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Aging and Temporal Patterns of Inhibition of Return

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Inhibition of return (IOR), an inhibitory component of spatial attention that is thought to bias visual search toward novel locations, is considered relatively well preserved with normal aging. We conducted two experiments to assess age-related changes in the temporal pattern of IOR. Inhibitory effects, which were strongly reflected in the performance of both younger adults (ages 18–34 years) and older adults (ages 60–79 years), diminished over a period of 5 s. The time point at which IOR began to diminish was delayed by approximately 1 s for older adults compared with younger adults; this pattern was observed on both a target detection task (Experiment 1) and a color discrimination task (Experiment 2). The finding that timing characteristics of IOR are altered by normal aging has potential implications for the manner in which inhibition aids search performance.

PEOPLE rely on spatial attention to locate goal-relevant items in the visual environment, and it is important to understand the cognitive mechanisms that underlie this ability. For example, how is it that searched locations are mentally tagged so as to prevent unnecessary reexamination? Posner and Cohen (1984) proposed that inhibition plays an important role in this tagging function. In the context of a spatial orienting study, they observed that a peripheral visual event (e.g., brightening of one of two boxes) was followed by a facilitated processing of items presented at that location, presumably as a result of a reflexive shift of attention toward the event. This facilitation occurred if the target item appeared within 300 ms of the orienting event. However, if attention was shifted either extrinsically by a visual event occurring elsewhere (e.g., brightening of a central cue) or intrinsically by a long time interval that brought attention back to fixation, an inhibitory aftereffect could be measured in terms of a delayed responding to items subsequently presented at the initial location. Posner and Cohen thought that this inhibition of return (IOR) effect functioned to bias attention toward novel locations, and Klein (1988) later proposed that IOR served to discourage reinspections during visual search, thus increasing search efficiency. Consistent with a search interpretation, subsequent studies have provided evidence that observers do indeed use inhibition when navigating complex search scenes (Klein, 1988; Klein & MacInnes, 1999; Kristjansson, 2000).

Reduced inhibitory control may account, at least in part, for age-related changes in search performance. Older adults are generally slower and more distractible than young adults during visual search, particularly on inefficient tasks that require effortful, sequential search through the display (Foster, Behrmann, & Stuss, 1995; Humphrey & Kramer, 1997; Plude & Doussard-Roosevelt, 1989). Although there is evidence that sensory changes and generalized cognitive slowing contribute to changes in search (Madden, 2001; Scialfa, 1990), attention-specific factors such as inhibition also likely contribute to it. Consistent with this idea, recent studies have found age-related changes in the time course of IOR (Castel, Chasteen, Scialfa, & Pratt, 2003; Langley, Fuentes, Hochhalter, Brandt, & Overmier, 2001). In the following sections, we review findings relevant to the timing characteristics of IOR and age differences in these effects.

Time Course of IOR

How quickly does IOR develop at a location, and how long does it last? In a recent graphical meta-analysis, Samuel and Kat (2003) addressed these questions by plotting IOR scores as a function of cue–target stimulus onset asynchrony (SOA) for studies that used a single peripheral cue (i.e., there was no central cue to extrinsically redirect attention toward fixation). Inhibited rather than facilitated orienting responses to the cued location were reliably observed as early as 300 ms and were maintained as long as 1,500 ms. However, there were few data points beyond 1,500 ms; follow-up experiments indicated that inhibitory effects lasted somewhere between 2 and 3 s.

Other research has found that although inhibition can remain at a particular location for as long as 5 s (Berlucchi, Chelazzi, & Tassinari, 2000; Danziger, Kingstone, & Snyder, 1998), the magnitude of IOR declines with increasing cue–target interval (Berlucchi et al.; Klein, 2000; Riggio, Bello, & Umilta, 1998). This temporal decline would be optimal for aiding search performance if inhibition were a limited resource; inhibition would be strongest for the most recently searched locations, and inhibition would diminish for earlier searched locations to free up resources for newly inspected sites. Studies using multiple cues have found just such a pattern; IOR could be maintained at multiple locations, but inhibition diminished in magnitude for earlier cued locations (Dodd, Castel, & Pratt, 2003; Snyder & Kingstone, 2000). Support for the idea that inhibition is resource limited can also be found in studies that report reduced negative priming (a nonspatial form of distractor inhibition) under resource-demanding conditions (Engle, Conway, Tuholski, & Shisler, 1995; Neumann & DeSchepper, 1992).

