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Inhibition of Return in Aging and Alzheimer's Disease: Performance as a Function of Task Demands and Stimulus Timing

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ABSTRACT

Inhibition of return (IOR) is a phenomenon of spatial attention that biases attention toward novel events in the environment. Recent evidence suggests that the magnitude and timing of IOR varies as a function of task conditions (e.g., detection vs. discrimination tasks, short vs. long cue-target intervals, intrinsic vs. extrinsic cues). Although IOR appears relatively preserved with both normal aging and Alzheimer's disease (AD), it has been tested under relatively simple task conditions. To test whether IOR is resistant to age and/or AD when cognitive demands are increased, we employed a double-cue IOR paradigm that required categorization as well as detection responses. The stimulus onset asynchrony (SOA) between the cue and target events was varied to determine whether group differences existed in IOR effects over time. Younger normal adults and older normal adults exhibited significant IOR effects on both the detection task and the categorization task at a short cue-target SOA (950 ms). In contrast, AD patients exhibited significant IOR effects at the short SOA on the detection task but not on the categorization task. From the short to the long SOA (3500 ms), IOR effects exhibited by younger normal adults declined significantly during both the detection and the categorization tasks, suggesting that inhibition resolved over time. In contrast, neither older normal adults nor AD patients exhibited SOA-related IOR reductions on the detection task. These results suggest that IOR may show differential age- and AD-related vulnerabilities depending on task conditions and timing characteristics.

Alzheimer's disease (AD) is a progressive neurological disorder whose earliest sign is a subtle decline in memory functions, followed by continuous deterioration in other cognitive functions. Attention processes are compromised early in the course of AD. Patients are impaired in disengagement of attention from spatial locations (Danckert, Maruff, Crowe, & Currie, 1998; Oken, Kishiyama, Kaye, & Howieson, 1994), attention to semantic information (Albert & Milberg, 1989; Chenery, Ingram, & Murdoch, 1994; Hartman, 1991), and selection of target information in the presence of distraction (Fisher, Freed, & Corkin, 1990; Greenwood, Parasuraman, & Alexander, 1997; Langley, Overmier, Knopman, & Prod'Homme, 1998; Massman et al., 1993; Sullivan, Faust, & Balota, 1995). Other attention processes are spared in the early stages of AD, including alertness (Nebes & Brady, 1993; Wens, Baro, & d'Ydewalle, 1989), sustained attention (Nebes &

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Brady, 1993), spatial orienting (Faust & Balota, 1997; Parasuraman, Greenwood, Haxby, & Grady, 1992), and target detection (Greenwood et al., 1997; Lines et al., 1991).

Inhibition of return (IOR) is an aspect of visual spatial attention that appears relatively resistant to the effects of AD (Danckert et al., 1998; Faust & Balota, 1997). This inhibitory ''aftereffect'' accompanies attentional shifts to cued locations (Klein, 2000). In a typical IOR paradigm, attention is drawn to a peripheral cue and then is drawn back to a central fixation. Targets subsequently presented at the previously cued location are detected *more slowly* than targets presented at previously uncued locations. This pattern of performance is thought to reflect inhibition toward recently searched locations, resulting in a preference for novel locations during visual search (Posner & Cohen, 1984; Posner, Rafal, Choate, & Vaughan, 1985). According to Posner et al. (1985), the cause of IOR is the initial orienting of attention toward a spatial location and the subsequent reorienting from that location. Later studies have supported the idea of IOR as an attentional phenomenon and have argued against IOR as simply an oculomotor process (Kingstone & Pratt, 1999; Reuter-Lorenz, Jha, & Rosenquist, 1996).

Time Course of IOR Effects

IOR effects last as long as three to five seconds after the initial cue is presented (Danziger, Kingstone, & Snyder, 1998; Tassinari, Aglioti, Chelazzi, Marzi, & Berlucchi, 1987; Tipper & Weaver, 1998). Although the effects are persistent, the magnitude of IOR declines with increasing intervals between the cue and target (Berlucchi, Tassinari, Marzi, & Di Stefano, 1989; Cheal, Chastain, & Lyon, 1998; Fuentes & Santiago, 1999; Hartley & Kieley, 1995; Klein, 2000; Riggio, Bello, & Umilta, 1998). From an ecological perspective, a decline in the magnitude of IOR with increasing delays is adaptive. The probability that a target will appear at a previously searched location increases over time, particularly if the target (e.g., prey) is in motion. Because inhibition is a limited cognitive resource, it cannot be maintained at more than a few searched locations at a time (Danziger et al., 1998). As IOR diminishes at earlier searched locations, inhibition becomes available for more recently explored locations, thus increasing the probability of successful search.

Generality of IOR Effects

To be considered an effective component of visual search, IOR must be demonstrated under a variety of conditions. Although inhibitory effects are robust on tasks that require the detection of single objects, visual search also entails identifying objects based on physical features and distinguishing targets from distractors. In initial studies in which IOR effects were compared under conditions of target detection and target discrimination, IOR effects were found on detection tasks but not on discrimination tasks (Schmidt, 1996; Tanaka & Shimojo, 1996; Terry, Valdes, & Neill, 1994). These initial findings suggested that IOR is a mechanism that is associated with certain types of information processing but not others. Because discrimination tasks require target feature identification, researchers speculated that IOR is limited to the spatial localization demands of target detection tasks. However, recent studies have demonstrated that IOR effects can be found on discrimination tasks, including those that require identification of features (Chasteen & Pratt, 1999; Cheal et al., 1998; Lupiáñez, Milan, Tornay, Madrid, & Tudela, 1997; Pratt & Abrams, 1999). This suggests that IOR is associated with a variety of cognitive processing demands.

Although the robustness of IOR across tasks suggests that it is a pervasive and general phenomenon, there is evidence that IOR is influenced by the conditions under which it is tested. IOR has been found on both discrimination and detection tasks, but the magnitude of IOR (Danziger & Kingstone, 1999; Kingstone & Pratt, 1999; Pratt, Kingstone, & Khoe, 1997; Terry et al., 1994) and the time course of IOR (Lupiáñez et al., 1997; Lupiáñez & Milliken, 1999; Tipper & Weaver, 1998) differs between the two tasks. IOR tends to be smaller in magnitude, slower to develop, and quicker to dissipate on discrimination tasks compared to detection tasks. These unique patterns of IOR as a function of task characteristics indicate that the neurocognitive mechanisms underlying IOR may vary.

Neural Basis of IOR Effects

The neural basis of IOR has been frequently associated with the superior colliculus, a midbrain nucleus in the visual pathway involved in saccadic eye movements. Patients with progressive supranuclear palsy, which is characterized by neuropathology within the superior colliculus and basal ganglia, exhibit a pattern of reduced IOR most notable in the vertical plane, paralleling their pattern of saccadic impairment (Posner et al., 1985; Rafal, Posner, Friedman, Inhoff, & Bernstein, 1988). The extrageniculate visual pathway and the superior colliculus have a temporal-nasal asymmetry that biases saccades toward the temporal hemifield, even under conditions of bilateral stimulation. Consistent with collicular involvement, IOR effects are larger and more constant in the temporal hemifield than in the nasal hemifield (Berger & Henik, 2000; Rafal, