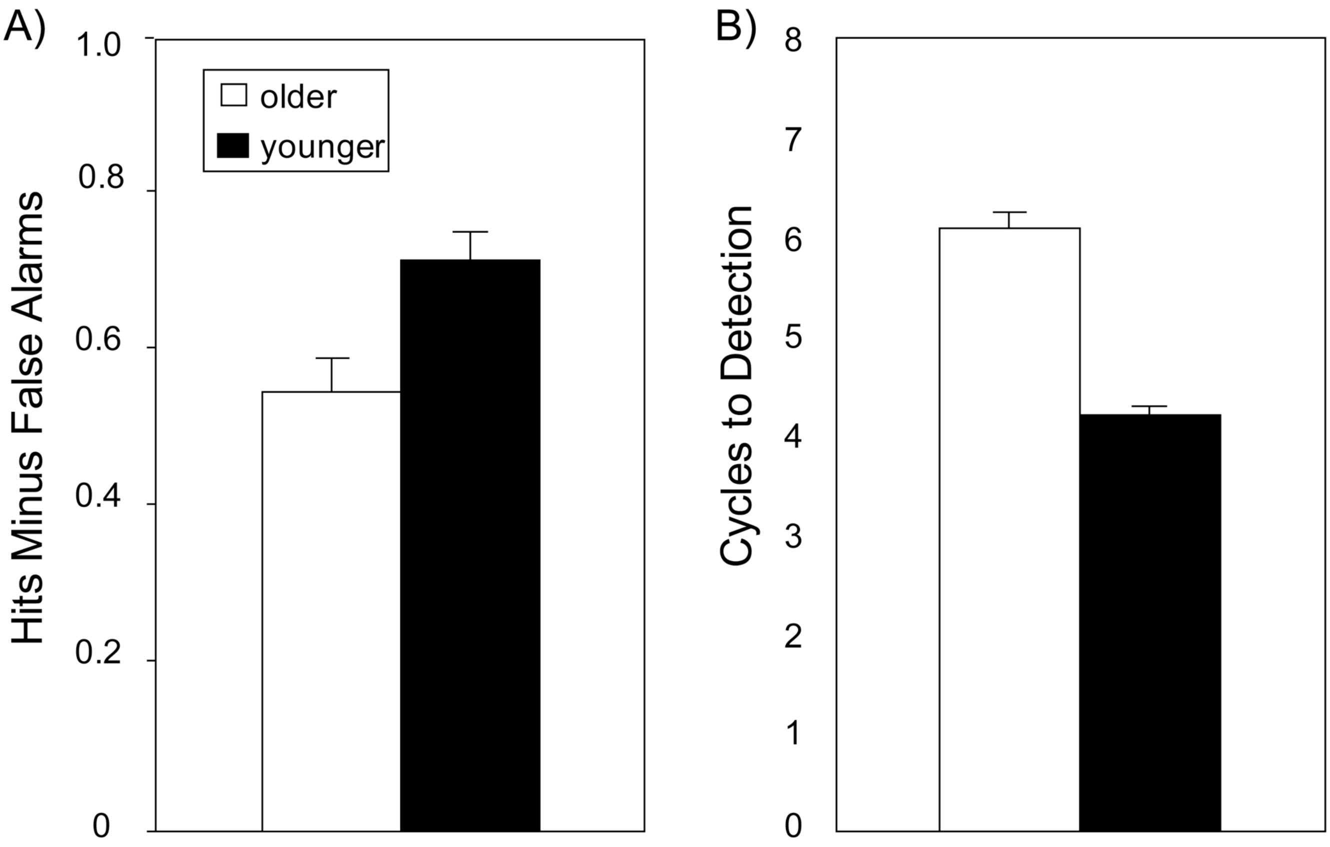

Figure 2.
Hits minus false alarms (A) and cycles to detection (B) measures of Experiment 1, as a function of age group. Error bars represent standard errors.

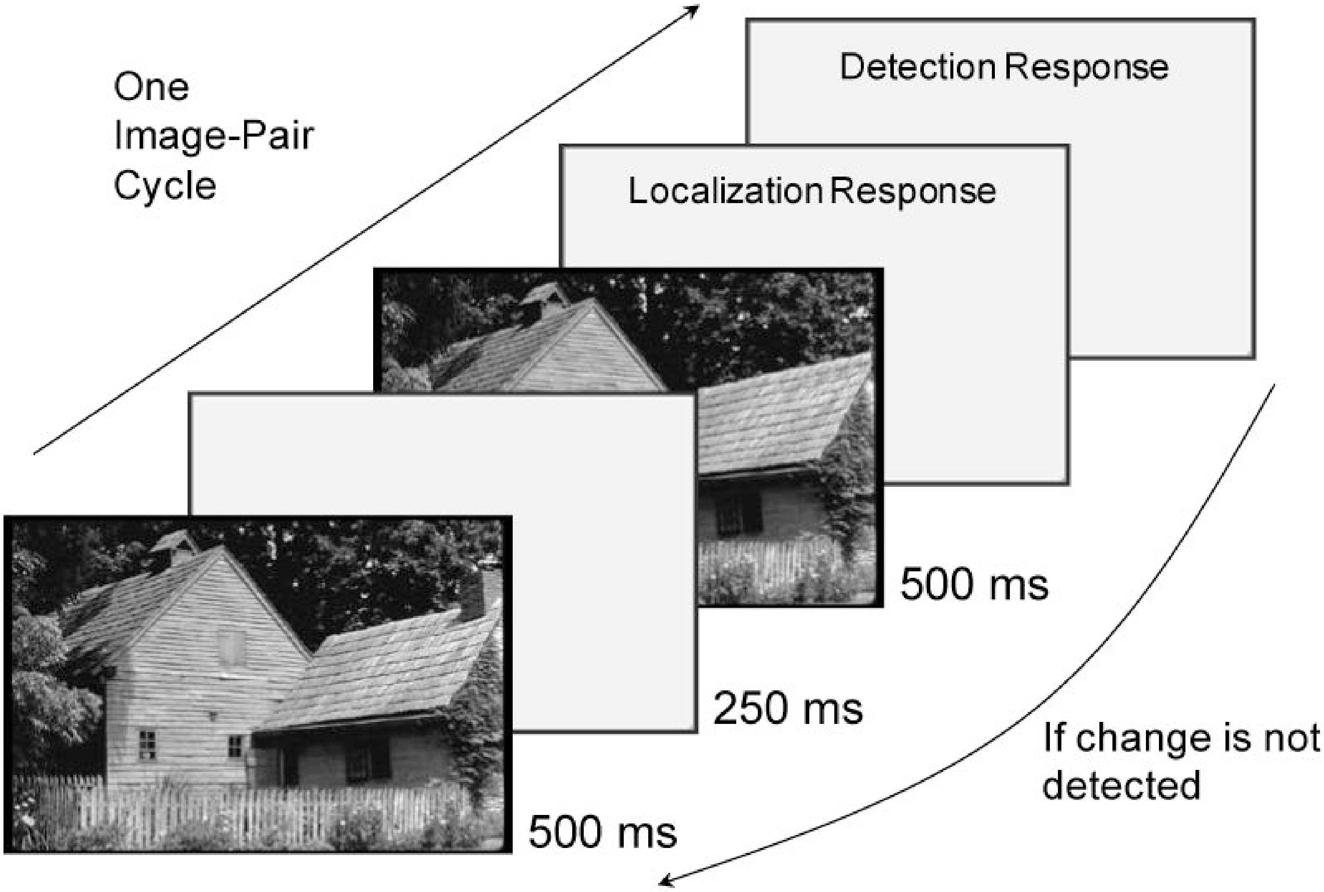

Figure 3.
Stimuli and course of events in a typical trial of Experiment 2. After each display of the image-pairs, participants used the mouse to click on the screen indicating where they thought the changed item was located. After each localization response, participants indicated a detection response: *didn't see*, possibly saw but needing to *verify*, and *saw*. The image-pairs were repeatedly shown until either correct or failed detection.

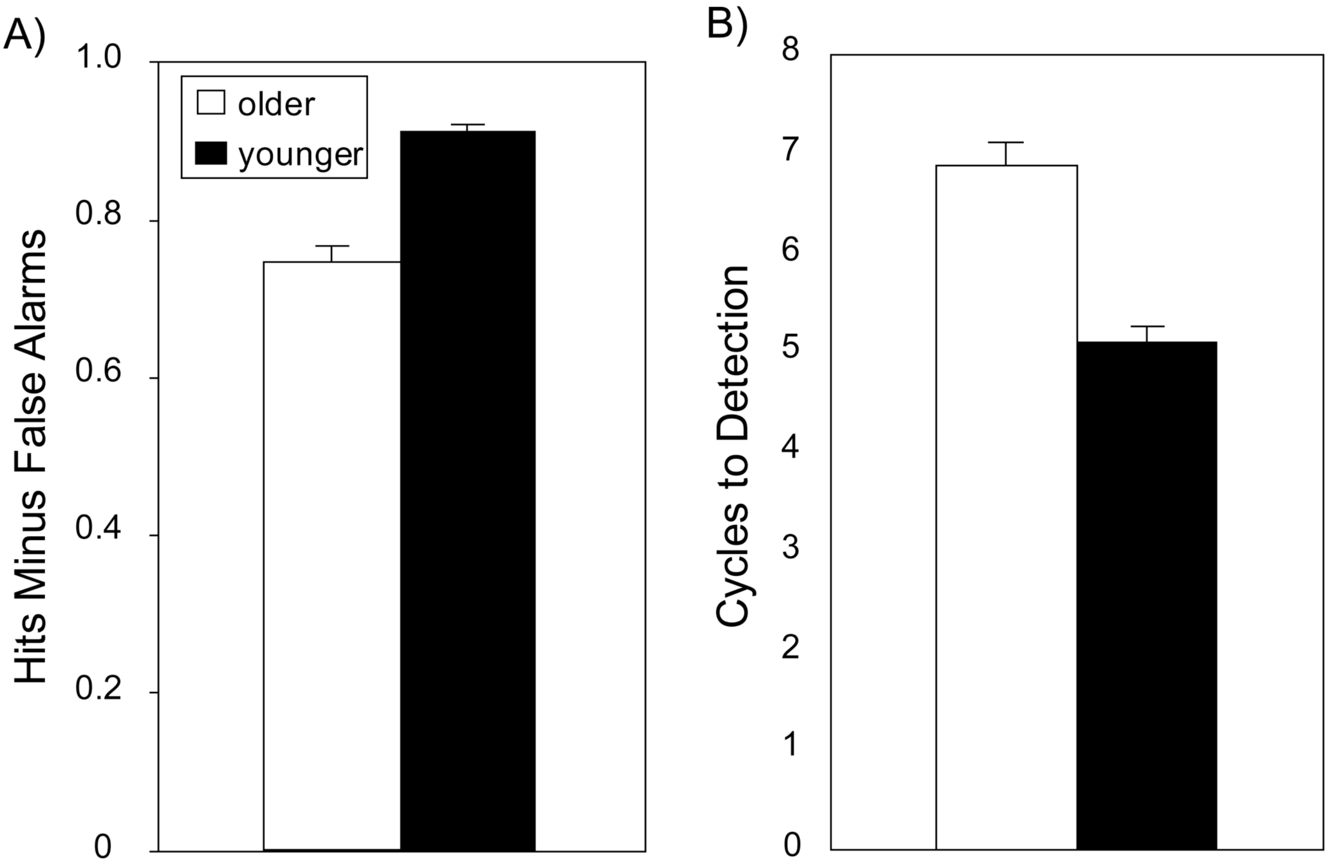

Figure 4.

Hits minus false alarms (A) and cycles to detection (B) measures of Experiment 2, as a function of age group. Error bars represent standard errors.

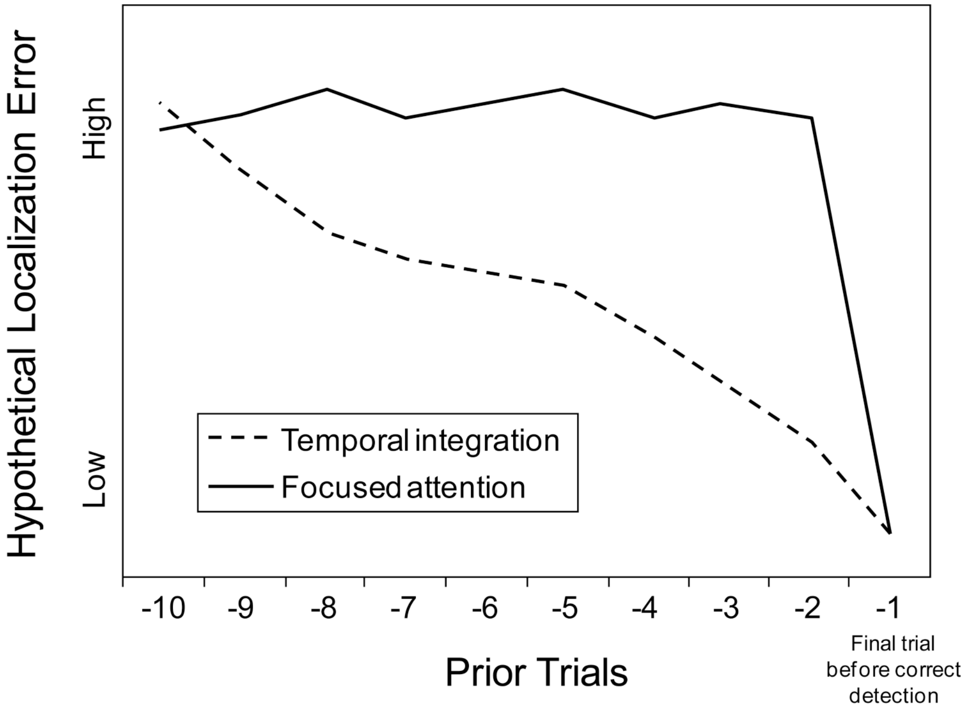

Figure 5.

Illustration of the temporal integration and focused attention models, with hypothetical localization error for change trials leading to correct detection, as a function of model type and cycles prior to detection. Cycle -1 represents the display-pair presented immediately prior to correct detection (Cycle 0, not displayed). Older adult performance will approximate the temporal integration model if they perform change detection with a more conservative response criterion compared to younger adults.

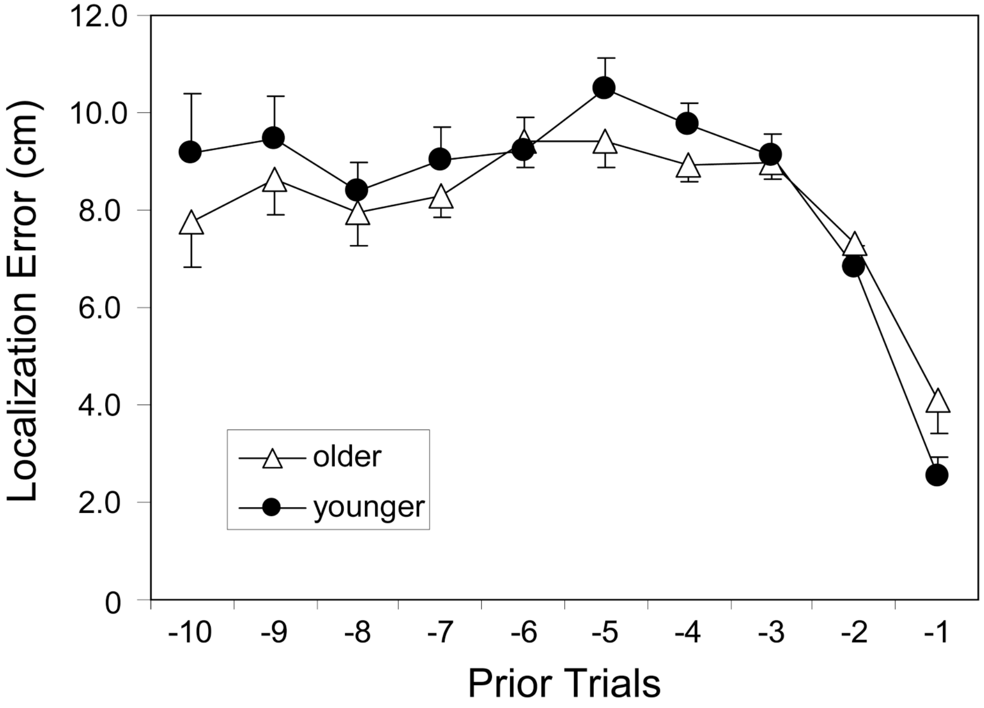

Figure 6.
Mean localization error (in cm) for change trials with successful detection of the changed item, as a function of age group and cycles prior to detection.