Tasks Demands and Timing of IOR

Inhibitory effects are robust on IOR tasks that require the simple detection of objects, but initial studies to examine IOR on tasks that require discrimination of target features (e.g., indicate the color or orientation of a target) failed to find IOR (Tanaka & Shimojo, 1996; Terry, Valdes, & Neill, 1994). Later studies demonstrated inhibitory effects for discrimination tasks when longer cue–target intervals were assessed, revealing that IOR developed later on discrimination tasks (e.g., 700 ms) than on detection tasks (e.g., 400 ms; Lupiáñez, Milan, Tornay, Madrid, & Tudela, 1997; Lupiáñez & Milliken, 1999; Lupiáñez, Milliken, Solano, Weaver, & Tipper, 2001). Explanations for time course differences in IOR as a function of task demands have focused on the interplay of facilitation and inhibition initiated by the peripheral cue. For example, Klein (2000) argued that the development of inhibition is delayed on discrimination tasks because discrimination requires a higher attentional control setting than detection (because of the greater difficulty with perceptual discrimination of the target). This higher setting remains relatively fixed throughout task performance and thus influences processing of the cue as well as the target. Heightened attention increases dwell time on the cue, enhancing early facilitation effects. With delayed disengagement of attention from the cue, it takes longer for facilitation effects of the cue to diminish and inhibition toward the cued location to be revealed, as compared with performance under lower control settings such as with simpler detection tasks (see Lupiáñez et al., 2001 for a similar explanation).

Aging and Temporal Patterns of IOR

Among studies that have examined age differences in the temporal patterns of IOR, in their study, Castel and colleagues (2003) found that the time point at which IOR first develops is delayed with age. On a single-cue IOR task, the cue–target SOA at which facilitated responses turned to inhibition was 222 ms for younger adults and 592 ms for older adults. Similar to the detection–discrimination explanation already described, the interpretation offered by Castel and colleagues was that the age-related delay in inhibition was due to task difficulty. Because older adults found the detection task more difficult than younger adults did, they allocated more attention for a longer duration to cued locations, delaying the onset of IOR.

Most research described to this point has used a single-cue IOR task. Another widely used IOR paradigm is the cue-back task, in which a second central cue reflexively draws attention back to fixation. The advantage of this task is that the timing of the observable shift from facilitation to inhibition in performance is less variable because the cue-back manipulation encourages extrinsic rather than intrinsic disengagement of attention from the initial cue. As a result of greater control over the development of IOR, stronger emphasis can be placed on manipulating and measuring the *duration* and *resolution* of inhibition.

The predominant pattern across aging studies that have used the cue-back task is a modest reduction in IOR at longer cue–target intervals, with a similar pattern of decline for younger and older adults (Experiment 2, Faust & Balota, 1997; Experiments 1 and 4, Hartley & Kieley, 1995). However, it is important to note that these studies used a restricted range of temporal intervals, with the longest SOA being 1,800 ms (Experiment 2, Faust & Balota). In a recent study (Langley et al., 2001), we included a cue–target interval that was sufficiently long (3,500-ms SOA) to demonstrate the resolution of IOR for younger adults. Both younger and older adults demonstrated IOR effects at the short cue–target interval (950-ms SOA). However, whereas younger adults showed a significant decline in IOR (from 42 ms to 11 ms) as the temporal interval increased, older adults showed a small *increase* in IOR (from 25 ms to 33 ms). This pattern of results suggests that the resolution of IOR is delayed or altered with age.

The Present Study

Our purpose in the present study was to further explore age differences in the temporal maintenance and resolution of IOR. We were interested in (a) the time point at which IOR begins to diminish for younger and older adults, (b) how long IOR is maintained in each age group, and (c) whether age differences in the IOR time course varied with task demands. To this end, we assessed IOR on a cue-back task at four cue–target intervals (SOAs of 950, 2,200, 3,450, and 4,700 ms). We chose these intervals because they would be sufficiently long to observe dissipation and resolution of IOR effects. Participants completed a detection task in Experiment 1 and a color discrimination task in Experiment 2.

We based our predictions for age and task differences in the time course on an attentional control setting theory (Klein, 2000) as applied to a cue-back task. We reasoned that control settings influence processing of the second central cue as well as the initial peripheral cue. The central cue serves to disengage attention from the cued location, which encourages inhibition rather than facilitation of attention at that location. Higher control settings may enhance facilitation effects of the peripheral cue, but this facilitation will be tempered by extrinsic reorienting toward the central cue. When attention returns to the central fixation, higher control settings will enhance engagement of the central cue. We hypothesized that this increased engagement at fixation would intensify inhibition at the initially cued location, which would be reflected in longer maintenance of IOR.

Because older adults would perceive both the detection and discrimination tasks to be more difficult than younger adults would, we predicted that older adults would have higher attentional control settings than younger adults. As a result, IOR would be maintained longer for older adults than younger adults, and this pattern would generalize to both the detection and discrimination tasks. Pertaining to task difficulty, both younger and older adults would have higher control settings for the more difficult discrimination task, so IOR would be maintained more strongly on the discrimination task than on the detection task.

Experiment 1

Methods

Participants

Participants were 32 younger adults (19 women, 13 men) and 32 older adults (21 women, 11 men). Screening and demographic data are provided in Table 1. Younger adults, in the age range of 18–32 years, were students in psychology courses at North Dakota State University who received extra credit for participating. Older adults, in the age range of 61–79 years, were residents from the Fargo–Moorhead community

Table 1. Participant Characteristics for Experiments 1 and 2

	Exp. 1: Detection				Exp. 2: Discrimination			
	M		*SD*		*M*		*SD*	
	YA	OA	YA	OA	YA	OA	YA	OA
Age (years)	19.9*	69.4	2.6	5.2	21.0*	68.6	3.6	5.9
Education (years)	13.8*	15.3	1.3	3.0	14.3	15.1	1.4	2.9
WASI	61.0*	70.4	5.8	4.7	60.8*	69.1	6.6	6.4
Snellen acuity	15.1*	21.9	2.8	5.0	15.4*	23.1	3.1	6.5
Color vision	10.4	10.6	0.7	0.6	10.6	10.6	0.6	0.7
MMSE	29.4	29.5	0.7	1.0	29.6	29.5	0.7	0.7
GDS	1.4	1.3	1.9	1.9	2.1	1.4	2.7	2.0

Notes: YA = younger adult group; OA = older adult group; *SD* = standard deviation. WASI = Wechsler Abbreviated Scale of Intelligence (Wechsler, 1999); the maximum score on the vocabulary subscale is 80 points, with a higher score indicating better performance. Snellen acuity = denominator of the Snellen fraction (20/ __) for corrected near vision; a smaller number indicates better vision. Color vision was assessed with the Ishahara color plates; the maximum score is 11, with a higher score indicating better color vision. MMSE = Mini-Mental State Examination; the maximum score is 30 points, with a higher score indicating better performance. GDS = Geriatric Depression Scale; the maximum score is 30, with a higher score indicating more depressive symptoms. An asterisk indicates that mean scores differed between age groups according to an independent *t* test, $p < .05$.

who received $20. All participants had at least a high school education. According to self-reports on a health screening questionnaire (Christensen, Moye, Armson, & Kern, 1992), all participants were free of medical conditions that could impair cognitive functioning (e.g., heart disease, stroke, neurological diseases such as Parkinson's or Alzheimer's disease, drug or alcohol abuse). Corrected near visual acuity was 20/40 or better as assessed with a Snellen eye chart (Precision Vision, La Salle, IL), and color vision was normal (9 points or higher out of 11) as assessed with Ishahara color plates (Kanehara Trading Inc., Tokyo, Japan). All participants scored 9 points or lower on the Geriatric Depression Scale (Yesavage & Brink, 1983), indicating minimal depressive symptomatology, and 26 points or higher on the Mini-Mental State Examination (Folstein, Folstein, & McHugh, 1975), indicating no observable signs of dementia or cognitive impairment. We excluded an additional 12 participants (4 younger adults and 8 older adults) from the data analysis for failing to meet the aforementioned inclusion criteria.

Materials and Stimuli

Stimuli were displayed on a 17-in. (43.18 cm) color monitor controlled by a personal computer with a Pentium 4 processor. Responses were made on a Model 200A five-button PST Serial Response Box (Psychology Software Tools, Pittsburgh, PA), and a chin rest maintained the participant's viewing distance at 40 cm.

We created the experimental task by using E-Prime, Version 1.1 (Psychology Software Tools). We had stimuli presented against a black background in three white unfilled boxes arranged vertically in the center of the screen. The boxes subtended visual angles of 2.2° in width by 2.9° in height, and the centers were separated by 4.7°. Target stimuli consisted of red and green Xs, shown in Arial font, subtending visual angles of 1.0° squared.

With two levels of cue–target relation (cued and uncued) and four levels of cue–target interval (SOAs of 950, 2,200, 3,450, and 4,700 ms), there were eight conditions. There were 24 trials per condition, which resulted in 192 cue–target trials. The inclusion of 48 catch trials (20% of trials), in which a cue was presented without an accompanying target, led to a total of 240 test trials. We divided trials into three blocks of 80 test trials (64 target trials and 16 catch trials). Each block consisted of two iterations of the 32 unique trials produced from all possible combinations of cue location (top–bottom), target location (top–bottom), target color (red–green), and cue–target interval (950, 2,200, 3,450, and 4,700 ms). Similarly, the 16 catch trials per block contained 8 trials for each of the top and bottom cue locations.

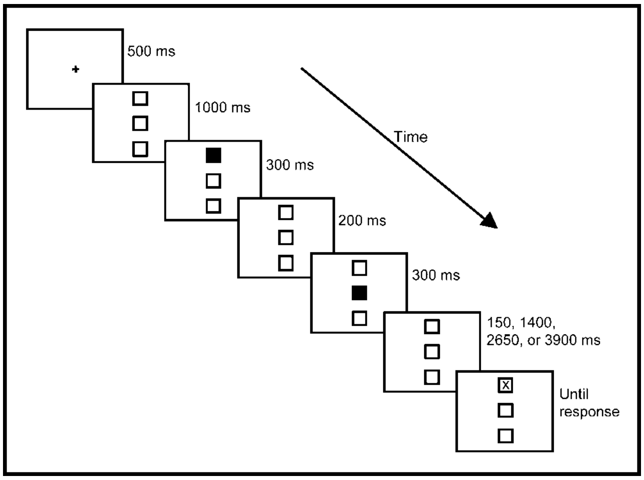

Figure 1. Sequence of events for a sample trial in Experiments 1 and 2. Stimuli are not scaled to size. In the experiment, white outlined boxes were presented against a black background, and the target "X" was printed in red or green. In Experiment 1 (detection trials), participants pressed a single button as soon as they detected the target. In Experiment 2 (discrimination trials), participants pressed one of two buttons to indicate the color of the target.

Procedure

The session lasted approximately 1 hr for younger participants and 1.5 hr for older participants. The experimenter explained the task to participants by using verbal instructions and a drawn representation of stimulus events. Test trials were preceded by 20 practice trials. The trial sequence, as outlined in Figure 1, began with a fixation cross presented for 500 ms that was replaced by three white boxes that stayed on the screen for the remainder of the trial. After 1,000 ms, the top or bottom box filled to white for 300 ms, serving as the initial spatial cue. The boxes reverted to white outline and black fill for 200 ms before the center box filled to white for 300 ms (the central cue). An interval corresponding to a cue–target SOA of 950, 2,200, 3,450, or 4,700 ms was presented before the target stimulus appeared at either the location of the initial cue (the cued condition) or the other peripheral box (the uncued condition). The target remained on the screen until the participant responded or 10 s had elapsed. On catch trials, we interposed an SOA of 6,800 ms before the fixation display of the next trial. The experimenter instructed participants to press the center

Table 2. Mean RTs and Error Rates as a Function of Age Group, SOA, and Target Location for Experiments 1 and 2

	Exp. 1: Detection				Exp. 2: Discrimination			
	YA		OA		YA		OA	
SOA (ms)	C	U	C	U	C	U	C	U
RT *M*s (ms)								
950	393*	374	475*	447	583*	567	771*	756
2,200	390*	381	461*	434	596*	572	787*	756
3,450	396	394	454*	442	591	593	799*	771
4,700	406	400	464*	450	608	602	809	812
RT *SD*s								
950	58	65	58	58	130	131	207	219
2,200	58	60	61	61	154	136	230	218
3,450	67	72	59	65	144	142	222	222
4,700	71	68	64	59	155	153	230	219
Error *M*s (%)								
950	0.3	0.3	0.1	0.0	2.4	1.8	1.8	1.1
2,200	0.3	0.4	0.0	0.0	1.3	1.8	1.2	0.6
3,450	0.3	0.0	0.1	0.1	2.2	2.2	1.3	1.2
4,700	0.1	0.1	0.0	0.0	2.5	2.8	1.3	1.5

Notes: RT = reaction time; SOA = stimulus onset asynchrony between the initial cue and target; YA = younger adults; OA = older adults; C = cued location; U = uncued location; *SD* = standard deviation. An asterisk indicates that the mean cued RT varied significantly from the uncued RT by *t* test, $p < .05$.

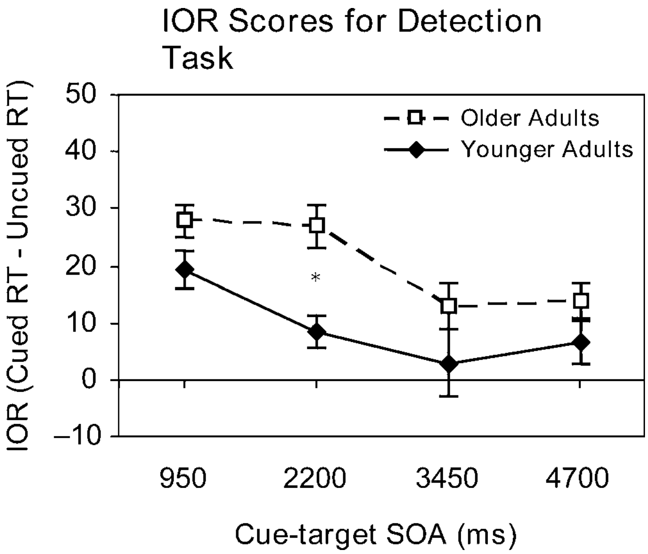

Figure 2. Mean inhibition of return (IOR) scores (± 1 *SE*) as a function of age group and cue–target SOA for the target detection task of Experiment 1. The IOR score is equal to the cued reaction time (or RT) minus the uncued RT. An asterisk indicates a significant difference between age groups in IOR score as indicated by *t* test, $p < .05$.

button of the response box with the index finger of their dominant hand as soon as they detected the target. Speed was emphasized but not at the expense of accuracy. The experimenter told the participants to keep their gaze focused on the center box for the duration of the trial. No information was provided on the validity of the cue.

Results

Reaction Time

We removed two types of outliers: reaction time (RT) values that were less than 150 ms or more than 2,000 ms, and RTs that differed from an individual participant's cell mean (for each combination of task condition) by more than 2.5 *SD*. This approach eliminated 3.0% of trials for younger adults and 2.3% of trials for older adults. Table 2 displays the mean RTs for correct trials.

A 2 × 4 × 2 mixed analysis of variance (ANOVA) with age group (younger adults and older adults) as the between-subjects factor and cue–target SOA (950, 2,200, 3,450, and 4,700 ms) and target location (cued and uncued) as the within-subjects factors revealed all main effects to be significant: age group, $F(1, 62) = 17.19$, $p < .0001$, $\eta_p^2 = .22$; SOA, $F(3, 186) = 5.28$, $p < .01$, $\eta_p^2 = .08$; and target location, $F(1, 62) = 109.09$, $p < .0001$, $\eta_p^2 = .64$. Older adults were slower than younger adults (453 vs 392 ms, respectively), and RTs at the 4,700-ms SOA (430 ms) were significantly slower than those at the 2,200-ms SOA (416 ms). The IOR effect (Figure 2) was evidenced by slower responses in the cued condition than in the uncued condition (430 vs 415 ms, respectively). In addition to main effects, there were significant two-way interactions of SOA × Location, $F(3, 186) = 7.44$, $p < .0001$, $\eta_p^2 = .11$, and Group × Location, $F(1, 62) = 15.20$, $p < .001$, $\eta_p^2 = .20$, reflecting modulation of IOR effects. The three-way Group × SOA × Location interaction was not significant, $p > .40$.

To examine the two-way interactions, we calculated IOR effects for each participant by subtracting uncued RTs from cued RTs. [To address the possibility that age differences in IOR effects were due in part to generalized slowing, we also computed individuals' IOR effects as a percentage of their uncued RT by using this formula: (cued RT − uncued RT)/uncued RT × 100. The statistical significance patterns, for both Experiments 1 and 2, did not differ as a function of the type of IOR change score.] As assessed by Bonferroni-corrected *t* tests, the SOA × Location interaction was due to IOR effects that were significantly greater at the 950-ms SOA (24 ms) than at the 3,450-ms or 4,700-ms SOAs (8 ms and 10 ms, respectively). The Group × Location interaction was due to significantly greater IOR effects for older adults (20 ms) than for younger adults (9 ms). One-way ANOVAs conducted at each SOA revealed that the only cue–target interval for which age differences in IOR were significant was the 2,200-ms SOA, $F(1, 62) = 12.23$, $p < .001$, $\eta_p^2 = .21$.

As a final analysis, we examined the time point at which IOR effects resolved. Older adults' IOR effects were significantly greater than zero (as measured by individual *t* tests) at all four SOAs, *t*s > 3.0, *p*s < .01. Younger adults' IOR effects were significantly greater than zero at the two shortest SOAs (950 ms and 2,200 ms), *t*s > 3.0, *p*s < .01, but not at the two longest SOAs (3,450 ms and 4,700 ms), *t*s < 2.0, *p*s > .05.

Errors

Error rates are presented in Table 2. Anticipation responses (responding before the target was presented) and response failures (failing to respond after the target was presented) were rare (less than 1% for each age group). Thus, we conducted no further analyses.

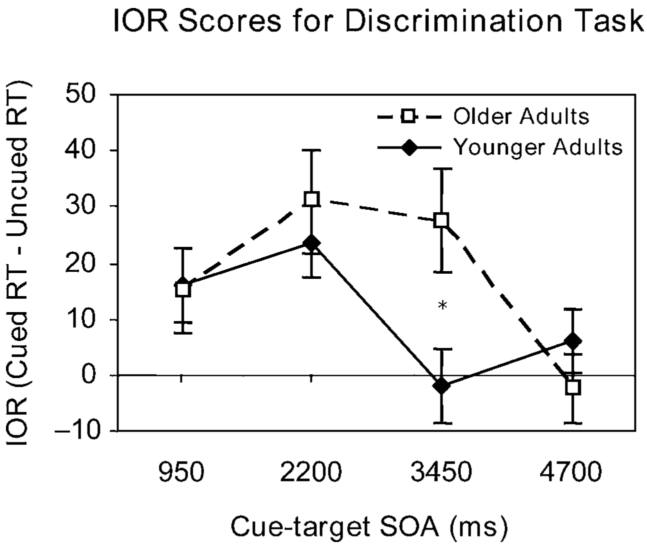

Figure 3. Mean inhibition of return (IOR) scores ($\pm$ 1 *SE*) as a function of age group and cue–target SOA for the color discrimination task of Experiment 2. The IOR score is equal to the cued reaction time (or RT) minus the uncued RT. An asterisk indicates a significant difference between age groups in IOR score as indicated by *t* test, $p < .05$.

Discussion

The two main findings of Experiment 1 were these: first, IOR effects diminished with increasing cue–target delay; second, IOR effects were greater for older adults than for younger adults. As we predicted, these findings together suggest that resolution of IOR was delayed with age. In fact, IOR effects had resolved between 2 and 3 s for younger adults but could still be observed in the performance of older adults at 4.5 s. In addition, age differences in IOR magnitude were most apparent at 2 s (2,200-ms SOA), a time point at which IOR had begun to diminish for younger but not older adults. Overall, the results of Experiment 1 suggest that timing is an aspect of IOR that changes with age.

Experiment 2

In Experiment 1, we found the predicted age-related delay in the resolution of IOR on a target detection task. Our purpose in Experiment 2 was to determine if this age effect would be replicated or even exaggerated on a color discrimination task, in which task difficulty (and presumably the attentional control setting) is increased. We used the same IOR trial sequence as in Experiment 1, but now we asked participants to make a two-choice color discrimination response. We predicted that the diminishment of IOR effects would be delayed compared with that observed in Experiment 1, as a result of the increased task difficulty (and thus, higher attentional control settings) of a color discrimination task as compared with a target detection task. We also predicted that older adults would again demonstrate a slower-resolving pattern of IOR than younger adults, and this age difference may be accentuated on this task as compared with the detection task because of increased age differences in perceived task difficulty (and thus greater discrepancies in attentional control settings).

Methods

Participants

Participants were 28 younger adults (12 men, 16 women; ages 18–34 years) and 28 older adults (8 men, 20 women; ages 60–79 years); demographic and screening data are reported in Table 1. None of the participants had taken part in Experiment 1. We excluded an additional 9 participants (1 younger adult and 8 older adults) for failing to meet inclusion criteria.

Materials and Procedure

The materials, stimuli, and procedures were identical to those described in Experiment 1, except that the experimenter instructed participants to press one of two buttons to indicate the color of the target (red or green). We counterbalanced button assignment across participants.

Results

Reaction Time

Removal of RT outliers (RT $<$ 150 ms, RT $>$ 2,000 ms, or RT $>$ 2.5 *SD* from the condition mean) eliminated 2.7% of trials for younger adults and 3.0% of trials for older adults. Mean RTs for correct trials are presented in Table 2.

A $2 \times 4 \times 2$ mixed ANOVA revealed all main effects to be significant: age group, $F(1, 54) = 15.59$, $p < .001$, $\eta_p^2 = .22$; cue–target SOA, $F(3, 162) = 19.19$, $p < .0001$, $\eta_p^2 = .26$; and target location, $F(1, 54) = 26.08$, $p < .0001$, $\eta_p^2 = .33$. Older adults were slower than younger adults (783 and 589 ms, respectively), and RTs increased as SOA did (669, 678, 688, and 708 ms for SOAs of 950, 2,200, 3,450, and 4,700 ms, respectively). The IOR effect was evidenced by slower responses to targets at the cued location compared with the uncued location (693 vs 679 ms, respectively).

In addition to main effects, there was a significant two-way SOA $\times$ Location interaction, $F(3, 162) = 4.62$, $p < .01$, $\eta_p^2 = .08$, which was qualified by a three-way Age $\times$ SOA $\times$ Location interaction, $F(3, 162) = 2.78$, $p < .05$, $\eta_p^2 = .05$. To examine the three-way interaction, we again calculated IOR effects by using difference scores (Figure 3). For older adults, IOR effects at 2,200 ms and 3,450 ms were significantly greater than IOR effects at 4,700 ms, $F(3, 81) = 3.69$, $p < .05$, $\eta_p^2 = .12$. For younger adults, IOR effects at 2,200 ms were significantly greater than IOR effects at 3,450 ms, $F(3, 81) = 3.72$, $p < .05$, $\eta_p^2 = .12$. One-way ANOVAs at each SOA revealed significant age differences in IOR at 3,450 ms, $F(1, 54) = 6.86$, $p < .05$, $\eta_p^2 = .11$, with greater IOR effects for older adults, but not at the other three SOAs.

As measured by individual *t* tests, older adults' IOR scores were significantly greater than zero at the three shortest SOAs, *t*s $>$ 2.4, *p*s $<$ .05, but younger adults' IOR scores were significantly greater than zero only at the two shorter SOAs, *t*s $>$ 2.8, *p*s $<$ .01.

Errors

Error rates are presented in Table 2. Combining the various types of errors (anticipation responses, failures to respond, and incorrect responses), we found that error rates were less than 3% for each age group; therefore, we did not conduct further analyses.

Discussion

Both younger and older adults demonstrated robust inhibitory effects on the color discrimination task, with diminishing IOR as cue–target interval increased. Replicating Experiment 1, we found that there were age differences in the temporal pattern of IOR. Whereas IOR effects began to diminish after 2,200 ms for younger adults, no such decline began until after 3,450 ms for older adults, resulting in an age-related increase in IOR at 3.5 s postcue. Thus, in both experiments, older adults maintained inhibition approximately 1 s longer than did younger adults. The findings differ from those of Experiment 1 in the time point at which IOR began to decline; reductions in IOR for both age groups began approximately 1 s later on the discrimination task (Experiment 2) than on the detection task (Experiment 1). There was no clear evidence that the age difference in the timing of IOR was accentuated on the discrimination task as compared with the detection task.

Table 3. IOR Effects as a Function of Task and SOA for Younger and Older Adults

	Younger Adults		Older Adults	
SOA (ms)	Detect	Discrim.	Detect	Discrim.
IOR *M*s (ms)				
950	19	16	28	15
2,200	8*	24	27	31
3,450	3	−2	13	28
4,700	7	6	14*	−3
IOR *SD*s				
950	19	35	17	40
2,200	15	33	21	48
3,450	33	34	23	48
4,700	21	30	17	32

Notes: Inhibition of return (IOR) effects = cued reaction time minus uncued reaction time; SOA = stimulus onset asynchrony between the initial cue and target; Detect = detection task (Experiment 1); Discrim. = discrimination task (Experiment 2); *SD* = standard deviation. An asterisk indicates that the magnitude of IOR effects varied significantly between tasks as indicated by *t* test, $p < .05$.

General Discussion

If inhibition is a limited resource (Engle et al., 1995), a desirable temporal profile for IOR would be one in which inhibition develops quickly for a searched location and then dissipates gradually to make resources available for subsequently searched locations. The results of Experiments 1 and 2 were consistent with this pattern; IOR effects were robust at early cue–target intervals and then diminished over a course of 5 s. As predicted, the time point at which IOR began to decline was delayed by age, and this pattern was observed on both a detection and a discrimination task. This age-related change in the *resolution* of IOR was consistent with past findings (Langley et al., 2001) and complimented single-cue findings of age differences in the *development* of IOR (Castel et al., 2003).

This study revealed age differences in spatial-based inhibition that might not have been observed on an IOR task measured at a single temporal interval. In fact, inhibitory effects at the shortest cue–target interval (950 ms), an interval at which IOR effects are commonly examined, did not vary by age on either task. Age effects were only revealed in terms of the length of time that inhibition remained at a particular location. With a cue-back task we were able to observe age differences in the *maintenance* of IOR, whereas research with a single-cue task has revealed age differences in the *development* of IOR (Castel et al., 2003). Together, the results call into question the conclusion that spatial variants of inhibition are relatively unaffected by age, and the findings could have important implications for how effectively inhibition aids older adults' search performance in cluttered visual displays. On the one hand, slower-developing and longer-lasting inhibition may be beneficial to older adults. With age-related slowing in search rates, older adults search fewer locations in a particular period of time, and delayed diminishment in IOR reduces the chances of premature return of attention to a location. On the other hand, if inhibition is a limited resource, then longer-lasting IOR for a particular location means that fewer locations can be simultaneously inhibited. If this is the case, then the effectiveness with which inhibition contributes to the search performance of older adults could be compromised by delayed timing. Thus, although this study revealed age differences in the resolution of IOR, it is for future studies to determine whether this difference represents an adaptive change to accommodate older adults' slower search rates or a sign of decline in the effectiveness with which inhibition assists search.

With regard to task difficulty, we predicted enhanced inhibitory effects on the discrimination task as compared with the detection task. To more directly evaluate support for this prediction, we compared task differences in IOR patterns across the two experiments; the results are reported in Table 3. For younger adults, IOR effects had resolved by 3,450 ms on both tasks, but the magnitude of IOR was significantly greater on the discrimination task than on the detection task at 2,200 ms. For older adults, there was a nonsignificant trend for IOR effects to be greater for discrimination than detection at 3,450 ms ($p =$ .13), but contrary to predictions, IOR was greater on the detection task than the discrimination task at the longest SOA (4,700 ms). Thus, there was mixed support for enhanced IOR effects on the discrimination task. Although IOR on the discrimination task maintained its magnitude longer (particularly for younger adults), it was resolved just as quickly, if not more quickly, than IOR on the detection task. However, this pattern must be interpreted cautiously, as data from separate experiments were compared.

Consistent with Klein (2000), we argue that attentional control settings moderated the observed influence of age and task demands on temporal patterns of inhibition. Control settings were adjusted on the basis of the perceived demands of the task; older adults perceived both detection and discrimination tasks to be more difficult than did younger adults, and both age groups perceived discrimination tasks to be more difficult than detection tasks. With a cue-back task, we hypothesized that a higher control setting enhanced processing of the central cue, leading to stronger inhibitory orienting toward the initially cued location. The finding that IOR maintained its peak magnitude longer (a) for older adults compared with younger adults and (b) for discrimination tasks compared with detection tasks supports a control settings interpretation. The finding of age-related temporal delays in IOR on both the detection and discrimination tasks suggests that age and task demands uniquely contributed to attentional control settings.

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References

Berlucchi, G., Chelazzi, L., & Tassinari, G. (2000). Volitional covert orienting to a peripheral cue does not suppress cue-induced inhibition of return. *Journal of Cognitive Neuroscience, 12*, 648–663.

Castel, A. D., Chasteen, A. L., Scialfa, C., & Pratt, J. (2003). Adult age differences in the time course of inhibition of return. *Journal of Gerontology: Psychological Sciences, 58B*, P256–P259.

