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Age-Related Differences in Object- and Location-Based Inhibition of Return of Attention

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Four experiments examined age-related differences in inhibition of return (IOR) of visual attention. Using static stimuli, both young and older adults were slower to detect targets in previously cued objects, showing equivalent IOR. With objects that moved after they had been cued, young adults were slower to detect targets in the cued object (compared with uncued ones), revealing object-based IOR, but older adults were faster to detect targets in such objects, failing to demonstrate object-based IOR. Both age groups were slower to detect targets at the initially cued location (location-based IOR). The results show that age has a differential effect on IOR depending on the frame of reference of the inhibition: Inhibition for objects breaks down with age, but that for location does not. This pattern of results is consistent with the view that there are specific inhibitory deficits in old age.

Attention serves to help people concentrate on a subset of the vast array of information typically available at any one moment. For example, if a person's visual attention is attracted to one part of a scene by a peripheral flash, he or she will be faster to detect targets presented at the cued location compared with other locations, even in the absence of eye movements (Posner & Cohen, 1984). Attention also serves to inhibit some information that may be less important for the task at hand: If a half second or so elapses after attention has been attracted to a location by an uninformative flash, people will actually be slower to detect stimuli at the cued location. Posner and Cohen (1984) referred to this latter effect as an "inhibition of return" (IOR), because it seemed as if participants were inhibited in returning their attention to the recently inspected (but then subsequently rejected) location. IOR is thought to improve the efficiency with which people can scan a scene because it biases them against returning attention to recently inspected locations.

For older adults, the benefits of both facilitatory and inhibitory attentional systems may be especially important. This is because older adults may experience a range of changes in cognitive, perceptual, and motor systems including impaired visual acuity (Scialfa, Garvey, Gish, Deering, & Leibowitz, 1988), increased reaction time for eye movements (Pratt, Abrams, & Chasteen, 1997), and declines in working memory (Baddeley, 1986). Thus, the ability to selectively attend or selectively inhibit certain parts of a scene may play an important role in the way in which an older adult interacts with and navigates through his or her environment. In the present article, we briefly review current theory on aging and inhibition and then focus specifically on the age-related changes that may affect the inhibitory component of selective visual attention, IOR.

Aging and Inhibition

Research on aging and inhibition has grown steadily since Hasher and Zacks (1988) proposed their original inhibitory deficit theory of cognitive aging. Early support for Hasher and Zacks's model came from studies of *negative priming* in which participants must detect or identify targets that sometimes share some features in common with distractors presented earlier (e.g., Hasher, Stoltzfus, Zacks, & Rypma, 1991; Stoltzfus, Hasher, Zacks, Ulivi, & Goldstein, 1993). In these earlier studies, young adults exhibited negative priming (i.e., inhibition),[1] but older adults did not; hence the results were consistent with a hypothesized general breakdown of inhibitory processing with normal aging.

The results of later studies of negative priming, however, are inconsistent with this hypothesis. Connelly and Hasher (1993) used a modified version of the negative priming task to demonstrate that not all types of inhibition in the negative priming task are affected by age. They found that both young and older adults demonstrated negative priming (inhibition) for the location of an earlier ignored distracting letter. However, only the young adults showed negative priming (inhibition) for the identity of the earlier letter. Other researchers (Kramer, Humphrey, Larish, Logan, & Strayer, 1994; Sullivan & Faust, 1993; Sullivan, Faust, & Balota,

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[1] Note that although negative priming and IOR are similar, the inhibition in each case is thought to arise from distinct mechanisms.

1995) have failed to replicate this result, finding age equivalence in identity negative priming instead.[2] Despite the conflicting results of these studies, it is important to note that none of them provide support for global inhibitory dysfunction with age.

Such contradictory findings have prompted researchers to caution against any reliance on negative priming as a measure of inhibitory functioning. McDowd (1997) and Milliken, Joordens, Merikle, and Seiffert (1998) pointed out that there are alternative explanations for negative priming (i.e., feature mismatch, episodic retrieval) that do not necessarily involve inhibitory processes. Fortunately, as questions have been raised regarding the inhibitory nature of the mechanisms underlying negative priming, researchers have begun exploring the effect of aging on inhibition in a variety of other cognitive domains, including language, memory, attention, and working memory. Results of this research have revealed age equivalence in many tasks, including object-based selective attention (Kramer & Weber, 1999), identity suppression (Kieley & Hartley, 1997), and online selection of word meaning during language processing (Paul, 1996). Rather than providing a complete review of that research here, suffice it to say that research from these various areas suggests that the effects of age on inhibitory functioning appear to be task specific rather than general. (See McDowd, 1997, and Burke, 1997, for excellent reviews of research in the domains of attention and language, respectively.) Findings from IOR also suggest task-specific effects with age. We turn to this next.

Aging and IOR

Research on aging and IOR adds to the growing body of evidence in favor of a new conceptualization of aging and inhibitory processing. Faust and Balota (1997) examined IOR in young adults, healthy older adults, and older adults with dementia of the Alzheimer type (DAT). They found no differences in the amount of IOR demonstrated by these three groups. Hartley and Kieley (1995) also examined age differences in IOR and found that the IOR effect was at least as large in older adults as in younger adults.

Both the Faust and Balota (1997) and Hartley and Kieley (1995) studies examined IOR using static stimuli and found age equivalence. Other researchers have examined IOR in a dynamic environment. In a study involving only younger adults, Tipper, Driver, and Weaver (1991) cued one of two boxes on a display (using a peripheral flash) and then had the boxes move to a new location prior to the presentation of a target in one of them. The intervals between cue and target were all greater than 400 ms—long enough to expect IOR to develop. However, because of the motion of the boxes, any relative slowness to detect a target in the cued box could occur only if some IOR could move with the cued object as it moved across the display. Indeed, such object-based IOR was present in the Tipper et al. (1991) study and has been shown in a variety of other contexts by several others (e.g., Abrams & Dobkin, 1994; Tipper, Weaver, Jerreat, and Burak, 1994; but see Muller & von Muhlenen, 1996, for a failure to replicate and Weaver, Lupianez, & Watson, 1998, for a rejoinder). Importantly, some inhibition also appears to affect responses to the originally cued location, even after the cued object has moved away, suggesting the existence of both object-based and location-based components of IOR (Abrams & Pratt, 2000; Tipper et al., 1997; Tipper & Weaver, 1998). The two components are presumed to reflect the operation of two, at least partially separate, inhibitory mechanisms.

Research into these two components of IOR is providing more information on inhibitory functioning in older adults. Tipper et al. (1997) included a control group of 20 younger adults (Experiment 1) and 9 older adults (Experiment 2) in a study examining object-based IOR in split-brain patients. They found the object-based IOR effect was somewhat larger in the older (21 ms) than the younger adults (8 ms). McDowd, Filion, Tipper, and Weaver (1995) assessed both location-based and object-based IOR and found the IOR effect was greater for older adults than for younger adults, for both object- and location-based inhibition. These results are rather surprising in that they suggest improved inhibitory function with age.

Despite McDowd et al.'s (1995) failure to find age-related differences in object- and location-based IOR, it is possible that differences do exist that remain to be detected. Indeed, our results suggest that is the case. One potential basis for such differences may involve the existence of distinct visual pathways for representing objects and locations (Hillyard, Mangun, Woldorff, & Luck, 1995; Moran & Desimone, 1985; Petersen, Corbetta, Miezin, & Shulman, 1994; Schneider, 1995). The tectopulvinar pathway is thought to be involved in the localization of visual stimuli (Posner & Petersen, 1990) and, hence, may be involved in location-based IOR. The geniculostriate pathway is capable of the sophisticated motion perception (Shipp, de Jong, Zihl, Frackowiak, & Zeki, 1994; Zihl, von Cramon, & Mai, 1983, 1991) required to track a moving object and, therefore, may be involved in object-based IOR. If one of these pathways is more age sensitive than the other, differences in the two types of IOR may emerge with age. Unfortunately, neuroanatomical evidence that directly examines age-related differences in these two visual pathways is not currently available (see chapter by Raz, 2000). Recent indirect evidence based on global measures (i.e., magnetic resonance imaging [MRI], positron-emission tomography [PET], and functional MRI [fMRI]) of neuroanatomy does not support such age-related differences. However, no clear conclusions can be drawn at this time, because these global measures do not rule out the possibility that specific structures within each of the pathways may be differentially affected by age.

Timing

Another way in which age might affect IOR has to do with its time course. In particular, Hartley and Kieley (1995) suggested that inhibition may take longer to build up and dissipate for older adults. Other research examining age differences in visual attention tasks has revealed different time courses for young and old adults (Greenwood, Parasuraman, & Haxby, 1993; Madden, 1990). The nature of these differences was that older adults were slower than younger adults to take advantage of cues in some situations.

[2] The stimuli used in these other studies, however, were considerably more complex than the letters used in Connelly and Hasher's (1993) negative priming paradigm: Sullivan and Faust (1993) and Sullivan et al. (1995) used drawings of common objects, Kramer et al. (1994) used displays with several distractors, and Kieley and Hartley (1997) used a Stroop procedure. Because different tasks were used in each of these studies, it is difficult to make direct comparisons.

Thus, it seems reasonable to suspect that IOR may have a longer time course for older adults than for younger adults.

In young adults, Lupianez, Milan, and Tornay (1997) demonstrated that IOR in a static environment was present at a stimulus onset asynchrony (SOA) of 400 ms and remained up to an SOA of 1,300 ms. The time course of IOR for older adults has not been examined. However, Tipper and Weaver (1998) demonstrated differences in the time course of location-based and object-based IOR in younger adults. Thus, it seems reasonable to suspect that older adults may also have different time courses for location- and object-based IOR. Whether age-related differences in the time course of inhibition differentially affect the object- and location-based components of IOR was a possibility we explored in the present research.

Overview of Experiments

As previously discussed, researchers have examined some aspects of the effects of age on IOR (i.e., Faust & Balota, 1997; Hartley & Kieley, 1995). However, distinct effects of age on object- and location-based IOR have not yet been adequately studied. The present study addresses this issue by including older and younger adults in four experiments. Experiment 1 examined IOR in a static environment—presumed to reflect the combined operation of both object- and location-based components. Experiment 2 measured object-based IOR with moving stimuli. Experiment 3 examined possible age-related differences in the time course of object-based IOR. Experiment 4 studied location-based IOR.

Experiment 1

This experiment examined IOR in young and old adults and was expected to replicate earlier research, revealing no effect of age on IOR in a static environment. Participants viewed a display containing two boxes. One of the boxes was cued exogenously (i.e., with a flash). The exogenous flash served to automatically attract the participants' attention to the cued box (despite the fact that the cue was not informative with respect to the location of the upcoming target; Yantis, 1996). Following a short delay, a target was presented either in the cued box or in the uncued one. IOR would be demonstrated if participants were slower to detect the target when it appeared in the cued box. Others have shown that the IOR effect is at least as large in older adults as in younger adults (Faust & Balota, 1997; Hartley & Kieley, 1995), and our primary purpose here was to confirm that observation and obtain baseline data for comparison in subsequent experiments.

Method

Participants. Two groups of 20 participants each volunteered for the experiment. The young adult group consisted of Washington University undergraduates, 11 women and 9 men, ranging in age from 18 to 22 years ($M = 19.26$, $SD = 1.58$). The older adult group, 12 women and 8 men, was obtained through Washington University's Aging and Development volunteer pool and ranged in age from 67 to 79 years ($M = 73.68$, $SD = 3.16$). To rule out the possibility that any age differences observed might be due to differences in overall health and vision between the young and older adults, we took steps to ensure that the older adult sample contained individuals with good general health and no diseases or other health problems of the eyes. All older adult participants had to pass an initial telephone screening. Potential participants who reported poor overall health by rating their health less than 5 on an 11-point scale (where 0 = *poor health,* 5 = *average health,* and 10 = *excellent health*) were excluded from participating. Individuals who reported poor eye health (i.e., glaucoma, cataracts), use of certain medications (i.e., psychotropics, beta blockers), or an inability to read a magazine or a newspaper (with correction) were also excluded. The older adult sample had a mean overall health rating of 8.06 ($SD = 1.14$) and a mean of 14.70 years of education ($SD = 2.56$). Visual acuity (with corrective lenses) was measured with the Rosenbaum Pocket Vision Test at a distance of 14 in. (35.6 cm).[3] Median visual acuity for both young adults (Mdn = 20/20) and older adults (Mdn = 20/50) was well below the 20/100 necessary to discriminate the stimuli in the experiment. Each subject participated in a single session lasting less than 1 hr. The young adults participated to earn course credit, and the older adults were paid $10 for their participation.

Apparatus and procedure. Testing was conducted in a dimly illuminated room. All stimuli were presented by an IBM compatible computer equipped with a video graphics adapter (VGA) card on a standard VGA monitor. Participants were seated 21 in. (53.3 cm) in front of the monitor with their heads supported by a chin rest. Figure 1 illustrates the sequence of events on a trial. At the beginning of each trial, participants saw two white boxes (0.75° × 0.75°) and a white plus sign horizontally aligned on a light gray background. The plus sign was in the center of the display and served as a fixation marker. The box centers were each 10° from fixation. The boxes appeared to be unfilled as a result of their white borders and light gray interiors.

At the start of each trial participants were required to fixate on the plus sign. Eye position was visually monitored (described below) to ensure that fixation was maintained throughout each trial. After 300 ms, the plus sign was brightened for 800 ms and then disappeared as the cue was presented. The cue consisted of a brightening of one of the peripheral boxes for 83 ms. Such exogenous cues are thought to automatically attract attention in most situations. The plus sign reappeared 100 ms after the offset of the peripheral cue, remained on the screen for 83 ms, and then disappeared again for 100 ms. In this manner, the plus sign was essentially "cued" to ensure that participants returned their attention to fixation following the peripheral cue. Following a delay of 100 ms, a target appeared on two thirds of the trials. This sequence of events results in an SOA (the interval between cue onset and target onset) of 467 ms. The target consisted of a small white box (0.25° × 0.25°) presented for 83 ms in the center of one of the peripheral boxes. The participants' task was to press the space bar on the keyboard in front of them as soon as the target appeared. They were instructed to refrain from responding on catch trials (i.e., trials with no target). A feedback tone and the message "Too early" appeared on the screen if a participant made an anticipatory response or a false alarm. Likewise, a tone and the message "Too slow" appeared on the screen if a participant failed to respond to a target within 2 s.

One third of the trials were catch trials. When a target was presented, it was equally likely to appear in either of the two peripheral boxes. Thus, one half of the noncatch trials involved targets presented in the same box as the cue. We refer to these trials as the *validly cued* trials. The other half of the noncatch trials involved targets that did not appear in the box that was cued. We refer to these trials as *invalidly cued* trials.

Each participant first performed a practice block of 20 trials that was not analyzed. There were eight test blocks consisting of 42 trials each (14 catch trials, 14 validly cued trials, and 14 invalidly cued trials). The target on a trial had a 50% likelihood of occurring in the box that had been cued, and this was equally likely on the right or left.

[3] It is possible that this test of the older adults' visual acuity at 14 in. (35.6 cm) overestimates somewhat their visual acuity at the 21-in. (53.3-cm) viewing distance used in this experiment.

Eye movement monitoring. Participants were instructed to fixate on the central plus sign and to detect the target using their peripheral vision. Ensuring that the participants did not move their eyes was important, because eye movements to the cue would be expected to produce facilitation (a result opposite the expected result of IOR) when the target appeared in the cued object. To ensure that fixation was maintained, all participants were monitored by the experimenter by means of visual inspection of an image from a video camera that was focused on one eye. The experimenter provided verbal feedback if it appeared that a participant was having difficulty maintaining fixation. The majority of participants (both young and old) exhibited very little difficulty maintaining fixation and did not need to be reminded to remain fixated. This was fortunate, because it was not possible to discard trials on which participants did not fixate correctly on the basis of visual monitoring. For the few who experienced some difficulty, this tended to occur during the first block of trials and typically disappeared after a single reminder from the experimenter of the importance of maintaining fixation.

Precise, quantitative monitoring of eye movements was provided by an eye position tracking system [ISCAN RK 426-PC, Iscan Inc., Cambridge, MA] for a subset of participants in each experiment. Unfortunately, the eye tracker could not be used for every participant for two reasons: (a) it was purchased after data collection had already started and (b) glare from the glass lenses of corrective eyewear (particularly bifocal and trifocal lenses) sometimes interfered with the proper functioning of the eye movement monitor. The number of participants tested and the percentage of trials on which eye movements were made are reported in the *Results* section of each experiment. Trials on which participants did not fixate correctly (eye position more than 3° from the correct position) were excluded from the analyses. Fortunately, eye movements were such a minor problem that the number of trials excluded was extremely low in all four experiments.

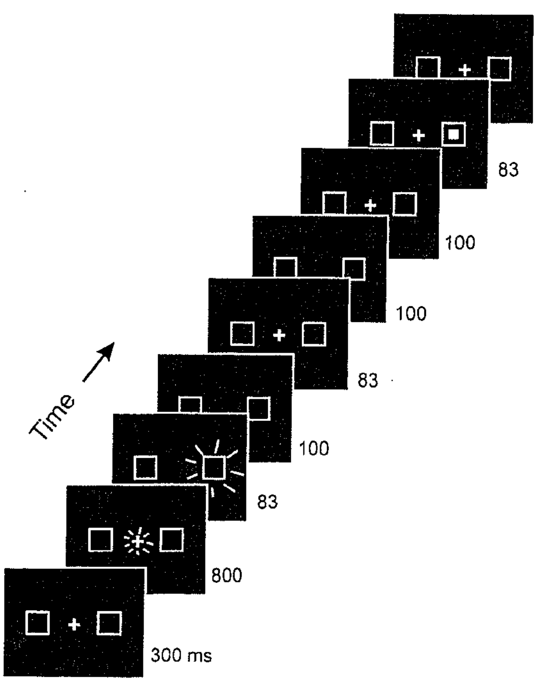

Figure 1. Sequence of events on a trial in Experiment 1. The sunbursts denote a brightening of the surrounded display element. (See text for additional explanation.)

Results and Discussion

Trials with inappropriate responses (i.e., responses on catch trials or misses on trials with targets), anticipatory responses (less than 100 ms), or delayed responses (greater than 1,500 ms) were excluded from the analyses. The percentage of trials deleted because of errors was extremely low for both groups (2% for young, 2% for old). Errors were not analyzed further. The eye position tracking system was used for a subset of 6 young adults and 6 older adults, and trials that contained eye movements were also excluded for these participants. The percentages of trials deleted because of eye movements were 5% for the young subset and 5% for the old subset. Overall the total number of trials excluded (based on both errors and eye movements) was very low (3% for younger adults, 3% for older adults). Mean reaction times for correct trials for each participant in each experimental condition were calculated, and these values were submitted to further statistical analyses.

Mean reaction times were analyzed with a 2 (age group: young or old) × 2 (trial type: validly cued vs. invalidly cued) × 2 (target location: right or left) analysis of variance (ANOVA). The data are shown in Figure 2. There was a main effect of age group, $F(1, 38) = 39.78$, $MSE = 24{,}053.2$, $p < .0001$. As expected, the older adults ($M = 472.2$ ms) were slower overall than the younger adults ($M = 317.5$ ms). There was also a main effect of trial type, $F(1, 38) = 94.00$, $MSE = 726.0$, $p < .0001$. Overall, participants were slower to respond in the validly cued condition ($M = 415.5$) than in the invalidly cued condition ($M = 374.2$), demonstrating a reliable IOR effect. The Trial Type × Age Group interaction was also significant, $F(1, 38) = 11.05$, $MSE = 726.0$, $p < .01$. Younger adults revealed a mean IOR effect (difference between validly cued and invalidly cued reaction times) of 27.7 ms, whereas older adults had a mean difference of 58.2 ms.

There was no main effect of target location, $F(1, 38) = 0.02$, $MSE = 416.8$, $p = .85$, but trial type did interact with target location, $F(1, 38) = 4.58$, $MSE = 466.7$, $p = .04$. When the cue was valid, participants were faster to respond to targets located on the left side ($M = 412.1$ ms) than on the right side ($M = 418.9$ ms). When the cue was invalid, however, participants were faster to respond to targets located on the right ($M = 370.3$ ms) than on the left ($M = 378.1$ ms). However, target location did not interact with age group, $F(1, 38) = 0.43$, $MSE = 416.8$, $p = .52$, and the Target Location × Trial Type × Age Group interaction was not significant, $F(1, 38) = 1.79$, $MSE = 466.7$, $p = .19$.

One possible explanation for the larger IOR effect in the older participants is that it is the result of the overall slower responses of the older adults. Two types of conversions were performed to examine this possibility. First, the IOR effect for each participant was computed as a proportion of his or her invalid cue latency. This type of correction would yield equivalent effect sizes (ESs) for old and young if the difference between age groups was due entirely to an overall ("general") slowing of the older participants and if the function relating old to young processing speed was a linear one with an intercept of zero (Spieler, Balota, & Faust, 1996). Although such assumptions might not be generally correct, some researchers have suggested that they are reasonably close over a limited range of latencies, such as in the present experiment (e.g., Hartley & Kieley, 1995). The results from the proportional conversion revealed that responses on valid cue trials were initiated 9% slower than responses on invalid cue trials

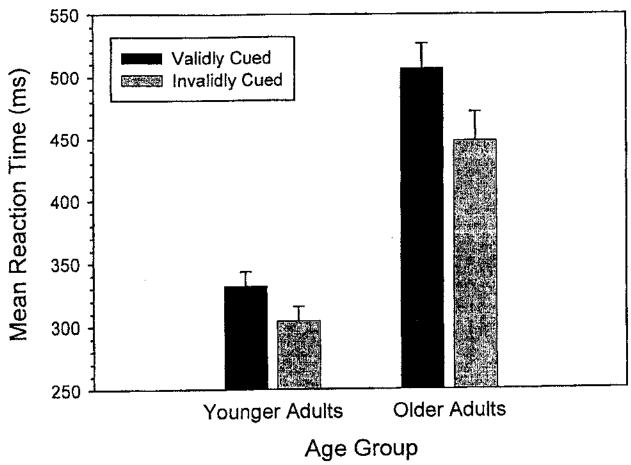

Figure 2. Mean reaction times and standard errors from Experiment 1 separately for each age group and condition. Both age groups exhibited inhibition of return (slower latencies to targets in the validly cued condition).

by the younger participants and 14% slower by the older participants. These values were significantly different from one another, $F(1, 38) = 5.01$, $MSE = 0.0$, $p < .05$. There was no main effect of target location, $F(1, 38) = 1.78$, $MSE = 0.0$, $p > .18$, and the Target Location × Age Group interaction was not significant, $F(1, 38) = 1.03$, $MSE = 0.0$, $p > .31$.

The present data were also analyzed by using a *z*-score conversion. Each participant's correct responses were first pooled together, ignoring any differences between conditions. The latencies were then converted to *z* scores based on the participant's overall mean and standard deviation. Mean *z* scores were calculated for each participant for valid cue trials and invalid cue trials, and these mean *z* scores were submitted to an ANOVA. Such *z*-score conversion converts all individual ESs to units that are relative to each individual's mean latency (e.g., Spieler et al., 1996). The results of this analysis show that there was an effect of cue validity, with participants faster on invalidly cued trials than on validly cued trials, $F(1, 38) = 116.04$, $MSE = 0.1$, $p < .0001$. There were no differences between the two age groups, $F(1, 39) = 0.38$, $MSE = 0.1$, $p > .55$, nor was there an Age × Trial Type interaction, $F(1, 38) = 2.24$, $MSE = 0.1$, $p > .13$.

Summary of Experiment 1

As expected, both younger and older adults were slower to respond to targets appearing in previously cued boxes—revealing IOR. Although the older adults demonstrated what appears to be a much larger amount of IOR (58 ms compared with 28 ms), this may be due to the fact that overall older adults were slower to respond (i.e., general slowing) than were younger adults. Indeed, the *z*-score conversion failed to permit the conclusion that the age differences reflected anything other than a general slowing. Regardless of whether the larger amount of IOR demonstrated by older adults in the present experiment can be attributed to general slowing, these results are similar to the results of Faust and Balota (1997) and Hartley and Kieley (1995) in that both young and old adults demonstrated IOR in a static environment.

Experiment 2

Because static stimuli were used in Experiment 1, the results there are believed to reflect the combined effects of both location-based and object-based IOR. This is because the cued location and cued object are identical when the objects do not move. In the present experiment, we attempted to dissociate the two components by first cuing one of two objects and then moving each of the objects to a new location. In that case, the cued objects and the location at which the cue had been presented differed. In Experiments 2 and 3 we specifically examined the object-based component of IOR. Location-based IOR was examined in Experiment 4.

Method

Participants. Two groups of 20 participants each volunteered for the experiment. The young adult group consisted of Washington University undergraduates, 11 women and 9 men, ranging in age from 18 to 21 years ($M = 19.00$, $SD = 1.00$). The older adult group, 10 women and 10 men, was obtained through Washington University's Aging and Development volunteer pool and ranged in age from 66 to 80 years ($M = 74.35$, $SD = 3.93$). All older adult participants had to pass the initial telephone screening described in Experiment 1. The older adult sample had a mean overall health rating of 7.95 ($SD = 0.92$) and a mean of 15.43 years of education ($SD = 2.57$). Visual acuity (with corrective lenses) was measured with the Rosenbaum Pocket Vision Test at a distance of 14 in. (35.6 cm). Median visual acuity for both young adults (*Mdn* = 20/20) and older adults (*Mdn* = 20/40) was well below the 20/100 necessary to discriminate the stimuli in the experiment. Each subject participated in a single session lasting less than 1 hr. The young adults participated to earn course credit, and the older adults were paid $10 for their participation.

Apparatus and procedure. The apparatus, and much of the procedure, was the same as that used in Experiment 1. The sequence of events was similar to that used by Tipper et al. (1997) and Abrams and Dobkin (1994), and is illustrated in Figure 3. At the beginning of each trial, participants saw two white boxes (0.75° × 0.75°) and a white plus sign vertically

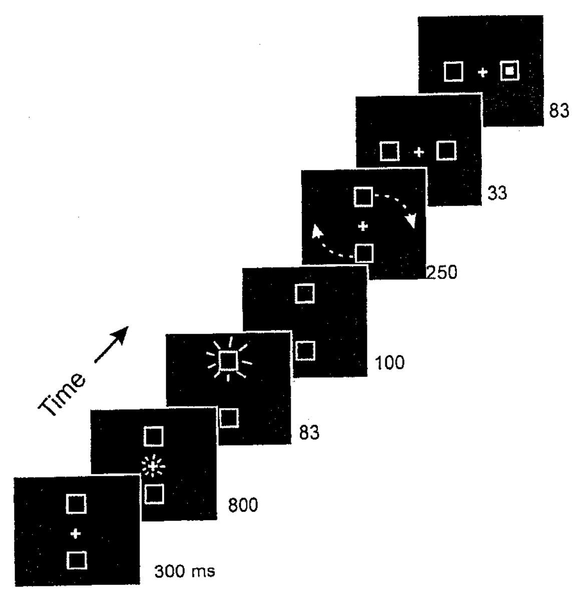

Figure 3. Sequence of events on a trial in Experiment 2. A cuing of the fixation marker 83 ms after the onset of the movement is not shown. (See text for additional explanation.)

aligned on a light gray screen. The plus sign was in the center of the display and served as a fixation marker. The two boxes flanked this plus sign on the top and bottom by 10°. The boxes appeared to be unfilled as a result of their white borders and light gray interiors.

At the start of each trial participants were required to fixate on the plus sign. Eye position was monitored visually as described in Experiment 1 to ensure that fixation was maintained throughout each trial. After 300 ms the plus sign was brightened for 800 ms and then disappeared as the cue was presented. The cue consisted of a brightening of one of the peripheral boxes for 83 ms. The plus sign reappeared 183 ms after the onset of the cue while the boxes smoothly moved 90° in a clockwise direction. This motion was accomplished by displaying the white box outlines at each of 15 equally spaced positions, each lasting 16.67 ms. The total movement time was 250 ms. The fixation marker was cued 83 ms after the onset of the movement to ensure that participants returned their attention to fixation, as was done in Experiment 1. Following the cessation of the movement and a delay of 33 ms, a target appeared on two thirds of the trials. The SOA was 467 ms, as in Experiment 1. Note that the position of each box at the time of target presentation was equidistant from the positions of each of the boxes at the time of cue presentation. Thus, any inhibition (or facilitation) to respond to targets in the cued box would be attributable to an object-based component.

One third of the trials were catch trials. When a target was presented, it was equally likely to appear in either of the two peripheral boxes. Thus, one half of the noncatch trials involved targets presented in the same box as the cue. We refer to these trials as the *cued-object* trials. The other half of the noncatch trials involved targets that did not appear in the box that was cued. We refer to these trials as *uncued* trials.

Each participant performed a practice block of 20 trials that was not analyzed. There were eight test blocks consisting of 42 trials each (14 catch trials, 14 cued-object trials, and 14 uncued trials). The target on a trial had a 50% likelihood of occurring in the box that had been cued, and this was equally likely on the right or left.

Results and Discussion

Trials with inappropriate responses (i.e., responses on catch trials or misses on trials with targets), anticipatory responses (latency less than 100 ms), or delayed responses (latency greater than 1,500 ms) were excluded from the analyses. The percentage of trials deleted because of errors was extremely low for both groups (2% for young, 3% for old). Errors were not analyzed further. The eye position tracking system was used for only 2 older adults (no data available for younger adults) and detected eye movements on only 3% of trials in one case and 1% in the other case. Overall, the total number of trials excluded for the older adults (including errors and eye movements) was very low (3%).

Mean correct reaction times were analyzed with a 2 (age group: young or old) × 2 (trial type: cued-object vs. uncued) × 2 (target location: right or left) ANOVA. Figure 4 presents the means of participants' mean response latencies for the experimental trials. There was an overall main effect of age group, $F(1, 38) = 52.49$, $MSE = 8{,}761.6$, $p < .0001$. As expected, the older adults (M = 457.5 ms) were slower overall than the younger adults (M = 314.6 ms).

There was no overall effect of trial type, but trial type did interact with age group, $F(1, 38) = 11.90$, $MSE = 191.7$, $p < .01$. As seen in Figure 4, younger adults were slower on cued-object trials than on uncued trials, demonstrating object-based IOR (M = 7.4 ms), $F(1, 19) = 12.16$, $MSE = 45.0$, $p < .01$, and this is consistent with previous results (e.g., Tipper et al., 1991). However, older adults were faster on cued-object trials compared

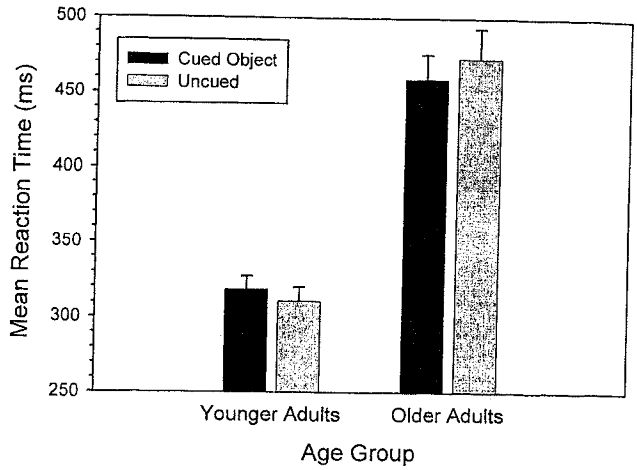

Figure 4. Mean reaction times and standard errors from Experiment 2 separately for each age group and condition. Younger adults exhibited inhibition of return but older adults were facilitated in detecting targets in the cued object.

with uncued trials, demonstrating a facilitatory effect (M = 14 ms) that was significant, $F(1, 19) = 5.76$, $MSE = 338.5$, $p < .05$. To further analyze this facilitatory effect for comparison with the results of Experiment 3, we calculated its ES by using a pooled error term. By Cohen's (1987) criteria, the facilitatory effect was large (M ES = 0.76) in this experiment.

There was also a main effect of target location. Responses to targets presented in the left box (M = 394.1 ms) were slower than to those in the right box (M = 378.0 ms), $F(1, 38) = 12.68$, $MSE = 810.2$, $p < .001$. Target location also interacted with age group, $F(1, 38) = 4.72$, $MSE = 810.2$, $p < .05$. The bias for right-sided targets was somewhat larger for older adults than for younger adults. Specifically, older adults responded 25.8 ms faster on average to targets on the right side (M = 444.6 ms) than on the left side (M = 470.4 ms). The younger adults were only 6.25 ms faster on average to targets on the right side (M = 311.5 ms) than on the left side (M = 317.7 ms). Fortunately, target location did not interact with any combination of variables containing the trial type variable (all Fs < 1.60, ps > .21).

Summary of Experiment 2

As expected, younger adults revealed a small but significant amount of object-based IOR. The more interesting finding, however, was that the older adults did not demonstrate object-based IOR but, instead, exhibited the opposite pattern of results—a significant facilitatory effect. This rather surprising result may have important implications for the brain mechanisms underlying object-based IOR and for the nature of age-related changes in those mechanisms. Although direct neuroanatomical evidence is not available and indirect evidence based on global measures does not support such age-related changes (see chapter by Raz, 2000), we cannot rule out the possibility that specific structures within the pathway mediating object-based IOR may be differentially affected by age.

However, a potential alternative explanation exists for the present results. It is possible that the older adults failed to demonstrate object-based IOR not because of an inability to produce inhibition but because they simply needed more time for the inhibition to develop. The relatively short interval that elapsed between the presentation of the cue and the target (467 ms) may not have been sufficient for them. This alternative is examined in Experiment 3.

Experiment 3

This experiment examined the possibility that the older adults failed to produce object-based IOR in Experiment 2 because the cue–target interval of 467 ms used there was too short and did not allow enough time for inhibition to develop. This explanation seems possible because there is evidence from other sources showing age-related differences in the time course of visual attention effects (i.e., Greenwood et al., 1993; Madden, 1990). In Experiment 3 we directly addressed the question by increasing the amount of time that elapsed between the presentation of the cue and the target to almost 4 s.

Method

Participants. Two groups of 30 participants each volunteered for the experiment. The young adult group consisted of Washington University undergraduates, 16 women and 14 men, ranging in age from 18 to 23 years (M = 19.53, SD = 1.78). The older adult group, 20 women and 10 men, was obtained through Washington University's Aging and Development volunteer pool and ranged in age from 67 to 77 years (M = 72.73, SD = 2.82). All older adult participants had to pass the initial telephone screening as described in Experiment 1. The older adult sample in the present experiment had a mean overall health rating of 8.60 (SD = 1.47) and a mean of 14.60 years of education (SD = 2.58). Visual acuity (with corrective lenses) was measured with the Rosenbaum Pocket Vision Test at a distance of 14 in. (35.6 cm). The median visual acuity for both young adults (Mdn = 20/20) and older adults (Mdn = 20/50) was well below the 20/100 necessary to discriminate the stimuli in the experiment. Each subject participated in a single session lasting less than 1 hr. The young adults participated to earn course credit, and the older adults were paid $10 for their participation.

Apparatus and procedure. This experiment was very similar to Experiment 2 with the exceptions noted here. After the boxes stopped moving (see Figure 3) we included delays of 33, 733, 2,033, and 3,533 ms. This resulted in SOAs of 467, 1,167, 2,467, and 3,967 ms, respectively. Note that the shortest SOA of 467 ms is the same as that used in Experiment 2.

Each participant performed a practice block of 20 trials that was not analyzed. The test trials consisted of 10 blocks of 32 trials each (i.e., 16 cued-object trials, 16 uncued trials). No catch trials were used in this experiment. In the single SOA designs used in Experiments 1, 2, and 4 catch trials were included to preclude anticipatory responses. The use of multiple SOAs in the present experiment made it unlikely that participants would anticipate the appearance of the target with any degree of accuracy. One fourth of the trials within each condition were performed at each of the four cue–target intervals. The trials were randomly ordered. The target was equally likely to appear on the left or right for both cued-object and uncued trials.

Results and Discussion

Trials with anticipatory responses (latency less than 100 ms) or delayed responses (latency greater than 1,500 ms) were excluded from the analyses. The percentage of trials deleted because of errors was extremely low for both groups (3% for young, 3% for old). Errors were not analyzed further. The eye position tracking system was used for a subset of 18 older adults (no data available for younger adults), and trials that contained eye movements were also excluded for these participants. The percentage of trials deleted because of eye movements was 9% for this older subset. There was very little difference in the number of eye movements at each of the four SOAs (467 ms: 8% of trials; 1,167 ms: 8% of trials; 2,467 ms: 9% of trials; 3,967 ms: 11% of trials). Overall, the total number of trials excluded for the older adults (based on both errors and eye movements) was very low (8%).

Mean reaction times were analyzed with a 2 (age group: young or old) × 2 (trial type: cued-object vs. uncued) × 2 (target location: right or left) × 4 (SOA: 467 ms, 1,167 ms, 2,467 ms, or 3,967 ms) ANOVA and are shown in Figure 5. There was an overall main effect of group, with younger adults (M = 369.2 ms) faster overall than the older adults (M = 485.7 ms), $F(1, 58) = 35.52$, MSE = 91,654.3, $p < .0001$. There was no main effect of trial type, $F(1, 58) < 1$, MSE = 361.7, $p = .68$. Latency also decreased with increasing SOA, $F(3, 174) = 98.18$, MSE = 4,235.4, $p < .0001$. As in Experiment 2, responses to targets located in the right box (M = 424.9 ms) were faster than to those in the left box (M = 429.9 ms), $F(1, 58) = 5.36$, MSE = 1,110.1, $p < .02$. Target position did not interact with age group nor with any combination of variables containing the trial type variable (all $Fs < 1.95$, $ps > .84$).

The Trial Type × Age Group interaction, however, was significant, $F(1, 58) = 4.03$, MSE = 388.7, $p < .05$. The simple effects of trial type, however, were not significant for either younger, $F(1, 29) = 1.07$, MSE = 4,066.1, $p = .31$, or older adults, $F(1, 29) = 1.41$, MSE = 141.4, $p = .24$. The Trial Type × Age × SOA interaction was not significant, $F(3, 174) < 1.50$, MSE = 409.7, $p = .23$. Examining the four SOAs separately, the effect of trial type was significantly different for young and old adults at the shortest SOA (467 ms), $F(1, 58) = 4.67$, MSE = 653.3, $p < .05$, but not at any of the longer SOAs (all $Fs < 0.52$, $ps > .52$). Notice that the shortest SOA (467 ms) in this experiment is identical to the SOA used in Experiment 2, and the pattern of results is also similar. Figure 5 helps to illustrate these similar patterns of results. An analysis of the simple effects at the shortest SOA (467 ms) revealed that the younger adults exhibited a significant amount of

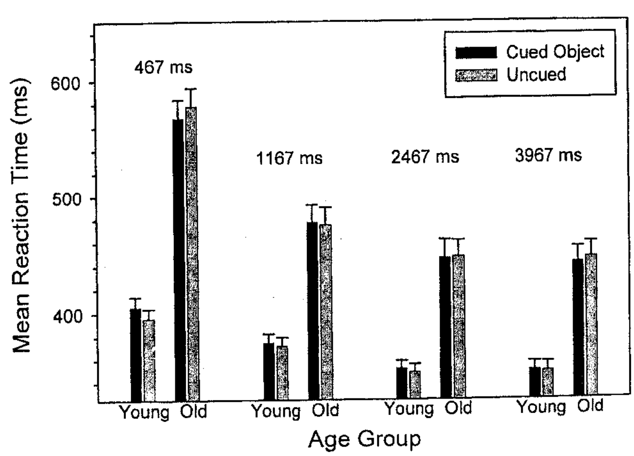

Figure 5. Mean reaction times and standard errors from Experiment 3.

object-based IOR (9.71 ms), $F(1, 29) = 5.41$, $MSE = 261.9$, $p < .05$, but the older adults did not. Note that the object-based effect was reliable for the young adults only at the shortest SOA (467 ms). For the older adults, the data were suggestive of facilitation (10.44 ms) but did not reach significance, $F(1, 29) < 1.60$, $MSE = 1{,}044.6$, $p = .22$. The fact that the older adults did not demonstrate a reliable amount of facilitation is not surprising given the multiple SOA design of this experiment, which resulted in fewer trials per condition. To further examine the facilitatory trend for the older adults at the shortest SOA, we calculated its ES by using a pooled error term. By Cohen's (1987) criteria, the size of the facilitatory trend falls between small and medium (*M* ES = .32). Obviously, the ES of the facilitatory trend in the present experiment is smaller than in Experiment 2 (*M* ES = .32 vs. *M* ES = .76) in which the older adults exhibited a reliable amount of facilitation. Thus, we do not feel confident in making the claim that the older adults exhibited facilitation in both Experiments 2 and 3. We can confidently claim, however, that the results of both experiments clearly demonstrate that the older adults did not exhibit object-based IOR at an SOA of 467 ms, but the younger adults did. In this manner, the pattern of results at the shortest SOA in the present experiment replicates that found in Experiment 2.

Summary of Experiment 3

The results from this experiment replicate and extend those of Experiment 2 for the young adults. The amount of inhibition exhibited by the young (9.71 ms) at the shortest SOA (467 ms) was very similar to that observed in Experiment 2 in which the SOA was also 467 ms (young adults, 7.39 ms of inhibition). The older adults in the present experiment also failed to produce object-based IOR, as had the older adults in Experiment 2. In addition, the present experiment helps to rule out the possibility that the older adults in Experiment 2 simply needed more time for inhibition to develop. The older adults failed to reveal object-based IOR even as the amount of time between the presentation of the cue and the target was increased up to about 4 s. Thus, the results from both Experiments 2 and 3 provide evidence of an age-related inhibitory deficit for objects.

Experiment 4

This experiment was designed to learn more about location-based IOR in young and old adults. Of the studies that have examined IOR in young and old adults (i.e., Faust & Balota, 1997; Hartley & Kieley, 1995; Tipper et al., 1997), only one (McDowd et al., 1995) has specifically examined its location-based component. For example, Faust and Balota (1997) and Hartley and Kieley (1995) were not specifically interested in separately assessing object- and location-based effects. Thus, those researchers used static paradigms in which the cued objects remained fixed on the display. Tipper et al. (1997) used a moving paradigm, in which the cued objects moved to new locations following cuing. However, those researchers were interested in assessing only the object-based component of IOR and did not include the conditions needed to measure the location-based component. McDowd et al. (1995) also used a moving paradigm but assessed both location- and object-based IOR. They found the IOR effect was greater for older adults than for younger adults, for both object- and location-based inhibition. To focus solely on the location-based component, the present experiment was designed to include only the conditions necessary to measure location-based IOR.

Method

Participants. Two groups of 20 participants each volunteered for the experiment. The young adult group consisted of Washington University undergraduates, 11 women and 9 men, ranging in age from 18 to 24 years ($M = 20.05$, $SD = 1.32$). The older adult group, 13 women and 7 men, was obtained through Washington University's Aging and Development volunteer pool and ranged in age from 70 to 80 years ($M = 73.95$, $SD = 2.94$). All older adult participants had to pass the initial telephone screening as described in Experiment 1. The older adult sample had a mean overall health rating of 7.80 ($SD = 1.44$) and a mean of 14.00 years of education ($SD = 2.24$). Visual acuity (with corrective lenses) was measured with the Rosenbaum Pocket Vision Test at a distance of 14 in. (35.6 cm). The median visual acuity for both young adults (*Mdn* = 20/20) and older adults (*Mdn* = 20/50) was well below the 20/100 necessary to discriminate the stimuli in the experiment. Each subject participated in a single session lasting less than 1 hr. The young adults participated to earn course credit, and the older adults were paid $10 for their participation.

Apparatus and procedure. The apparatus was the same as that used in the earlier experiments. Figure 6 illustrates the sequence of events on a trial in the experiment. At the beginning of each trial, participants saw four white boxes (0.75° × 0.75°) displayed on a light gray screen. A plus sign was presented in the center of the display and served as a fixation marker. The four boxes flanked the plus sign on the top, bottom, left, and right by 10°.

At the start of each trial, participants were required to fixate on the plus sign. Eye position was visually monitored to ensure that fixation was maintained throughout each trial. After 300 ms the plus sign was brightened for 800 ms and then disappeared as the cue was presented. The cue consisted of a brightening of either the right or left peripheral box for 83 ms. The plus sign then reappeared 183 ms after the onset of the cue while all four boxes smoothly moved 90° in a clockwise direction. This motion

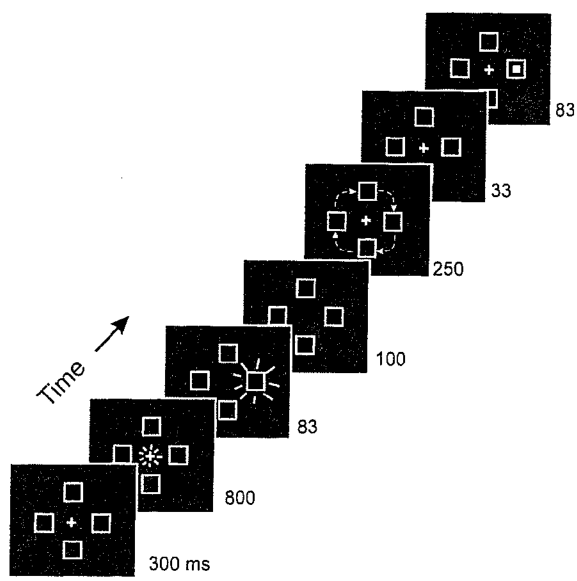

Figure 6. Sequence of events on a trial in Experiment 4. A cuing of the fixation marker 83 ms after the onset of the movement is not shown. (See text for additional explanation.)

was accomplished by displaying the boxes at each of 15 equally spaced angular positions between the vertical and horizontal orientations, each lasting 16.67 ms. Total movement time was 250 ms. The fixation marker was cued 83 ms after the onset of movement to ensure that participants returned their attention to fixation. This was accomplished by having the plus sign disappear for 100 ms and then reappear. Following the cessation of the movement and a delay of 33 ms, a target appeared on two thirds of the trials. This sequence of events yielded an SOA of 467 ms. The target consisted of a small white box (0.25° × 0.25°) presented for 83 ms in the center of either the left or right peripheral box. The participants' task was to press the space bar on the keyboard in front of them as soon as the target was presented. Participants were instructed to refrain from responding on catch trials (trials with no target). A feedback beep and the message "Too early" appeared on the screen if a participant made an anticipatory response (<100 ms) or a false alarm. Likewise, a feedback beep and the message "Too slow" appeared on the screen if participant failed to respond to a target within 2 s.

When the target was presented, it was equally likely to appear in the left or right peripheral box. Thus, one half of the noncatch trials involved targets presented at the same location as the cue (i.e., on the same side; but note that the cued object had since moved to a new location). We refer to these trials as the *cued-location* trials. The other half of the targets appeared in the location that was not cued (i.e., on the opposite side). We refer to these trials as *uncued* trials.

Each participant performed a practice block of 20 trials that was not analyzed. There were eight test blocks consisting of 42 trials each (14 catch trials, 14 cued-location trials, and 14 uncued trials). The target on a trial had a 50% likelihood of occurring in the box that had been cued, and this was equally likely on the right or left.

Results and Discussion

Trials with inappropriate responses (i.e., responses on catch trials or misses on trials with targets), anticipatory responses (latency less than 100 ms), or delayed responses (latency greater than 1,500 ms) were excluded from the analyses. The percentage of trials deleted because of errors was extremely low for both groups (2% for young, 2% for old). Errors were not analyzed further. The eye position tracking system was used for a subset of 4 young adults and 9 older adults, and trials that contained eye movements were also excluded for these participants. The percentages of trials deleted because of eye movements were 5% for the young subset and 5% for the old subset. Overall, the total number of trials excluded (based on both errors and eye movements) was very low (3% for younger adults, 5% for older adults).

Mean reaction times were analyzed with a 2 (age group: young or old) × 2 (trial type: cued-location vs. uncued) × 2 (target location: right or left) ANOVA and are illustrated in Figure 7. There was an overall main effect of age group, $F(1, 38) = 85.34$, $MSE = 10{,}600.6$, $p < .0001$. As expected, the older adults (M = 468.5 ms) were slower overall than the younger adults (M = 318.1 ms). There was also a main effect of target type, $F(1, 38) = 52.96$, $MSE = 100.4$, $p < .0001$. Overall participants were slower on cued-location trials (M = 401.7) than on uncued trials (M = 385.4), demonstrating a reliable location-based IOR effect. As in Experiments 2 and 3, there was a main effect of target location, $F(1, 38) = 19.59$, $MSE = 429.1$, $p < .001$. Responses to targets presented in the right box (M = 386.1) were faster than to targets presented in the left box (M = 400.6). Effects of target position did not interact with age group, $F(1, 38) = 0.96$, $MSE = 429.1$, p = .66, or with any combination of variables containing the trial type variable (all Fs < 1.20, ps > .28).

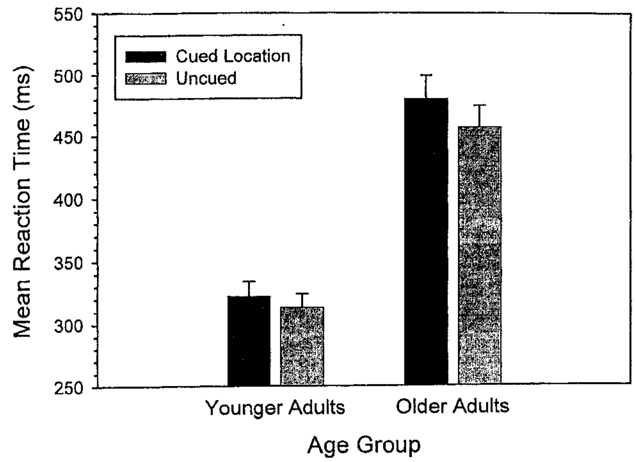

Figure 7. Mean reaction times and standard errors from Experiment 4.

As seen in Figure 7, both younger and older adults were slower to detect targets at the cued location, revealing a significant amount of location-based IOR: for young, M = 9.2 ms, $F(1, 19) = 20.43$, $MSE = 41.1$, $p < .001$; for old, M = 23.5 ms, $F(1, 19) = 31.47$, $MSE = 168.3$, $p < .001$. However, the magnitude of the inhibition was greater for the older than for the younger adults, $F(1, 38) = 10.17$, $MSE = 100.4$, $p < .01$.

Because at least part of the increased IOR may be due to the slower latencies overall exhibited by the older adults, the two types of conversions performed in Experiment 1 were also performed here. The first conversion involved computing the IOR effect for each participant as a proportion of his or her invalid cue latency. As described in Experiment 1, such a correction should equate ESs for old and young if the difference between age groups was due entirely to a "general" slowing of the older participants and if the function relating old to young processing speed was a linear one with an intercept of zero (Spieler et al., 1996). The results from the proportional conversion revealed that responses on valid cue trials were initiated 4% slower than responses on invalid cue trials by the younger participants and 5% slower by the older participants. These values, however, were not significantly different from one another, $F(1, 38) < 0.19$, $MSE = 0.0$, $p > .66$. There was also no main effect of trial type, $F(1, 38) < .14$, $MSE = 0.0$, $p > .70$, nor a Trial Type × Age Group interaction, $F(1, 38) < 0.03$, $MSE = 0.0$, $p > .83$.

A z-score conversion was also performed. Each participant's correct responses were pooled together, ignoring differences between conditions, and the latencies were then converted to z scores based on the participant's overall mean and standard deviation. Mean z scores were calculated for each participant for valid cue trials and invalid cue trials, and these mean z scores were submitted to an ANOVA. Such z-score conversion translates all individual ESs to units that are relative to each individual's mean latency (e.g., Spieler et al., 1996). The results of this analysis show that there was an effect of cue validity, with participants faster on invalidly cued trials than on validly cued trials, $F(1, 38) = 47.21$, $MSE = 0.0$, $p < .0001$. There were no differences between the two age groups, $F(1, 39) = 0.13$, $MSE = 0.0$, $p > .71$, nor was there an Age × Trial Type interaction, $F(1, 38) = 1.81$, $MSE = 0.0$, $p > .18$.

Summary of Experiment 4

As expected, both young and older adults demonstrated a significant amount of location-based IOR. The older adults demonstrated what appears to be a much larger amount of IOR (58 ms compared with 28 ms), however, the two types of conversions performed on the data suggest this may be due to the fact that overall older adults were slower to respond (i.e., general slowing) than younger adults. Regardless of whether the larger amount of IOR demonstrated by older adults in the present experiment can be attributed to general slowing, the results of the present experiment clearly show that both young and old adults produce location-based IOR.

General Discussion

We conducted four experiments to examine the effects of age on the inhibitory mechanism known as inhibition of return (IOR). Younger adults exhibited both object-based (Experiments 2 and 3) and location-based IOR (Experiment 4). Older adults, however, failed to inhibit the return of attention to previously attended objects (Experiments 2 and 3), yet they demonstrated location-based IOR (Experiment 4). This pattern of results clearly demonstrates that age has a differential effect on the two types of IOR and is consistent with the newly emerging idea that age-related inhibitory deficits are task specific rather than general (i.e., Burke, 1997; McDowd, 1997).

IOR

The present research advances our understanding of IOR in two ways. First, the study is among the first to examine IOR and age by using a moving spatial cuing paradigm and, thus, provides some of the first information regarding the effects of age on the two frames of reference of IOR. Because previous research on IOR and age has either failed to find age-related differences (e.g., Faust & Balota, 1997; Hartley & Kieley, 1995; Tipper et al., 1997) or found a greater IOR effect in older adults (e.g., McDowd et al., 1995; Tipper et al., 1997), the finding that older adults failed to exhibit object-based IOR in the present research takes on particular significance. Second, the finding that young adults exhibited both object-based and location-based IOR is particularly interesting because the existing research on this topic has produced conflicting results. Each of these findings is examined in greater depth in the discussion that follows.

IOR and Aging

The literature to date regarding the effects of age on IOR is sparse, but the findings have been relatively clear and uncontroversial. In a static environment, two studies have shown that age does not have an effect on IOR (Faust & Balota, 1997; Hartley & Kieley, 1995). In a moving environment, however, two studies have shown that age has a very clear effect (McDowd et al., 1995; Tipper et al., 1997). In the study by McDowd et al. (1995) the IOR effect was greater for older than for younger adults for both location- and object-based inhibition. A comparison of the results of the present research with those of Tipper et al. (1997) is particularly interesting. For the young adults, the results of the present study are consistent with those of Tipper et al. In particular, the amount of object-based IOR demonstrated by the young adults in the present Experiment 2 (7.39 ms) was similar to that exhibited by Tipper et al.'s young adult control group (8 ms, Experiment 1). The facilitation (13.96 ms) demonstrated by the older adults in Experiment 2, however, is inconsistent with the object-based IOR demonstrated by Tipper et al.'s older adult control group (21 ms, Experiment 2).

These inconsistencies may be attributable to differences in the older adult samples used in the present study and in Tipper et al. (1997). First, the 20 (Experiment 2) and 30 (Experiment 3) older adults sampled in the present study were considerably older (Experiment 2: M = 74 years; Experiment 3: M = 73 years) than Tipper et al.'s 9 older adult controls (i.e., M = 64 years). Second, the older adult reaction times in the present research were considerably slower (e.g., Experiment 2, M = 466 ms) than those of the older adults studied by Tipper et al. (M = 320 ms). In the present research, the mean reaction times demonstrated by the older adults (M = 466 ms) were reliably slower than those of the younger adults (M = 314 ms). In Tipper et al., however, young and old reaction times differed little (young: M = 310 ms; old: M = 320 ms). Thus, the samples of older adults in the two experiments were very different, with Tipper et al.'s older adult sample being much younger and faster than the older adult samples used in the present study. It is possible that the differences in the participants explain why the older adults in the Tipper et al. study produced patterns of IOR that were similar to those of the young adults in the present investigation. We attempted to examine this further by performing a median split on the older adult data. Unfortunately, this still produced a "younger" older adult group (n = 10) that was considerably older (M = 71 years) and slower (M = 468 ms) than Tipper et al.'s older group (M = 64 years; M = 320 ms). Thus, perhaps not surprisingly, only 1 of our "younger" older adults demonstrated a pattern indicative of object-based IOR; the remaining "younger" older adults did not. Any further comparison of the older adult samples in terms of health, visual acuity, or education is not possible because this information was not reported for the Tipper et al. sample.

Location-Based and Object-Based IOR

Regarding IOR more generally, the question of whether IOR operates at the level of both objects and locations has been a matter of some debate recently. Although several researchers have reported IOR for both objects and locations (e.g., Abrams & Dobkin, 1994; Abrams & Pratt, 2000; Jordan & Tipper, 1998; Tipper & Weaver, 1998; Tipper et al., 1994), there has also been at least one failure to replicate IOR for objects (Muller & von Muhlenen, 1996). The results of the present investigation as well as that of McDowd et al. (1995) clearly indicate the existence of both object-based and location-based IOR. In our study, the younger adults demonstrated small but reliable amounts of object-based IOR at an SOA of 467 ms in Experiments 2 and 3 (7.4 ms and 9.7 ms, respectively) and of location-based IOR in Experiment 4 (10.0 ms). Thus, despite Muller and von Muhlenen's (1996) failure to replicate object-based IOR, the results obtained in the present study and in McDowd et al. clearly support the existence of inhibition for objects consistent with the findings of Tipper et al. (1991) and others (Abrams & Dobkin, 1994; Weaver et al., 1998).

Timing

Experiment 3 was conducted to rule out the possibility that age affects the time course of IOR. The idea that inhibition might build up or dissipate more slowly for older adults has been suggested by others (Hartley & Kieley, 1995) and is consistent with work demonstrating different time courses for young and old adults in visual attention tasks (i.e., Greenwood et al., 1993; Madden, 1990). The results of the present study, however, clearly do not support this idea. In Experiment 3 the cue–target interval varied from about 0.5 to about 4 s and still the older adults did not exhibit object-based IOR. For the younger adults, the object-based IOR was present only at the shortest SOA, which is consistent with Tipper and Weaver's (1998) suggestion that object-based IOR dissipates more quickly than location-based IOR. Rapid dissipation of object-based IOR seems reasonable considering what might be involved in attending to an environment with moving objects. Although a small amount of object-based IOR might be beneficial, events change relatively quickly in a moving environment. Thus, it might be adaptive for object-based IOR to dissipate quickly in order to allow one's attention to return to a moving object if necessary. The fact that the older adults did not demonstrate object-based IOR at any time within 4 s of the initial cue, however, suggests that they truly are not able to inhibit the return of attention to moving objects.

Other Considerations

Although the discussion so far has focused on insights into aging and IOR provided by the present research, there are several alternative explanations that might also account for the obtained pattern of results. For example, if participants in the present experiments were frequently looking to the cued object, that could have produced facilitation for the cued object. The experiments in which contamination by eye movements seems most likely were Experiments 2 and 3. If the older adults were making more eye movements than were the younger adults, that could explain the finding of object-based IOR in the young adults and facilitation in the older adults in those two experiments.

Indeed, there is some evidence to suggest that older adults do move their eyes more than younger adults. For example, Faust and Balota (1997) examined IOR and found that older adults with DAT made more eye movements than healthy older adults who, in turn, made more eye movements than healthy young adults. The fact that the objects moved in the present experiments represents yet another reason to suspect that the older adults may have moved their eyes.

Because eye movements were a concern, we attempted to minimize their possible contribution. Methods used to control for the role of eye movements included (a) verbal instruction regarding the importance of maintaining fixation, (b) experimenter observation and feedback on eye movements, and (c) use of an eye position tracking system. These methods appear to have been successful because the number of eye movements produced was relatively low (e.g., only 2–9% of trials) in all four experiments. The older adults in the present research did not appear to make more eye movements than did the young adults. In fact, the eye position tracking system was used to monitor eye movements for small subgroups of young and old adults in Experiment 4, and the average number of eye movements made by the young adults (e.g., only 17.5 eye movements on 336 trials) was equivalent to that of the older adults (e.g., only 18.0 eye movements on 336 trials). In Experiment 2, older adults who were monitored for eye movement and thus had eye-movement trials removed from the analyses were compared with older adults who were not monitored for eye movement and did not have eye-movement trials removed from the analyses. Both of these groups failed to exhibit inhibition for objects. Thus, the role of eye movements in all four experiments appears to have been minimal.

Future Directions

An interesting and important question for future research is whether the larger amount of IOR that is typically found in static environments is some combination of the object- and location-based components as measured in a moving environment. IOR is typically larger in static environments than in moving environments (e.g., Tipper et al., 1994), presumably because in a static environment the cued object remains at the cued location. Thus, both sources of IOR might affect it. Researchers have typically assumed that the two components would both affect static objects (e.g., Abrams & Dobkin, 1994; Jordan & Tipper, 1998; Tipper et al., 1994).

Because evidence, albeit indirect, suggests distinct visual pathways for the representation of objects and locations (Hillyard et al., 1995; Moran & Desimone, 1985; Petersen et al., 1994; Schneider, 1995), it is reasonable to suggest that activity in these pathways might operate in tandem in a static environment where the target appears both in the originally cued location and in the originally cued object. The question thus becomes whether IOR in a static display is simply the sum of the outcome of inhibition that might arise in the separate pathways. The results of the present study clearly do not support this. Both younger and older adults exhibited larger amounts of static IOR in Experiment 1 (27.7 ms and 58.3 ms, respectively) than would be expected on the basis of the simple addition of the separate components as revealed in Experiments 2 and 4. Specifically, the older adults in the present study would be expected to demonstrate about 13 ms of IOR in a static display (adding the outcomes of Experiments 2 and 4: 10.44 ms of facilitation and 23.45 ms of location-based IOR, respectively). The younger adults in the present project would be expected to exhibit 19 ms of IOR in a static display (9.71 ms and 9.17 ms of location-based IOR, respectively).

We have recently reported results that also fail to support the suggestion that IOR in a static environment might simply be the additive combination of object- and location-based IOR in dynamic environments (Christ, McCrae, & Abrams, in press). In particular, we showed that almost all IOR may be eliminated when a cued object moves away from, but then returns to, the initially cued location. Additional research examining the relationship between static IOR and IOR for objects and locations is needed and might result in a reconceptualization of IOR.

Finally, the inclusion of older adults in future research will help clarify some of the issues raised by the present study. Research examining the effects of age on IOR in static and moving environments is needed to further clarify the effects of age on inhibitory processing. Clearly, the emerging idea that age-related deterioration in inhibitory processing is task specific is consistent with the present findings.

Conclusions

The results of the present study provide the first evidence for the existence of a differential effect of age on object- and location-based IOR. Although the older adults failed to demonstrate IOR for objects, they were clearly able to inhibit the return of attention to cued locations. Furthermore, older adults were capable of tracking a cued object that moved. These findings are consistent with the emerging idea of task-specific breakdown of inhibitory process with age. Because older adults failed to demonstrate IOR for objects, one implication of the present results is that older adults might have difficulty in performing visual searches involving moving objects or people. Overall, our results suggest that the mechanism underlying object-based IOR is impaired with age but that underlying location-based IOR is relatively resistant to degradation with age. Unfortunately, direct neuroanatomical evidence of such age-related changes is not currently available. Although indirect evidence based on global measures does not support such age-related changes (see chapter by Raz, 2000), global measures do not provide the level of detail necessary to rule out the possibility that age may differentially affect specific structures within the two pathways mediating object- and location-based IOR.

References

Abrams, R. A., & Dobkin, R. S. (1994). Inhibition of return: Effects of attentional cueing on eye movement latencies. *Journal of Experimental Psychology: Human Perception and Performance, 20,* 467–477.

Abrams, R. A., & Pratt, J. (2000). Oculocentric coding of inhibited eye movements to recently attended locations. *Journal of Experimental Psychology: Human Perception and Performance, 26,* 776–788.

Baddeley, A. (1986). *Working memory.* Oxford: Clarendon.

Burke, D. M. (1997). Language, aging, and inhibitory deficits: Evaluation of a theory. *Journal of Gerontology: Psychological Sciences, 52,* 254–264.

Christ, S. E., McCrae, C. S., & Abrams, R. A. (in press). Inhibition of return in static and dynamic displays. *Psychonomic Bulletin and Review.*

Cohen, J. (1987). *Statistical power analysis for the behavioral sciences* (Rev. ed.). Hillsdale, NJ: Erlbaum.

Connelly, S. L., & Hasher, L. (1993). Aging and the inhibition of spatial location. *Journal of Experimental Psychology: Human Perception and Performance, 19,* 1238–1250.

Faust, M. E., & Balota, D. A. (1997). Inhibition of return and visuospatial attention in healthy older adults and individuals with dementia of the Alzheimer type. *Neuropsychology, 11,* 13–29.

Greenwood, P. M., Parasuraman, R., & Haxby, J. V. (1993). Changes in visuospatial attention over the adult lifespan. *Neuropsychology, 31,* 471–485.

Hartley, A. A., & Kieley, J. M. (1995). Adult age differences in the inhibition of return of visual attention. *Psychology and Aging, 10,* 670–683.

Hasher, L., Stoltzfus, E. R., Zacks, R. T., & Rypma, B. (1991). Age and inhibition. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 17,* 163–169.

Hasher, L., & Zacks, R. T. (1988). Working memory, comprehension, and aging: A review and a new view. In G. G. Bower (Ed.), *The psychology of learning and motivation* (Vol. 22, pp. 193–225). San Diego, CA: Academic Press.

Hillyard, S. A., Mangun, G. R., Woldorff, M. G., & Luck, S. J. (1995). Neural systems mediating selective attention. In M. S. Gazzaniga (Ed.), *The cognitive neurosciences* (pp. 665–681). Cambridge, MA: The MIT Press.

Jordan, H., & Tipper, S. P. (1998). Object-based inhibition of return in static displays. *Psychonomic Bulletin and Review, 5,* 504–509.

Kieley, J. M., & Hartley, A. A. (1997). Age-related equivalence of identity suppression in the Stroop color–word task. *Psychology and Aging, 12,* 22–29.

Kramer, A. F., Humphrey, D. G., Larish, J. F., Logan, G. D., & Strayer, D. L. (1994). Aging and inhibition: Beyond a unitary view of inhibitory processing in attention. *Psychology and Aging, 9,* 491–512.

Kramer, A. F., & Weber, T. A. (1999). Object-based attentional selection and aging. *Psychology and Aging, 14,* 99–107.

Lupianez, J., Milan, E. G., & Tornay, F. J. (1997). Does IOR occur in discrimination tasks? Yes, it does, but later. *Perception & Psychophysics, 59,* 1241–1254.

Madden, D. J. (1990). Adult age differences in attentional selectivity and capacity. *European Journal of Cognitive Psychology, 2,* 229–252.

McDowd, J. M. (1997). Inhibition in attention and aging. *Journal of Gerontology: Psychological Sciences, 52,* 265–273.

McDowd, J. M., Filion, D. L., Tipper, S. P., & Weaver, B. (1995, November). *Object and environment-based IOR in young and old adults.* Paper presented at the Annual Meeting of the Psychonomic Society, Los Angeles.

Milliken, B., Joordens, S., Merikle, P. M., & Seiffert, A. E. (1998). A re-evaluation of the implications of negative priming. *Psychological Review, 105,* 203–229.

Moran, J., & Desimone, R. (1985, August). Selective attention gates visual processing in the extrastriate cortex. *Science, 229,* 782–784.

Muller, H. J., & von Muhlenen, A. (1996). Attentional tracking and inhibition of return in dynamic displays. *Perception & Psychophysics, 58,* 224–249.

Paul, S. T. (1996). Search for semantic inhibition failure during sentence comprehension by younger and older adults. *Psychology and Aging, 11,* 10–20.

Petersen, S. E., Corbetta, M., Miezin, F. M., & Shulman, G. (1994). PET studies of parietal involvement in spatial attention: Comparison of different task types. *Canadian Journal of Experimental Psychology, 48,* 319–338.

Posner, M. I., & Cohen, Y. (1984). Components of visual orienting. In H. Bouma & D. G. Bouwhuis (Eds.), *Attention and Performance X* (pp. 531–554). Hillsdale, NJ: Erlbaum.

Posner, M. I., & Petersen, S. E. (1990). The attention system of the human brain. *Annual Review of Neuroscience, 13,* 25–42.

Pratt, J., Abrams, R. A., & Chasteen, A. L. (1997). Initiation and inhibition of saccadic eye movements in younger and older adults: An analysis of the gap effect. *Journal of Gerontology: Psychological Sciences, 52,* 103–107.

Raz, N. (2000). Aging of the brain and its impact on cognitive performance: Integration of structural and functional findings. In F. I. M. Craik & T. A. Salthouse (Eds.), *Handbook of aging and cognition* (2nd ed., pp. 1–90). Mahwah, NJ: Erlbaum.

Schneider, W. X. (1995). VAM: A neuro-cognitive model for visual attention, control of segmentation, object recognition, and space-based motor action. *Visual Cognition, 2,* 331–375.

Scialfa, C. T., Garvey, P. M., Gish, K. W., Deering, L. M., & Leibowitz, H. W. (1988). Relationships among measures of static and dynamic visual sensitivity. *Human Factors, 30,* 677–687.

Shipp, S., de Jong, B. M., Zihl, J., Frackowiak, R. S. J., & Zeki, S. (1994). The brain activity related to residual motion vision in a patient with bilateral lesions of V5. *Brain, 117,* 1023–1038.

Spieler, D. H., Balota, D. A., & Faust, M. E. (1996). Stroop performance in younger adults, healthy older adults, and individuals with senile

dementia of the Alzheimer's type. *Journal of Experimental Psychology: Human Perception and Performance, 22,* 461–479.
Stoltzfus, E. R., Hasher, L., Zacks, R. T., Ulivi, M. S., & Goldstein, D. (1993). Investigations of inhibition and interference in younger and older adults. *Journal of Gerontology: Psychological Sciences, 48,* 179–188.
Sullivan, M. P., & Faust, M. E. (1993). Evidence for identity inhibition during selective attention in old adults. *Psychology and Aging, 8,* 589–598.
Sullivan, M. P., Faust, M. E., & Balota, D. A. (1995). Identity negative priming in old adults and individuals with dementia of the Alzheimer type. *Neuropsychology, 9,* 537–555.
Tipper, S. P., Driver, J., & Weaver, B. (1991). Object-centered inhibition of return of visual attention. *The Quarterly Journal of Experimental Psychology, 43A,* 289–298.
Tipper, S. P., Rafal, R. D., Reuter-Lorenz, P., Starrveldt, Y., Ro, T., Egly, R., & Weaver, B. (1997). Object-based facilitation and inhibition from visual orienting in the human split-brain. *Journal of Experimental Psychology: Human Perception and Performance, 23,* 1522–1532.
Tipper, S. P., & Weaver, B. (1998). The medium of attention: Location-based, object-centered, or scene-based? In R. Wright (Ed.), *Visual attention* (pp. 77–107). London: Oxford University Press.
Tipper, S. P., Weaver, B., Jerreat, L. M., & Burak, A. L. (1994). Object-based and environment-based inhibition of return of visual attention. *Journal of Experimental Psychology: Human Perception and Performance, 20,* 478–499.
Weaver, B., Lupianez, J., & Watson, F. L. (1998). The effects of practice on object-based, location-based, and static-display inhibition of return. *Perception & Psychophysics, 60,* 993–1003.
Yantis, S. (1996). Attentional capture in vision. In A. F. Kramer, M. G. H. Coles, & G. D. Logan (Eds.), *Converging operations in the study of visual selective attention* (pp. 45–76). Washington, DC: American Psychological Association.
Zihl, J., von Cramon, D., & Mai, N. (1983). Selective disturbance of movement after bilateral brain damage. *Brain, 106,* 313–340.
Zihl, J., von Cramon, D., & Mai, N. (1991). Disturbance of movement vision after bilateral posterior brain damage: Further evidence and follow up observations. *Brain, 114,* 2235–2252.

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Correction to Briggs et al. (1999)

The article "Age-Related Deficits in Generation and Manipulation of Mental Images: I. The Role of Sensorimotor Speed and Working Memory," by Susan D. Briggs, Naftali Raz, and William Marks (*Psychology and Aging,* 1999, Vol. 14, No. 3, pp. 427–435), contained several errors, none of which alter the conclusions of the article.

On page 431, right-hand column, the first part of the second paragraph should read (with corrected values in boldface): "The results of the analysis revealed significant main effects of age, $F(1, 83) = 29.06$, $MSE = 0.720$, $p < .001$, $\eta^2 = .26$; task difficulty, $F(3, 81) =$ **58.46**, $p < .001$, $\eta^2 = .42$; and stimulus complexity, $F(1, 83) =$ **71.61**, $MSE =$ **0.021**, $\eta^2 = .47$, $p < .001$; as well as two significant interactions: Age × Stimulus Complexity, $F(1, 83) =$ **5.95**, $MSE = 0.021$, $p < .05$, $\eta^2 = .07$, and Task Difficulty × Stimulus Complexity, $F(3, 249) =$ **27.40**, $MSE = 0.016$, $p < .001$, $\eta^2 = .10$."

On page 432, left-hand column, the second full paragraph should read (with corrected values in boldface): "Introduction of log-transformed SRT into the model changed neither the effect of age, $F(1, 82) = 24.16$, $MSE = 0.700$, $p < .001$, $\eta^2 = .23$, nor the Age × Stimulus Complexity interaction, $F(1, 82) = 8.44$, $MSE = 0.016$, $p < .05$, $\eta^2 = .09$. However, the main effect of stimulus complexity was **not** eliminated, $F(1, 82) =$ **78.27**, $MSE = 0.020$, *ns*, $\eta^2 =$ **.45,** and a significant SRT × Stimulus Complexity interaction was observed, $F(1, 82) = 4.17$, $MSE = 0.020$, $p < .05$, $\eta^2 = .06$. . . . When both covariates, SRT and WM, were entered simultaneously, their influence combined to halve the effect of age, $F(1, 81) = 11.04$, $MSE = 0.600$, $p < .01$, $\eta^2 = .12$; to eliminate the main effect of stimulus complexity, $F(1, 81) =$ **61.09**, $MSE = 0.020$, *ns*, $\eta^2 =$ **.40**; and to show a significant SRT × Stimulus Complexity interaction, $F(1, 81) = 5.20$, $MSE = 0.020$, $p < .05$, $\eta^2 = .06$."

On page 433, left-hand column, lines 3 and 4 should read (with corrected values in boldface): "**It did not reduce** the main effect of stimulus complexity, $F(1, 82) =$ **16.87**, $MSE = 0.811$, *ns*, $\eta^2 =$ **.16**."