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Assessment of Age-Related Changes in Inhibition and Binding Using Eye Movement Monitoring

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Age-related memory deficits may result from attending to too much information (inhibition deficit) and/or storing too little information (binding deficit). The present study evaluated the inhibition and binding accounts by exploiting a situation in which deficits of inhibition should benefit relational memory binding. Older adults directed more viewing toward abrupt onsets in scenes compared with younger adults under instructions to ignore any such onsets, providing evidence for age-related inhibitory deficits, which were ameliorated with additional practice. Subsequently, objects that served as abrupt onsets underwent changes in their spatial relations. Despite successful inhibition of the onsets, eye movements of younger adults were attracted to manipulated objects. In contrast, the eye movements of older adults, who directed more viewing to the late onsets compared with younger adults, were not attracted toward manipulated regions. Similar differences between younger and older adults in viewing of manipulated regions were observed under free viewing conditions. These findings provide evidence for concurrent inhibition and binding deficits in older adults and demonstrate that age-related declines in inhibitory processing do not lead to enhanced relational memory for extraneous information.

Keywords: aging, memory, inhibition, binding, eye movement monitoring

Older adults typically demonstrate poor memory performance compared with younger adults, as assessed by tests of recall and recognition (e.g., Craik & Jennings, 1992; Graf, 1990; Winocur, Moscovitch, & Stuss, 1996). There are numerous theories regarding the underlying cause of such age-related memory problems, including general cognitive slowing (e.g., Salthouse, 1995, 1996), sensory difficulties (Schneider & Pichora-Fuller, 2000), and decreases in attentional processing resources (e.g., Cerella, 1985; Craik & Byrd, 1982) or the level at which encoding processes are directed (e.g., superficial vs. elaborative encoding; Craik & Lockhart, 1972), among others (for reviews, see Balota, Dolan, & Duchek, 2000; Light, 1996; Zacks, Hasher, & Li, 2000). The present work investigates two current theories of age-related changes in memory: Older adults encode and store more information than is needed for any given task and older adults do not store enough information, causing memory representations to be impoverished.

On the first account, older adults encode too much information because of a deficit in inhibitory processing, which would otherwise allow one to filter out irrelevant information and select only the information needed to perform a given task (Hasher & Zacks, 1988; Rabbitt, 1965). Deficits in inhibitory processing allow too much information into memory, leading on some occasions to competition at retrieval between relevant and irrelevant information (Hasher & Zacks, 1988; Hasher, Zacks, & May, 1999; May, Zacks, Hasher, & Multhaup, 1999). By contrast, should the irrelevant information become relevant, older adults can also show a performance advantage over young adults (Kim, Hasher, & Zacks, in press; Rowe, Valderrama, Hasher, & Lenartowicz, 2006). On the second account, age-related declines in memory performance are due to a binding deficit at encoding that prevents information from being stored successfully into a memory representation that can later be retrieved (e.g., Chalfonte & Johnson, 1996). Binding encompasses the ability to make arbitrary associations among features to form a memory representation of an object (feature binding) as well as the ability to make arbitrary associations among multiple objects to form memory representations of a scene or event (relational binding; Moses & Ryan, 2006; Naveh-Benjamin, 2000; Ryan, Altoff, Whitlow, & Cohen, 2000). For the current purposes, our discussion of binding focuses on the latter definition of between-object relations.

Age-Related Impairments in Inhibition

Age-related deficits have been observed on tests that require participants to ignore (experimenter-designated) irrelevant infor-

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mation. Older adults show increased access to irrelevant information, as assessed by later priming tests (Hasher, Quig, & May, 1997; May et al., 1999), including ones that are quite different from the initial encoding task (Kim et al., in press; Rowe et al., 2006). Moreover, in reading tasks, older adults are more likely than younger adults to generate multiple inferences regarding text passages and are less likely to quickly abandon erroneous interpretations in the face of conflicting evidence (Hamm & Hasher, 1992).

Findings from eye movement studies also provide evidence for an inhibition deficit in older adults. For instance, age-related deficits are observed on the antisaccade task, in which a target stimulus is flashed to one side of fixation and the viewer is instructed to not look at the location of the abruptly presented cue but rather to make an antisaccade (i.e., initiate a saccade of equal amplitude) in the opposite direction of where the cue was presented. If the viewer fails to inhibit responding to the cue, an eye movement toward the cue, a prosaccade, is generated before the antisaccade (see Munoz & Everling, 2004, for review; Olk & Kingstone, 2003). Compared with younger adults, older adults have more difficulty suppressing the reflexive prosaccade in response to an antisaccade cue, but, when they respond correctly, there are no age differences in the accuracy of the location of the eye movement (Butler, Zacks, & Henderson, 1999; Olincy, Ross, Young, & Freedman, 1997). In other words, although older adults may have intact memory for the location of the cue, their eye movement data point to an inhibition deficit.

Further eye movement evidence for an age-related deficit in inhibition comes from oculomotor capture studies in which an array of stimuli is presented and the viewer is instructed to move his or her eyes to the location of a color singleton while ignoring an abrupt-onset stimulus (Colcombe et al., 2003; Kramer, Hahn, Irwin, & Theeuwes, 1999). Older adults made more saccades to the location of the abrupt-onset stimulus than did younger adults when the abrupt onset was particularly salient (Kramer, Hahn, Irwin, & Theeuwes, 2000). Oculomotor capture tasks also reveal age-related deficits in inhibition when singleton features, rather than abrupt onsets, serve as distractors. For example, older adults were less accurate than younger adults at fixating on a shape singleton in an array of letters (e.g., a green *X* among green *O*s) when a color singleton was also present (e.g., a red *X*), as color is a more salient feature than shape and serves to attract attention. Older adults also made more saccades in anticipation of the display onset compared with younger adults, further providing evidence for age-related deficits in inhibition (Ryan, Shen, & Reingold, 2006).

Although the above findings suggest that there are age-related impairments in inhibitory processing, no existing study, to the best of our knowledge, has assessed whether binding impairments coexist with inhibition deficits in older adults. There is some evidence to suggest that having processed an irrelevant stimulus (for which there is an existing representation in memory) as a result of an inhibitory deficit confers an advantage in a subsequent priming task for older adults (Hasher et al., 1997; Kim et al., in press; Rowe et al., 2006). However, it remains unclear whether the additional information encoded by older adults can be bound into a memory representation with other processed information. Given that binding and the processes underlying priming may be mediated by distinct neural systems (Cohen & Eichenbaum, 1993; Moses & Ryan, 2006), there is no a priori reason to expect similar advantages for binding as have been observed for priming. In fact, the findings outlined below suggest a distinct age-related impairment in binding performance.

Age-Related Impairments in Binding

Older adults have shown deficits in forming associations, or binding relations, among distinct items (Naveh-Benjamin, 2000), as evidenced by decreased sensitivity in the recognition of previously studied word pairs (Castel & Craik, 2003), combinations of pictures (Naveh-Benjamin, Hussain, Guez, & Bar-On, 2003), and combinations of face and name pairs (Naveh-Benjamin, Guez, Kilb, & Reedy, 2004). Older adults have also demonstrated poor eyewitness identification and poor memory for source information relative to younger adults, which may be indicative of a general impairment in binding, in forming relations among distinct objects, or in forming relations between an object and a context (e.g., Hashtroudi, Johnson, & Chrosniak, 1989; Multhaup, de Leonardis, & Johnson, 1999; Schacter, Koutstaal, Johnson, Gross, & Angell, 1997). Binding of between-object relations would thus appear to be compromised in older adults.

It is important to note that the above tasks assessed binding using explicit memory instructions in which younger and older adults must report on the contents of their memories. Tasks that use such instructions may elicit a negative stereotype regarding memory and aging and/or cause an increase in arousal levels that would otherwise cause poor memory performance to be observed (Rahhal, Colcombe, & Hasher, 2001; for review, see Zacks et al., 2000). Evidence suggests that merely requiring older adults to explicitly report on the contents of their memory can elicit poor performance in older adults for reasons that have nothing to do with memory per se, thereby potentially obscuring otherwise intact binding performance (e.g., Rahhal et al., 2001). Therefore, an advantage of the current work is that participants were not required to report on the contents of their memories. Instead, eye movement measures were used to assess inhibitory and binding performance within a single task.

The Current Study

To examine inhibition and binding within the same paradigm, participants were presented with displays of three novel objects on real-world scenes while their eye movements were monitored. Two of the objects were presented concurrently with the onset of the scene, and one object was presented as an abrupt onset 500 ms later. Participants were instructed to either freely view or ignore the object that served as an abrupt onset. Examining eye movement behavior under free viewing conditions provides an indication of whether older and younger adults generally differ in their patterns of scanning scenes. Using the logic from antisaccade and oculomotor capture paradigms, the extent to which older and younger adults direct eye movements to the abrupt onset under ignore conditions relative to free viewing conditions provides a measure of age-related differences in inhibition. If inhibitory processing is impaired in older adults, then older adults should direct more viewing toward the abrupt-onset object compared with younger adults.

Eye movement monitoring can also inform us about the integrity of binding. Previous work has demonstrated that eye movements are attracted to regions in a display that change across displays, regardless of whether people are intentionally trying to detect any changes. This pattern of findings suggests that information regarding the relations among objects has been bound into a lasting representation (Ryan et al., 2000; Ryan & Cohen, 2004a). To examine binding function in the present study, the object that served as the abrupt onset during initial viewing either did or did not change its spatial position (and so between-object spatial relations) during a subsequent viewing. This design thereby exploits a situation in which deficits of inhibition should benefit relational memory binding because of increased processing of the to-be-manipulated objects.

Three possible outcomes can be considered depending on whether age differences are restricted to inhibitory deficits, to binding deficits, or to both. If inhibitory processes are impaired with aging, then older adults should look longer or more often at the abrupt-onset stimulus during the encoding phase than should younger adults when specifically instructed to avoid looking at the onset. If binding processes are impaired with aging, then older participants should fail to show increased eye movement behavior to the changed object under all conditions. If both are impaired, then older adults should direct more viewing to the abrupt onset compared with the younger adults during the encoding phases but not show increased viewing of the changed region during the critical block when changes are made to the stimuli. This paradigm allows predictions from inhibitory and binding accounts to be assessed within the same session, using the same materials and the same eye movement measures in a manner that is not confounded by issues surrounding task demands and negative stereotypes about memory and aging.

Table 1
Means and Standard Deviations for Younger and Older Adults on the Background Measures

Variable	Free viewing instructions *M*	Free viewing instructions *SD*	Ignore instructions *M*	Ignore instructions *SD*
Age				
Younger adults	23.50	3.28	23.92	4.59
Older adults	71.54	7.21	73.83	6.66
Years of education				
Younger adults	16.08	1.53	16.25	1.82
Older adults	14.96	3.57	15.44	5.86
ERVT				
Younger adults	17.25	8.06	19.40	8.66
Older adults	24.61	11.41	26.99	10.52
CVLT: Short-delay free recall				
Younger adults	11.17	3.02	12.04	2.81
Older adults	9.62	3.56	7.92	3.26
CVLT: Long-delay free recall				
Younger adults	11.87	2.59	11.42	2.83
Older adults	10.29	3.42	8.75	3.53
CVLT: Long-delay recognition				
Younger adults	14.88	1.23	14.83	1.40
Older adults	14.25	1.65	13.62	2.28
CVLT: Long-delay false alarms				
Younger adults	2.04	2.14	2.96	3.85
Older adults	4.17	5.71	4.71	8.18

Note. ERVT = Extended Range Vocabulary Test; CVLT = California Verbal Learning Task.

Method

Participants

Ninety-six participants participated in this study in exchange for monetary compensation. Forty-eight younger adults (22 men, 26 women; age range = 18–35 years) and 48 older adults (7 men, 41 women; age range = 60–85 years) were recruited from the Rotman Research Institute (Toronto, Ontario, Canada) participant pool. Post hoc examination of the eye movement data revealed similar patterns of performance between genders; therefore gender was not included as a factor in the reported analyses.

The design was between-participants; half of the younger and older participants received free viewing instructions during the study block whereas the other half received ignore instructions, as outlined in detail below. Age was significantly different between the younger and older adults, $F(1, 92) = 1{,}797.31$, $p < .001$, but there was no difference in age across the instruction conditions, $F(1, 92) = 1.37$, $p > .2$, nor was there an interaction between age and instruction condition ($F < 1$). Means and standard deviations are presented in Table 1. All participants had normal or corrected-to-normal vision and reported no incidence of traumatic brain injury in the last 3 years.

Each participant completed a background information sheet, the Extended Range Vocabulary Test (ERVT; Educational Testing Service, 1976), and the California Verbal Learning Test-second edition (CVLT-II; Delis, Kramer, Kaplan, & Ober, 2000). Means and standard deviations for the background measures are presented in Table 1. Younger and older adults did not differ on years of education, $F(1, 92) = 1.74$, $p = .19$; there was no difference in years of education across instruction conditions ($F < 1$) and no significant interaction between age group and instruction condition ($F < 1$). However, younger adults performed significantly worse than the older adults on the ERVT, $F(1, 92) = 14.80$, $p < .001$, similar to previous reports (e.g., Rahhal, May, & Hasher, 2002). There was no difference on ERVT scores across instruction conditions, $F(1, 92) = 1.35$, $p > .2$, and no significant interaction between age and instruction condition ($F < 1$). Younger adults performed either marginally or significantly better than older adults on the short- and long-delay measures of the CVLT: short-delay free recall, $F(1, 92) = 19.15$, $p < .001$; long-delay free recall, $F(1, 92) = 11.15$, $p = .001$; long-delay recognition, $F(1, 92) = 7.08$, $p < .01$; and long-delay recognition false alarms, $F(1, 92) = 3.03$, $p = .085$. CVLT scores were not significantly different across instruction conditions (all *F*s < 1). The interactions between age group and instruction condition were not significant for any measures of the CVLT (*F*s < 1) except the short-delay free recall, $F(1, 92) = 3.98$, $p < .05$, in which the discrepancy between the scores of younger and older adults was larger under ignore instructions.

Stimuli and Design

Participants were presented with displays consisting of three abstract objects placed on a real-world background (see Figure 1). Each display measured 1,024 × 768 pixels and subtended approximately 33.4° of visual angle 25 in. (63.5 cm) from the monitor. Objects were created using Corel Draw V. 12; likewise, the real-

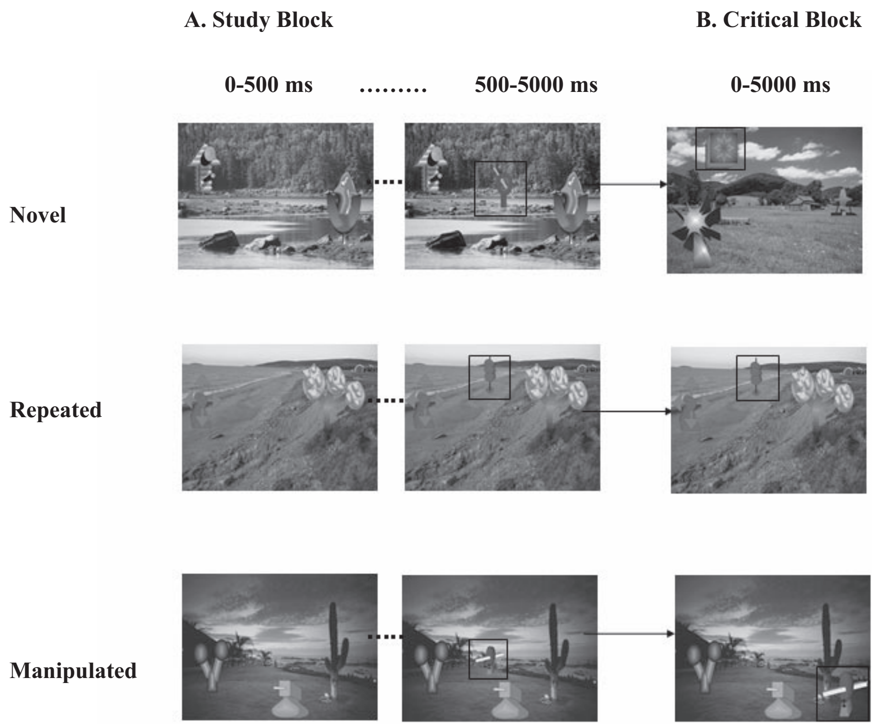

Figure 1. Examples of displays of novel, repeated, and manipulated scenes for the study blocks (A) and the final critical block (B). Novel scenes are shown only once during the experiment; repeated scenes are shown once in each block. Manipulated scenes are shown in their original version once in each of the study blocks, and during the critical block a change is made to the left–right spatial location of one of the objects. During the study blocks, scenes are presented with only two abstract objects from 0 to 500 ms. After 500 ms, a third object is added to the scene as an abrupt-onset object (late-onset area is outlined in black), and the scene remains for the rest of the 5-s viewing period. During the critical block, a change occurs in the spatial relations for the previously viewed onset object in the manipulated scenes (critical regions for novel, repeated, and manipulated scenes are outlined in black).

world scenes were taken from the gallery of outdoor scenes available on Corel Draw. The objects were uniquely designed to minimize resemblance to real-world objects and are likely void of an associated verbal label or other contextually meaningful information. This was done to prevent participants from using linguistic strategies (i.e., "The cat is to the left of the boy") to circumvent difficulties in binding processes per se (see Moses, Villate, & Ryan, 2006, for further discussion). Real-world scenes were used as the background to provide an understandable spatial context onto which the objects were overlaid.

In total, 180 uniquely designed abstract three-dimensional objects and 60 backgrounds were used. Three objects were randomly paired with a background to create a unique scene. Sixty such unique scenes were thus created for the experiment; therefore, objects were presented with only one background. For each display, there was an original and a manipulated version in which one of the objects underwent a change in its left–right spatial relationship relative to the other objects within the scene, similar to previous work (Ryan et al., 2000; Ryan & Cohen, 2004a, 2004b; see Figure 1). Every manipulation thus involved a change in the object–location relations and in the between-object relations. Occasionally, the manipulated object was also reduced–expanded in size in an effort to change the perceived relations of depth and/or distance between the objects. Across participants, each scene was viewed in each condition. As a result, viewing patterns were always compared for physically identical stimuli to guard against stimulus-specific effects resulting from left–right and size changes within the scene.

Participants viewed 30 scenes in each of two study blocks in a different random order. A set of 10 scenes served as novel scenes in the first study block, and a separate, unique set of 10 scenes was presented as novel scenes in the second study block. A set of 20 scenes was shown in the first block and was repeated in the second block. Participants then viewed 40 scenes in a final critical block. Twenty of the scenes presented in the final block were novel and had not been previously viewed in the experiment. A group of 10 scenes served as repeated scenes in the final block; these were scenes that had been presented in each of the study blocks and were re-presented in the same form in the critical block. A separate group of 10 scenes served as manipulated scenes in the final block; these scenes had been presented in each of the two study blocks and a modified version was presented in the critical block. For the manipulated scenes, the object that had been viewed as the late-onset object during the study blocks was always the object that underwent a change in its relations during the final critical block. Stimuli were counterbalanced such that across participants, each scene was viewed equally often as a novel, repeated, or manipulated scene. In addition, displays that served as the manipulated version for one set of participants were presented as the original and repeated versions for another group of participants. This procedure exactly follows that of Ryan et al. (2000) and permits comparisons of viewing across physically identical stimuli.

Procedure

Prior to testing in the eye movement study, participants provided informed consent and were given the short-delay section of the CVLT. The long-delay section of the CVLT was completed after the eye movement task.

In the eye movement task, participants were told to imagine that aliens have invaded planet Earth and that they would view scenes of places where the aliens have been sighted. Participants were further told that the aliens always traveled in groups of three. In the two study blocks, participants were instructed to either freely view all of the aliens and the background scene (free viewing instructions) or to ignore (i.e., do not look at) the late-onset alien at all times but otherwise freely view the rest of the aliens and the background scene (ignore instructions). During the critical block, all participants were instructed to engage in free viewing of the aliens and the background scene.

During the study blocks, regardless of task instructions, the scene was initially presented with two objects. After a 500-ms delay, the third object appeared on the scene. The entire scene was displayed for a total of 5,000 ms. During the critical block, all three objects appeared coincidental with the onset of the scene. Each scene was initiated by the participant who was required to fixate a square presented at the center of the screen and press a button on a keypad. The only delay between the trials was the time taken for the participant to fixate at the central fixation point and press the button. Displays for the critical block were presented in random order.

Eye Movement Data Collection and Analysis

Eye movements were measured with the Eyelink II eye-tracking system (SR Research, Ltd., Mississauga, Ontario, Canada) and sampled at a rate of 500 Hz with a spatial resolution of 0.1°. A 9-point calibration was performed at the start of the experiment followed by a 0-point calibration accuracy test. Calibration was repeated if the error at any point was more than 1°. Eye movements were analyzed with respect to the experimenter-drawn interest areas corresponding to the location of the late-onset object and to the original, but now empty, location of the late-onset object. Specific eye movement measures that were analyzed for the study and critical blocks are presented in detail in each subset of the Results section.

Following the eye movement experiment, participants completed the long-delay CVLT, the ERVT, and the background information sheet and were given a written debriefing outlining the nature of the experiment.

Results

Study Blocks

Viewing to the abrupt- or late-onset object was examined for younger and older participants who were either given free viewing or ignore instructions during the study blocks. The extent to which the older adults directed more eye movements to the late-onset object compared with younger adults under ignore instructions over and beyond what occurs in free viewing instructions provides an index of an age-related inhibition deficit.

Eye movement measures of interest included ones characterizing viewing across the entire trial length for the critical region corresponding to the late-onset interest area. The following measures were analyzed: duration of viewing time, proportion of total viewing time, number of fixations, and proportion of total fixations. These measures provided an index for the amount of encoding younger and older adults directed toward the late-onset object. The duration of viewing time and the number of fixations measures provide an indication of whether younger and older adults differ in the baseline amount of viewing directed to the critical region. The proportion measures take any potential baseline differences into account to determine whether the pattern of viewing is different across younger and older adults.

Two additional measures, number of transitions into the interest area and number of trials fixated, outlined how often viewers returned to the late-onset interest area within a trial and the number of trials in which the viewer fixated the late-onset interest area. These measures were used to indicate whether younger and older adults have a similar tendency across and within trials to view the late-onset interest area.

Analyses of variance (ANOVAs) were conducted on these measures of viewing to the late-onset object using age (young, old) and instruction (free viewing, ignore) as between-subject factors and block (first block, second block) as the within-subject factor. All possible interactions were evaluated. Effects were considered significant at $p < .05$ and marginally significant at $p < .10$. Means and standard errors are presented in Table 2, and the statistical results for each of the eye movement measures are presented in Appendix A. For brevity, we highlight the major findings of interest below.

An inspection of means (see Table 2) suggests that viewing within the free viewing condition was similar for older and younger participants for all measures. Differences arose between the younger and older adults under ignore instructions, although both groups of participants spent less time looking at the late-onset object in the ignore compared with the free viewing conditions, suggesting that both groups were attempting to comply with instructions.

The difference in viewing between younger and older adults across instruction conditions is evident in the three-way interaction between age, instruction, and block, which was significant for the measures of viewing time (duration of viewing time, proportion of viewing time) and for the number of trials in which the late-onset object was fixated and was marginal for the number and proportion of fixations (see Appendix A).

Planned contrasts examined the viewing to the late-onset region for younger and older adults separately for each block for each condition. Younger and older adults directed similar viewing to the late-onset object in the first and the second blocks under free viewing instructions.

However, under ignore instructions, older adults directed significantly more viewing, on every measure, to the late-onset object compared with younger adults in the first study block (see Appendix A for statistics). This effect was lessened in the second block;

Table 2
Viewing of the Late-Onset Region Across the Study Blocks for Participants Under Free Viewing and Ignore Instructions

	Free viewing instructions				Ignore instructions			
	Younger adults		Older adults		Younger adults		Older adults	
Eye movement measure	*M*	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*
Block 1								
Duration of viewing time (ms)	1,205.09	48.84	1,146.82	76.07	191.02	27.11	338.44	28.10
Proportion of viewing time	.27	.01	.26	.02	.04	.01	.08	.01
No. of fixations	4.26	0.18	4.07	0.20	0.63	0.08	1.24	0.10
Proportion of fixations	.26	.01	.25	.01	.05	.01	.08	.01
No. of transitions	2.22	0.10	2.23	0.11	0.44	0.06	0.82	0.08
No. of trials	28.88	0.51	29.17	0.25	8.92	1.21	13.38	1.03
Block 2								
Duration of viewing time (ms)	1,186.08	56.81	1,195.87	101.12	112.40	20.22	177.01	31.62
Proportion of viewing time	.27	.01	.27	.02	.03	.00	.04	.01
No. of fixations	4.23	0.22	4.06	0.27	0.41	0.07	0.61	0.09
Proportion of fixations	.26	.01	.25	.02	.03	.00	.04	.01
No. of transitions	2.17	0.10	2.10	0.11	0.33	0.05	0.42	0.05
No. of trials	28.92	0.34	29.08	0.25	7.33	0.87	8.33	0.87

Note. No. of transitions refers to the number of transitions into–out of the late-onset regions; no. of trials refers to the number of trials in which the late-onset region was fixated (max = 30).

although younger adults still directed less viewing to the abrupt-onset object compared with the older adults (see Table 2 for relevant means and standard errors), planned comparisons revealed differences between younger and older adults to either be marginal or nonsignificant in the second study block (see Appendix A for statistics).

From these findings, it appears that younger and older adults distributed viewing to the late-onset object similarly under free viewing conditions but that older adults had more difficulty inhibiting viewing of the late-onset object under ignore conditions. Under ignore conditions in the first study block, older adults fixated the late-onset region on more trials, with more fixations and more viewing time, and returned to the late-onset region more often within a trial compared with the younger adults. These findings are indicative of an age-related inhibition deficit that can be moderated through additional practice and/or repetition, as evidenced by a decrease in viewing of the late-onset region by the older adults from the first to the second block such that viewing performance for the older adults was similar to that of younger adults. The findings from the study blocks suggest that the older adults may have directed more encoding processes to the late-onset object compared with the younger adults. As a result, if binding were intact in older adults, then the older adults who were given ignore instructions during the study blocks may have a better representation for that object and its relations compared with the younger adults who were also given the ignore instructions. If age-related impairments in binding also exist, then it was expected that eye movements of younger adults would be attracted to the critical region of manipulated scenes compared with the same regions within the novel and repeated scenes to a greater extent than the older adults.

Critical Block

Viewing to the critical region. The late-onset object during the study blocks always served as the manipulated object for the manipulated displays during the critical block. For the critical block, eye movements were analyzed with respect to the interest areas corresponding to the present location of the manipulated object (object-filled location) and to the original, but now empty, location of the manipulated object. The same measures used in the study blocks (excluding the number of trials fixated) were also used to examine viewing to the critical region. Differences in viewing of the critical region between changed (manipulated) and unchanged scenes (novel, repeated) reveals the extent to which information regarding the relations among the elements in the scene was retained in memory (Ryan et al., 2000; Ryan & Cohen 2004a). Comparing viewing of the manipulated scenes with that of the novel as well as the repeated scenes ensures that any observed differences between repeated and manipulated scenes is not due to repetition rather than manipulation.

Eye movements to the empty critical region were not different between the trial types (novel, repeated, manipulated) for either the younger or the older adults, regardless of condition (free viewing or ignore instructions). As such, the results described below are exclusively for the object-filled critical region (as shown outlined in Figure 1).

Custom ANOVAs were conducted that examined main effects of instruction (free viewing, ignore), age (young, old), and trial type (novel, repeated, manipulated), and only the interactions of Age $\times$ Trial Type and Instruction $\times$ Trial Type. Simple contrasts were conducted to examine viewing toward the critical region for manipulated displays compared with the same region within the novel and the repeated displays (i.e., manipulated vs. novel; manipulated vs. repeated) for the main effect of trial and for the interactions of Age × Trial Type and Instruction × Trial Type. Means and standard errors for each measure of viewing for the younger and older adults are presented in Table 3. Appendix B presents the statistical findings for each of the measures. For brevity, results of interest are highlighted below.

The pattern of findings was similar across instruction conditions, as revealed by nonsignificant effects of instruction and nonsignificant interactions between trial type and instruction (see Appendix B). There was a significant main effect of trial (novel, repeated, manipulated) on multiple measures of viewing of the critical region (see Appendix B). The main effect of trial was marginal for the number of fixations directed to the critical region. Altogether, increased viewing was directed to the critical region of the manipulated scenes compared with the same region within the novel and repeated scenes, as revealed by the simple contrasts. The main effect of age was significant for some of the measures of viewing (see Appendix B), but these effects can be interpreted more clearly in light of the interactions noted below.

The Age × Trial Type interaction was either marginal (number of fixations, proportion of fixations, number of transitions into–out of the critical region) or nonsignificant (duration of viewing time, proportion of viewing time), although the numerical trends were similar (see Appendix B). As shown in Table 3, younger adults showed an increase in viewing the critical region of manipulated scenes, for which a change had occurred, over the novel and repeated scenes, for which no change had occurred. This was evident for both groups of younger adults, regardless of whether they had viewed the displays in the study blocks under free viewing or ignore conditions. However, this pattern was not evident for the older adults, regardless of whether they had studied the displays under free viewing or ignore conditions.

Examination of the simple contrasts revealed significant or marginal interactions between age and trial for the manipulated versus novel trial comparison. The simple contrast of the manipulated versus repeated scenes did not result in significant Age × Trial Type interactions, although the observed differences between manipulated and repeated scenes across younger and older viewers were similar to those of manipulated versus novel contrasts (see Appendix B for relevant statistics).

Performance for the younger and older participants was examined separately for each condition to further illuminate the interactions between age and trial. Whereas younger adults showed significant or marginal effects of trial type (novel, repeated, manipulated) for three out of five measures under free viewing conditions—duration of viewing time, $F(2, 46) = 2.93$, $p = .06$; proportion of viewing time, $F(2, 46) = 3.05$, $p = .06$; and number of transitions, $F(2, 46) = 5.24$, $p < .01$—and showed significant effects of trial type for all of the measures under ignore instructions—duration of viewing time, $F(2, 46) = 3.85$, $p < .05$; number of fixations, $F(2, 46) = 3.60$, $p < .05$; proportion of viewing time, $F(2, 46) = 3.33$, $p < .05$; proportion of fixations, $F(2, 46) = 3.80$, $p < .05$; and number of transitions, $F(2, 46) = 4.29$, $p < .05$—older adults did not show any evidence of increased viewing to the manipulated region, as revealed by nonsignificant effects of trial type on every measure, whether under free viewing (duration of viewing time, number of fixations, proportion of viewing time, and proportion of fixations: Fs < 1; number of transitions: $F = 1.97$, *ns*) or ignore (duration of viewing time, number of fixations,

Table 3
Means and Standard Errors for Eye Movement Measures From the Critical Block for Younger and Older Adults in Free Viewing and Ignore Conditions

Eye movement measure and trial type	Free viewing instructions				Ignore instructions			
	Younger adults		Older adults		Younger adults		Older adults	
	M	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*
Duration of viewing time (ms)								
Novel	1,066.38	52.60	1,029.65	61.66	1,143.46	40.48	1,015.56	60.21
Repeated	1,052.17	62.88	1,002.58	60.79	1,203.58	76.29	1,084.07	83.23
Manipulated	1,169.68	78.07	1,021.72	45.17	1,326.10	76.28	1,098.28	61.59
Proportion of viewing time								
Novel	.24	.01	.23	.01	.26	.01	.23	.01
Repeated	.24	.01	.23	.01	.27	.02	.24	.02
Manipulated	.27	.02	.23	.01	.30	.02	.24	.01
No. of fixations								
Novel	3.94	0.22	3.82	0.22	3.91	0.15	3.68	0.23
Repeated	3.97	0.23	3.64	0.24	4.01	0.27	3.78	0.30
Manipulated	4.32	0.32	3.71	0.18	4.44	0.24	3.79	0.23
Proportion of fixations								
Novel	.24	.01	.23	.01	.25	.01	.22	.01
Repeated	.24	.01	.23	.01	.26	.02	.23	.02
Manipulated	.26	.02	.22	.01	.29	.01	.23	.01
No. of transitions								
Novel	2.09	0.13	2.06	0.10	1.99	0.09	1.98	0.11
Repeated	2.15	0.12	1.91	0.12	2.02	0.09	2.05	0.14
Manipulated	2.38	0.16	2.06	0.11	2.22	0.11	2.05	0.10

Note. No. of transitions refers to the number of transitions into–out of the critical region.

proportion of viewing time, proportion of fixations, and number of transitions: all Fs < 1) instructions during the initial study blocks. This suggests that the interactions between age and trial observed above may result from a lack of power rather than a lack of consistent effects. Indeed, the younger adults showed increased viewing of the critical region for the manipulated scenes compared with the same region within the novel and repeated scenes, for which no change had occurred (see Table 3 for means and standard errors). These effects were evident irrespective of the instructions that were provided to the participants in the study blocks. This is in contrast to the findings from older adults, who did not demonstrate increased viewing of the critical region of the manipulated scenes even during the ignore condition, when they had directed more viewing, compared with the younger participants, to the late-onset object that underwent a change in its spatial relations in the manipulated scenes (see Table 3 for means and standard errors).

Overall viewing. The number of fixations made to each display was analyzed to examine whether the scanning patterns of younger and older adults were affected by repetition of the scenes (Ryan et al., 2000). The number of regions sampled was not analyzed here because viewing was largely constrained to the abstract objects within the scene—thus there was little variance in the number and kind of distinct regions sampled across the groups of participants. As for the analysis above, main effects of age, instruction, and trial and the interactions of Age × Trial Type and Instruction × Trial Type were examined. Simple contrasts on novel scenes versus repeated and manipulated scenes for the main effect of trial and the interactions with trial were also conducted.

Main effects of age, $F(1, 93) = 1.36$, $p > .2$, and instruction, $F(1, 93) = 1.15$, $p > .25$, were not significant. Younger and older adults directed a similar number of fixations to the displays, and previous viewing instructions did not have an impact on the number of fixations directed to the displays. A main effect of trial was observed, $F(2, 186) = 7.08$, $p = .001$; this effect did not interact with either age or instruction (Fs < 1). Viewers made more fixations on the novel scenes compared with either the repeated or manipulated scenes (see Figure 2). Simple contrasts of trial revealed a significant contrast between the novel and repeated scenes, $F(1, 93) = 13.41$, $p = .0001$, and between the novel and manipulated scenes, $F(1, 93) = 10.08$, $p < .01$. Although only the eye movements of younger adults were sensitive to effects of manipulation, the eye movements of both younger and older adults were sensitive to the repetition of the scene itself. The pattern of findings for older adults is similar to what we have previously observed for amnesic patients who demonstrated normal memory for the items (scenes) but impaired memory for the relations among the objects within the scene (Ryan et al., 2000).

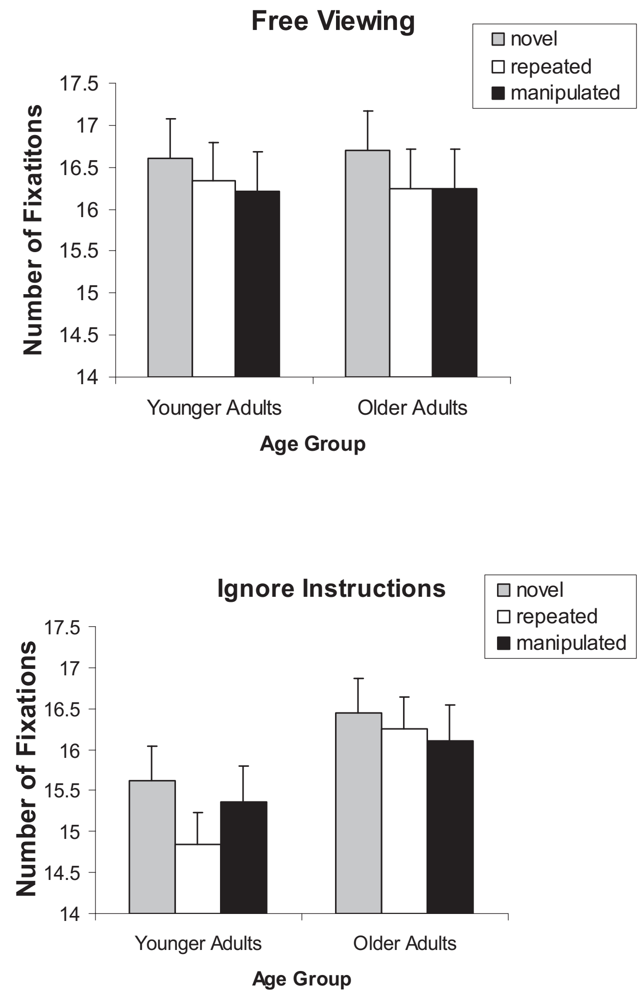

Figure 2. Means and standard errors for the number of fixations made to the novel, repeated, and manipulated scenes for younger and older adults who were either given free viewing or ignore instructions during the initial study blocks. Younger and older adults, regardless of instruction condition, showed a decrease in viewing behavior for the scenes that had been viewed throughout the experiment (repeated, manipulated) compared with those scenes that were novel.

Discussion

The present work assessed inhibitory and binding function in younger and older adults using eye movement monitoring. Inhibition was assessed by examining the extent to which participants directed viewing toward an abrupt-onset object when instructed to ignore such an object. Both younger and older adults directed some viewing toward the abrupt-onset stimulus, but older adults directed significantly more viewing toward the object they were instructed to ignore. These findings are indicative of an age-related deficit in inhibition (Hasher et al., 1999). This age-related inhibitory deficit, which was present in the first block on each of the eye movement measures, was lessened in the second block, suggesting that inhibitory deficits in older adults can be modulated (Hasher et al., 1997; Ryan et al., 2006).

In the test block, memory for the relations among the objects was assessed by examining viewing that was directed at regions within displays that had been altered from previous viewings. Younger adults directed increased viewing to the altered regions for manipulated scenes regardless of whether they were engaged in free viewing or were instructed to ignore the to-be-manipulated object during the initial study blocks, consistent with the suggestion that younger adults formed a memory representation that contained information regarding the relations among the objects in the scene. It is interesting to note that the effects for younger adults were more robust under ignore compared with free viewing instructions. Our previous findings have suggested that having conscious awareness for the implemented change may lessen the attraction of the eyes to the critical region (Ryan et al., 2000; Ryan & Cohen, 2004a). That is, when one becomes aware of the change in the scene, that region of the display is no longer informative and the eyes become attracted to other, more informative, regions within the scene. It is conceivable that younger adults under free viewing conditions may have had enhanced conscious access to the changes made to the relations among the objects compared with their ignore instructions counterparts, perhaps because of a more well-developed memory representation that arose from increased viewing of the to-be-changed object and its relations. Further work is needed to determine the relation between conscious access and the observed binding effects in younger (and older) adults in the present work.

In addition, the findings of increased viewing to the changed region for younger adults under ignore instructions suggests that either brief viewing of the to-be-manipulated object was enough to form a memory representation comprised of relations or that younger adults were able to adequately encode the abrupt-onset object within the periphery, such that foveal fixation was unnecessary. By contrast, the older adults did not demonstrate robust increases in viewing of the critical region for manipulated scenes, regardless of study instructions. In particular, older adults showed no increase in viewing of the manipulated region on any of the eye movement measures regardless of their initial viewing instructions. These findings suggest that older adults have deficits in binding as well as inhibition; that is, although older adults may direct more viewing toward information, this information is not always maintained in a lasting memory representation that consists of relations among objects. We turn now to a discussion of the current findings with respect to previous work on age-related impairments in inhibition and binding, including underlying neural mechanisms, and examine alternative interpretations of the current findings and future work to be considered.

Age-Related Impairments in Inhibition

In the current work, older adults directed more viewing to information they were instructed to ignore when compared with younger adults, consistent with oculomotor capture tasks (Butler et al., 1999; Kramer et al., 2000; Ryan et al., 2006) and findings from neuroimaging that show reduced inhibitory regulation by older adults (Gazzaley, Cooney, Rissman, & D'Esposito, 2005). Age-related deficits in inhibitory processing have been linked to impaired frontal lobe function (Chao & Knight, 1997). The present findings of increased viewing to an abrupt onset may reflect compromised frontal lobe function in the older adults (Munoz, Broughton, Goldring, & Armstrong, 1998; Nieuwenhuis, Ridderinkhof, de Jong, Kok, & van der Molen, 2000; Olincy et al., 1997).

Age-related increases in viewing of the abrupt-onset objects are sometimes interpreted in terms of goal activation or preparatory set, which has been shown to be impaired in older adults (Nieuwenhuis, Broerse, Nielen, & de Jong, 2004; but see Butler & Zacks, 2006). DeSouza, Menon, and Everling (2003) found that activation within the dorsolateral prefrontal cortex was evident following the presentation of a cue stimulus that instructed viewers to either make a pro- or antisaccade in response to the target onset. With respect to the findings here, impaired frontal function in older adults may have disrupted the maintenance of the goal of not looking at the late-onset object. A disruption in goal activation or preparatory set would lead to impairments in inhibitory processing, such that eye movements would be directed toward the object that was to be ignored. However, the recent work of Butler and Zacks (2006), which varied the inhibitory demands in the context of a Stroop task while holding the goal maintenance requirements constant, suggested the existence of age differences in inhibitory regulation over and above any differences in goal maintenance. Alternatively, older adults may have had difficulties remembering which object served as the late-onset object, thereby revisiting the object they were instructed to ignore.

Of interest, these age-related impairments in inhibitory processing (whether due to inefficient goal maintenance, impaired memory, etc.) seem to be reduced under certain conditions. For instance, in the present work under ignore instructions, older and younger adults directed less viewing to the abrupt-onset objects across blocks, suggesting that additional practice or additional information in some instances (Hasher et al., 1997) can modulate deficits in inhibitory processing. Other work suggests that predictable locations for distractors or for targets also enables older adults to ignore distraction (Li, Hasher, Jonas, Rahhal, & May, 1998; Madden, 1983; Plude & Hoyer, 1986; Wright & Elias, 1979), as does cuing of locations (Ryan et al., 2006). Together, these findings suggest that although age-related impairments in inhibitory processing exist, these deficits can be attenuated through additional practice, with additional external cuing of location, or with knowledge about probabilities. In particular, if older adults have difficulty remembering which object served as the abrupt-onset object, then repeated exposures to the stimuli could lessen viewing to the to-be-ignored object through the accumulation of memory for the item.

However, one could interpret the present findings as suggesting that older adults merely required additional processing time to move their eyes away from the object they were supposed to ignore. That is, perhaps sufficient processing of an object's location or identity is required before one can then successfully ignore it. In that case, younger adults may process the object location and/or identity information faster than older adults, thereby resulting in a decrease in viewing that is directed to the late-onset objects. Investigation of the number of trials in which the late-onset region was fixated demonstrates that this region was fixated on approximately one third of the trials for younger and older adults under ignore instructions, whereas the late-onset region was fixated on nearly every trial under free viewing instructions. This suggests, at the very least, that the late-onset object does not necessarily have to be initially foveated before successful suppression of viewing behavior can occur. Furthermore, older adults fixated on the late-onset region in more trials under ignore instructions compared with the younger adults, suggesting that the observed age-related inhibition deficit was not only due to a slower reaction time to move the eyes away from the late-onset area. As a result of an inhibition deficit, older adults directed additional eye movement behavior toward stimuli they were instructed to ignore, although information regarding the relations among the viewed objects was not maintained into a lasting memory representation.

Age-Related Impairments in Binding

The present findings support an account that suggests age-related deficits in binding occur along with an age-related impairment in inhibition. Younger adults directed more eye movements toward regions within a scene that had been altered, compared with the same regions for scenes that had not been changed. This effect was not observed in the older adults. However, both older and younger adults showed eye movement evidence of memory for the scenes themselves; both groups showed a decrease in the number of fixations that were made to scenes that had been viewed throughout the experiment (repeated, manipulated) compared with the novel scenes. The pattern of findings for older adults is similar to that observed for amnesic patients (Ryan et al., 2000), including a patient with damage restricted to the hippocampus who demonstrated normal memory for the items (scenes) but impaired memory for the relations among the objects within the scene (Ryan & Cohen, 2004b). Memory for the relations among objects depends on the integrity of the medial temporal lobe and, in particular, the hippocampus, which would thus appear to be compromised in older adults.

What is of particular interest here is the fact that older adults did not show memory for the changes in the relations among the objects even in the ignore condition. Given that older adults directed more viewing, and therefore potentially more encoding processes (Deubel & Schneider, 1996; Hoffman & Subramaniam, 1995; Kowler, Anderson, Dosher, & Blaser, 1995), toward the abrupt onset object under ignore conditions compared with younger adults, it would have been expected, if binding were intact, that older adults would have shown better memory for the change in relations that occurred to the to-be-ignored object in the subsequent critical block compared with the younger adults. However, older adults did not show a more robust eye movement effect for the relations among the objects when compared with the younger adults; in fact, only the younger adults showed eye movement evidence of memory for the relations. Because our results were obtained using an implicit eye movement task, consistent findings of an age-related binding impairment obtained with explicit memory instructions, as in studies of associative memory (Chalfonte & Johnson, 1996; Light & La Voie, 1993; Light & Singh, 1987; Naveh-Benjamin, 2000; Winocur et al., 1996), are unlikely to be solely attributable to the increased anxiety and arousal caused by explicit memory instructions (cf. Rahhal et al., 2001). Nevertheless, the current results should be interpreted with caution with respect to a binding account, as not all of the eye movement measures provided significant differences between viewing manipulated versus either novel or repeated scenes. Also, other interpretations, outlined below, could be applied to the current findings.

Further Considerations

The current work provides evidence for an age-related deficit in binding between object relations. However, one could argue that the present findings are indicative of a feature binding deficit (the grouping of distinct features or properties to form a coherent percept or item) rather than a relational binding deficit. Previous work has shown that impaired feature binding leads to impairments in relational binding; that is, it is difficult to form and maintain relations among distinct objects if the representations of those objects are incomplete (Moses, Cole, & Ryan, 2005). However, the current findings of impaired relational binding may not be secondary to an age-related deficit in feature binding, given that the eye movements of the older adults were sensitive to repetition of the scenes in a manner similar to that of younger adults. This lack of a difference between age groups on overall viewing also argues against a pure sensory deficit account of the current findings (Schneider & Pichora-Fuller, 2000). Further studies that specifically explore eye movements to feature changes would shed light on whether the current findings are primarily due to a feature binding deficit.

It is also possible that older adults have a problem in the processing of relations that would, in turn, create a deficit in the formation and maintenance of lasting relational representations. It has been suggested in previous work that the processing of relations, in contrast to the formation of a lasting representation, is not necessarily dependent on the medial temporal lobes and instead may rely on frontal systems (Moses & Ryan, 2006; Ryan & Cohen, 2004a, 2004b; Waltz et al., 1999). Further work could address the processing versus long-term retention of relations in older adults and the relative contribution of frontal versus medial temporal lobe function to the observed deficits.

Also, further work using real-world objects would also speak to whether the current findings of age-related inhibition and binding deficits can be attenuated through the use of existing memory representations. Binding deficits may be lessened if relations need to be formed among objects for which there are existing representations in memory, particularly if the presented objects have already been related (i.e., semantically or otherwise) in the real world (Howard, 1983). Increasing preexperimental knowledge regarding relations (and increasing processing time; Howard, Heisey, & Shaw, 1986) may lessen the demands on the medial temporal lobe to form and maintain new, arbitrary associations (see Moses et al., 2006, for further discussion).

References

Balota, D. A., Dolan, P. O., & Duchek, J. (2000). Memory changes in healthy older adults. In E. Tulving & F. I. M. Craik (Eds.), *The Oxford handbook of memory* (pp. 395–409). New York: Oxford University Press.

Butler, K. M., & Zacks, R. T. (2006). Age deficits in the control of prepotent responses: Evidence for an inhibitory decline. *Psychology and Aging, 21,* 638–643.

Butler, K. M., Zacks, R. T., & Henderson, J. M. (1999). Suppression of reflexive saccades in younger and older adults: Age comparisons on an antisaccade task. *Memory & Cognition, 27,* 584–591.

Castel, A. D., & Craik, F. I. M. (2003). The effects of aging and divided attention on memory for item and associative information. *Psychology and Aging, 18,* 873–885.

Cerella, J. (1985). Information processing rates in the elderly. *Psychological Bulletin, 98,* 67–83.

Chalfonte, B. L., & Johnson, M. K. (1996). Feature memory and binding in young and older adults. *Memory & Cognition, 24,* 403–416.

Chao, L. L., & Knight, R. T. (1997). Prefrontal deficits in attention and inhibitory control with aging. *Cerebral Cortex, 7,* 63–69.

Cohen, N. J., & Eichenbaum, H. (1993). *Memory, amnesia, and the hippocampal system.* Cambridge, MA: MIT.

Colcombe, A. M., Kramer, A. F., Irwin, D. E., Peterson, M. S., Colcombe, S., & Hahn, S. (2003). Age-related effects of attentional and oculomotor capture by onsets and color singletons as a function of experience. *Acta Psychologica, 113,* 205–225.

Craik, F. I. M., & Byrd, M. (1982). Aging and cognitive deficits: The role of attentional resources. In F. I. M. Craik & S. E. Trehub (Eds.), *Aging and cognitive processes* (pp. 191–211). New York: Plenum Press.

Craik, F. I. M., & Jennings, J. J. (1992). Human memory. In F. I. M. Craik & T. A. Salthouse (Eds.), *The handbook of aging and cognition* (pp. 51–110). Hillsdale, NJ: Erlbaum.

Craik, F. I. M., & Lockhart, R. S. (1972). Levels of processing: A framework for memory research. *Journal of Verbal Learning and Verbal Behavior, 11,* 671–684.

Delis, D. C., Kramer, J., Kaplan, E., & Ober, B. A. (2000). *California Verbal Learning Test-second edition.* San Antonio, TX: The Psychological Corporation.

DeSouza, J. F., Menon, R. S., & Everling, S. (2003). Preparatory set associated with pro-saccades and anti-saccades in humans investigated with event-related fMRI. *Journal of Neurophysiology, 89,* 1016–1023.

Deubel, H., & Schneider, W. X. (1996). Saccade target selection and object recognition: Evidence for a common attentional mechanism. *Vision Research, 36,* 1827–1837.

Educational Testing Service. (1976). *Kit of factor-referenced test.* Princeton, NJ: Author.

Gazzaley, A., Cooney, J. W., Rissman, J., & D'Esposito, M. (2005). Top-down suppression deficit underlies working memory impairment in normal aging. *Nature Neuroscience, 8,* 1298–1300.

Graf, P. (1990). Life span changes in implicit and explicit memory. *Bulletin of the Psychonomic Society, 28,* 353–358.

Hamm, V. P., & Hasher, L. (1992). Age and the availability of inferences. *Psychology and Aging, 7,* 56–64.

Hasher, L., Quig, M. B., & May, C. P. (1997). Inhibitory control over no-longer-relevant information: Adult age differences. *Memory & Cognition, 25,* 286–295.

Hasher, L., & Zacks, R. T. (1988). Working memory, comprehension, and aging: A review and a new view. In G. Bower (Ed.), *The psychology of learning and motivation* (pp. 193–225). New York: Academic Press.

Hasher, L., Zacks, R. T., & May, C. P. (1999). Inhibitory control, circadian arousal, and age. In A. Koriat & D. Gopher (Eds.), *Attention and performance XVII: Cognitive regulation of performance: Interaction of theory and application* (pp. 653–675). Cambridge, MA: MIT Press.

Hashtroudi, S., Johnson, M. K., & Chrosniak, L. D. (1989). Aging and source monitoring. *Psychology and Aging, 4,* 106–112.

Hoffman, J. E., & Subramaniam, B. (1995). The role of visual attention in saccadic eye movements. *Perception & Psychophysics, 57,* 787–795.

Howard, D. V. (1983). The effects of aging and degree of association on the semantic priming of lexical decisions. *Experimental Aging Research, 9,* 145–151.

Howard, D. V., Heisey, J. G., & Shaw, R. (1986). Aging and the priming of newly learned associations. *Developmental Psychology, 22,* 78–85.

Kim, S., Hasher, L., & Zacks, R. T. (in press). Aging and a benefit of distractibility. *Psychonomic Bulletin & Review.*

Kowler, E., Anderson, E., Dosher, B., & Blaser, E. (1995). The role of attention in the programming of saccades. *Vision Research, 35,* 1897–1916.

Kramer, A. F., Hahn, S., Irwin, D. E., & Theeuwes, J. (1999). Attentional capture and aging: Implications for visual search performance and oculomotor control. *Psychology and Aging, 14,* 135–154.

Kramer, A. F., Hahn, S., Irwin, D. E., & Theeuwes, J. (2000). Age differences in the control of looking behavior: Do you know where your eyes have been? *Psychological Science, 11,* 210–217.

Li, K. Z., Hasher, L., Jonas, D., Rahhal, T. A., & May, C. P. (1998). Distractibility, circadian arousal, and aging: A boundary condition? *Psychology and Aging, 13,* 574–583.

Light, L. L. (1996). Memory and aging. In E. L. Bjork & R. A. Bjork (Eds.), *Memory* (pp. 443–490). San Diego, CA: Academic Press.

Light, L. L., & La Voie, D. (1993). Direct and indirect measures of memory in old age. In P. Graf & M. E. J. Masson (Eds.), *Implicit memory: New directions in cognition, development, and neuropsychology* (pp. 207–230). Hillsdale, NJ: Erlbaum.

Light, L. L., & Singh, A. (1987). Implicit and explicit memory in young and older adults. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 13,* 531–541.

Madden, D. J. (1983). Aging and distraction by highly familiar stimuli during visual search. *Developmental Psychology, 19,* 499–507.

May, C. P., Zacks, R. T., Hasher, L., & Multhaup, K. S. (1999). Inhibition in the processing of garden-path sentences. *Psychology and Aging, 14,* 304–313.

Moses, S. N., Cole, C., & Ryan, J. D. (2005). Relational memory for object identity and spatial location in rats with lesions of perirhinal cortex, amygdala and hippocampus. *Brain Research Bulletin, 65,* 501–512.

Moses, S. N., & Ryan, J. D. (2006). A comparison and evaluation of the predictions of relational and conjunctive accounts of hippocampal function. *Hippocampus, 16,* 43–65.

Moses, S. N., Villate, C., & Ryan, J. D. (2006). An investigation of learning strategy supporting transitive inference performance in humans compared to other species. *Neuropsychologia, 44,* 1370–1387.

Multhaup, K. S., de Leonardis, D. M., & Johnson, M. K. (1999). Source memory and eyewitness suggestibility in older adults. *Journal of General Psychology, 126,* 74–84.

Munoz, D. P., Broughton, J. R., Goldring, J. E., & Armstrong, I. T. (1998). Age-related performance of human subjects on saccadic eye movement tasks. *Experimental Brain Research, 121,* 391–400.

Munoz, D. P., & Everling, S. (2004). Look away: The anti-saccade task and the voluntary control of eye movement. *Nature Reviews Neuroscience, 5,* 218–228.

Naveh-Benjamin, M. (2000). Adult age differences in memory performance: Tests of an associative deficit hypothesis. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 26,* 1170–1187.