Christensen, K. J., Moye, J., Armson, R. R., & Kern, T. M. (1992). Health screening and random recruitment for cognitive aging research. *Psychology and Aging, 7*, 204–208.

Danziger, S., Kingstone, A., & Snyder, J. J. (1998). Inhibition of return to successively stimulated locations in a sequential visual search paradigm. *Journal of Experimental Psychology: Human Perception and Performance, 24*, 1467–1475.

Dodd, M. D., Castel, A. D., & Pratt, J. (2003). Inhibition of return with rapid shifts of attention: Implications for memory and visual search. *Perception and Psychophysics, 65*, 1126–1135.

Engle, R. W., Conway, A. R. A., Tuholski, S. W., & Shisler, R. J. (1995). A resource account of inhibition. *Psychological Science, 6*, 122–125.

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.

Folstein, M. F., Folstein, S. E., & McHugh, P. R. (1975). Mini-Mental State: A practical method for grading the cognitive state of the patient for the clinician. *Journal of Psychiatric Research, 12*, 189–198.

Foster, J. K., Behrmann, M., & Stuss, D. T. (1995). Aging and visual search: Generalized cognitive slowing or selective deficit in attention? *Aging and Cognition, 2*, 279–299.

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

Humphrey, D. G., & Kramer, A. F. (1997). Age differences in visual search for feature, conjunction, and triple-conjunction targets. *Psychology and Aging, 12*, 704–717.

Klein, R. M. (1988). Inhibitory tagging system facilitates visual search. *Nature, 334*, 430–431.

Klein, R. M. (2000). Inhibition of return. *Trends in Cognitive Sciences, 4*, 138–147.

Klein, R. M., & MacInnes, W. J. (1999). Inhibition of return is a foraging facilitator in visual search. *Psychological Science, 10*, 346–352.

Kristjansson, A. (2000). In search of remembrance: Evidence for memory in visual search. *Psychological Science, 11*, 328–332.

Langley, L. K., Fuentes, L. J., Hochhalter, A. K., Brandt, J., & Overmier, J. B. (2001). Inhibition of return in aging and Alzheimer's disease: Performance as a function of task demands and stimulus timing. *Journal of Clinical and Experimental Neuropsychology, 23*, 431–446.

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

Lupiáñez, J., & Milliken, B. (1999). Inhibition of return and the attentional set for integrating versus differentiating information. *Journal of General Psychology, 126*, 392–418.

Lupiáñez, J., Milliken, B., Solano, C., Weaver, B., & Tipper, S. P. (2001). On the strategic modulation of the time course of facilitation and inhibition of return. *The Quarterly Journal of Experimental Psychology, 54A*, 753–773.

Madden, D. J. (2001). Speed and timing of behavioral processes. In J. E. Birren & K. W. Schaie (Eds.), *Handbook of the psychology of aging* (5th ed., pp. 288–312). San Diego, CA: Academic Press.

Neumann, E., & DeSchepper, B. G. (1992). An inhibition-based fan effect: Evidence for an active suppression mechanism in selective attention. *Canadian Journal of Psychology, 46*, 1–40.

Plude, D. J., & Doussard-Roosevelt, J. A. (1989). Aging, selective attention, and feature integration. *Psychology and Aging, 4*, 98–105.

Posner, M. I., & Cohen, Y. (1984). Components of visual orienting. In H. Bouma & D. G. Bowhuis (Eds.), *Attention and performance X* (pp. 531–556). Hillsdale, NJ: Erlbaum.

Riggio, L., Bello, A., & Umilta, C. (1998). Inhibitory and facilitatory effects of cue onset and offset. *Psychological Research, 61*, 107–118.

Samuel, A., & Kat, D. (2003). Inhibition of return: A graphical meta-analysis of its time course and an empirical test of its temporal and spatial properties. *Psychonomic Bulletin and Review, 10*, 897–906.

Scialfa, C. T. (1990). Adult age differences in visual search: The role of non-attentional processes. In J. T. Enns (Ed.), *The development of attention: Research and theory. Advances in psychology, 69* (pp. 509–526). Amsterdam: North-Holland.

Snyder, J. J., & Kingstone, A. (2000). Inhibition of return and visual search: How many separate loci are inhibited? *Perception and Psychophysics, 62*, 452–458.

Tanaka, Y., & Shimojo, S. (1996). Location vs. feature: Reaction time reveals dissociation between two visual functions. *Vision Research, 36*, 2125–2140.

Terry, K. M., Valdes, L. A., & Neill, W. T. (1994). Does "inhibition of return" occur in discrimination tasks? *Perception and Psychophysics, 55*, 279–286.

Wechsler, D. (1999). *Wechsler Abbreviated Scale of Intelligence.* San Antonio, TX: The Psychological Corporation.

Yesavage, J. A., & Brink, T. L. (1983). Development and validation of a geriatric depression screening scale: A preliminary report. *Journal of Psychiatric Research, 17*, 37–49.

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