Table 1

Participant Characteristics by Age Group: Experiment 1

	M		*SD*	
	Younger	**Older**	**Younger**	**Older**
Age (years)	19.75_a	72.21_b	1.75	5.67
Education	13.50_a	16.04_a	1.77	2.74
Vocabulary	63.79_a	61.92_a	3.80	3.65
Digit Symbol Acc	97.62_a	96.82_a	3.03	2.97
Digit Symbol RT	1325.50_a	1896.70_b	149.14	371.11

Note. *n* = 24 per age group. Vocabulary = raw score (maximum of 70) on the Wechsler Adult Intelligence Scale-Revised (Wechsler, 1981); Digit Symbol Acc and Digit Symbol RT = percentage correct and reaction time (ms), respectively, on a computer test of digit-symbol coding (Salthouse, 1992a). Means in the same row that do not share subscripts differ by *t*-test at $p < .05$.

Table 2

Hierarchical Regression Analyses Determining Attenuation of Age Effect on Cycle Count and Hits Minus False Alarms in Experiment 1

***DV*, Model, Predictor**	***B***	***SE B***	**β**	**r^2**	**Δr^2**	***F***	**Percentage Attenuation**
Cycle Count							
Model 1							
Age	.948	.098	.819	.670		93.39**	
Model 2							
Digit Symbol RT	.0021	.0003	.711	.506		47.15**	
Age	.736	.136	.635	.701	.195	29.47**	70.90
Hits Minus False Alarms							
Model 1							
Age	-.083	.027	-.414	.172		9.53*	
Model 2							
Digit Symbol RT	-.0002	.00007	-.367	.135		7.16*	
Age	-.063	.039	-.311	.182	.047	2.58 *n.s.*	72.64

Note. r^2 is cumulative for current and preceding steps; Δr^2 = unique effect of age.

* p < .01

** p < .0001

Table 3
Participant Characteristics by Age Group: Experiment 2

	M		*SD*	
	Younger	**Older**	**Younger**	**Older**
Age (years)	20.25_a	68.29_b	2.31	5.22
Education	13.79_a	16.88_b	1.59	2.47
Vocabulary	63.04_a	63.83_a	4.48	3.53
Digit Symbol Acc	97.89_a	97.77_a	1.44	2.59
Digit Symbol RT	1320.75_a	1820.40_b	212.83	338.85

Note. n = 24 per age group. Vocabulary = raw score (maximum of 70) on the Wechsler Adult Intelligence Scale-Revised (Wechsler, 1981); Digit Symbol Acc and Digit Symbol RT = percentage correct and reaction time (ms), respectively, on a computer test of digit-symbol coding (Salthouse, 1992a). Means in the same row that do not share subscripts differ by t-test at $p < .05$.

Table 4

Hierarchical Regression Analyses Determining Attenuation of Age Effect on Cycle Count and Hits Minus False Alarms in Experiment 2

***DV*, Model, Predictor**	***B***	***SE B***	**β**	**r^2**	**Δr^2**	***F***	**Percentage Attenuation**
Cycle Count							
Model 1							
Age	.910	.144	.687	.472		40.19 ***	
Model 2							
Digit Symbol RT	2.53	.410	.677	.458		37.98 ***	
Age	.562	.178	.424	.558	.100	9.95 *	78.73
Hits Minus False Alarms							
Model 1							
Age	-0.086	.012	-.718	.516		47.90 ***	
Model 2							
Digit Symbol RT	-0.209	.039	-.620	.385		28.12 ***	
Age	-0.065	.016	-.548	.552	.167	16.38 **	63.83

Note. r^2 is cumulative for current and preceding steps; Δr^2 = unique effect of age.

[*] $p < .01$,

[**] $p < .001$,

[***] $p < .0001$