Naveh-Benjamin, M., Guez, J., Kilb, A., & Reedy, S. (2004). The associative memory deficit of older adults: Further support using face-name associations. *Psychology and Aging, 19,* 541–546.

Naveh-Benjamin, M., Hussain, Z., Guez, J., & Bar-On, M. (2003). Adult age differences in episodic memory: Further support for an associative-deficit hypothesis. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 29,* 826–837.

Nieuwenhuis, S., Broerse, A., Nielen, M. M., & de Jong, R. (2004). A goal activation approach to the study of executive function: An application to antisaccade tasks. *Brain and Cognition, 56,* 198–214.

Nieuwenhuis, S., Ridderinkhof, K. R., de Jong, R., Kok, A., & van der Molen, M. W. (2000). Inhibitory efficiency and failures of intention activation: Age-related decline in the control of saccadic eye movements. *Psychology and Aging, 15,* 635–647.

Olincy, A., Ross, R. G., Young, D. A., & Freedman, R. (1997). Age diminishes performance on an antisaccade eye movement task. *Neurobiology of Aging, 18,* 483–489.

Olk, B., & Kingstone, A. (2003). Why are antisaccades slower than prosaccades? A novel finding using a new paradigm. *NeuroReport, 14,* 151–155.

Plude, D. J., & Hoyer, W. J. (1986). Age and the selectivity of visual information processing. *Psychology and Aging, 1,* 4–10.

Rabbitt, P. M. (1965). An age-decrement in the ability to ignore irrelevant information. *Journal of Gerontology, 20,* 233–238.

Rahhal, T. A., Colcombe, S., & Hasher, L. (2001). Instructional manipulations and age differences in memory: Now you see them, now you don't. *Psychology and Aging, 16,* 697–706.

Rahhal, T. A., May, C. P., & Hasher, L. (2002). Truth and character: Sources that older adults can remember. *Psychological Science, 13,* 101–105.

Rowe, G., Valderrama, S., Hasher, L., & Lenartowicz, A. (2006). Attention disregulation: A benefit for implicit memory. *Psychology and Aging, 21,* 826–830.

Ryan, J. D., Altoff, R. R., Whitlow, S., & Cohen, N. J. (2000). Amnesia is a deficit in relational memory. *Psychological Science, 11,* 454–461.

Ryan, J. D., & Cohen, N. J. (2004a). The nature of change detection and online representations of scenes. *Journal of Experimental Psychology: Human Perception and Performance, 30,* 988–1015.

Ryan, J. D., & Cohen, N. J. (2004b). Processing and short-term retention of relational information in amnesia. *Neuropsychologia, 42,* 497–511.

Ryan, J. D., Shen, J., & Reingold, E. M. (2006). Modulation of distraction in aging. *British Journal of Psychology, 97,* 339–351.

Salthouse, T. A. (1995). Selective influences of age and speed on associative memory. *American Journal of Psychology, 108,* 381–396.

Salthouse, T. A. (1996). The processing speed theory of adult age differences in cognition. *Psychological Review, 103,* 403–428.

Schacter, D. L., Koutstaal, W., Johnson, M. K., Gross, M. S., & Angell, K. E. (1997). False recollection induced by photographs: A comparison of older and younger adults. *Psychology and Aging, 12,* 203–215.

Schneider, B., & Pichora-Fuller, M. K. (2000). Implications of sensory deficits for cognitive aging. In F. I. M. Craik & T. Salthouse (Eds.), *The handbook of aging and cognition* (2nd ed., pp. 155–219). Mahwah, NJ: Erlbaum.

Waltz, J. A., Knowlton, B. J., Holyoak, K. J., Boone, K. B., Mishkin, F. S., Santoa, M. D. M., et al. (1999). A system for relational reasoning in human prefrontal cortex. *Psychological Science, 10,* 119–125.

Winocur, G., Moscovitch, M., & Stuss, D. T. (1996). Explicit and implicit memory in the elderly: Evidence for double dissociation involving medial temporal- and frontal-lobe functions. *Neuropsychology, 10,* 57–65.

Wright, L. L., & Elias, J. W. (1979). Age differences in the effects of perceptual noise. *Journal of Gerontology, 34,* 704–708.

Zacks, R. T., Hasher, L., & Li, K. Z. (2000). Human memory. In F. I. M. Craik & T. Salthouse (Eds.), *The handbook of aging and cognition* (2nd ed., pp. 293–357). Mahwah, NJ: Erlbaum.

Appendix A

Analyses of Variance for the Measures of Viewing to the Late-Onset Object for the Study Blocks

	Duration of viewing time		Proportion of viewing time		No. of fixations		Proportion of fixations		No. of transitions		No. of trials fixated	
Variable	*F*	*p*	*F*	*p*	*F*	*p*	*F*	*p*	*F*	*p*	*F*	*p*
Age[a]	<1	*ns*	<1	*ns*	<1	*ns*	<1	*ns*	1.82	*ns*	5.24	<.05
Block[a]	7.53	<.01	7.66	<.01	15.26	<.001	9.36	<.01	29.58	<.001	18.54	<.001
Instruction[a]	354.30	<.001	383.45	<.001	481.58	<.001	455.90	<.001	457.98	<.001	912.59	<.001
Age × Block[a]	<1	*ns*	<1	*ns*	2.93	.10	<1	*ns*	8.81	<.01	5.36	<.01
Age × Instruction[a]	1.57	*ns*	1.75	*ns*	3.48	.065	2.99	.09	2.80	.10	3.74	.06
Block × Instruction[a]	12.46	<.01	14.03	<.001	12.30	<.01	15.20	<.001	6.95	<.05	18.08	<.001
Age × Block × Instruction[a]	3.89	.05	4.06	<.05	3.47	.07	3.28	.07	2.35	*ns*	4.63	<.05
Planned contrasts												
Block 1: Free viewing vs. age[b]	<1	*ns*	<1	*ns*	<1	*ns*	<1	*ns*	<1	*ns*	<1	*ns*
Block 2: Free viewing vs. age[b]	<1	*ns*	<1	*ns*	<1	*ns*	<1	*ns*	<1	*ns*	<1	*ns*
Block 1: Ignore vs. age[b]	14.25	<.001	15.49	<.001	21.80	<.001	16.00	<.001	15.48	<.001	7.86	<.01
Block 2: Ignore vs. age[b]	2.96	.09	2.72	.10	2.80	.10	3.30	.08	2.01	*ns*	<1	*ns*

[a] $df = 1, 92$. [b] $df = 1, 46$.

Appendix B

Custom Analyses of Variance and Simple Contrasts for the Eye Movement Measures of Viewing to the Manipulated Region for the Final Critical Block

	Duration of viewing time		Proportion of viewing time		No. of fixations		Proportion of fixations		No. of transitions	
Variable	*F*	*p*	*F*	*p*	*F*	*p*	*F*	*p*	*F*	*p*
Age[a]	4.75	<.05	6.34	<.05	3.20	.08	8.34	<.01	1.48	*ns*
Instruction[a]	2.64	*ns*	1.87	*ns*	<1	*ns*	1.24	*ns*	<1	*ns*
Trial[b]	4.95	<.01	4.66	<.05	2.79	.06	3.13	<.05	6.14	<.01
Age × Trial[b]	2.03	*ns*	1.78	*ns*	2.40	.09	2.41	.09	2.85	.06
Instruction × Trial[b]	1.35	*ns*	<1	*ns*	<1	*ns*	<1	*ns*	<1	*ns*
Simple contrast										
Trial: Manipulated vs. novel[a]	11.03	<.01	10.84	<.01	6.27	<.05	8.32	<.01	11.54	<.01
Trial: Manipulated vs. repeated[a]	4.03	<.05	3.64	.06	2.79	.10	2.07	*ns*	7.70	<.01
Age × Trial: Manipulated vs. novel[a]	3.78	.06	2.96	.09	6.10	<.05	5.90	<.05	6.87	<.05
Age × Trial: Manipulated vs. repeated[a]	2.30	*ns*	2.34	*ns*	1.89	*ns*	2.17	*ns*	1.84	*ns*

[a] $df = 1, 93$. [b] $df = 2, 186$.

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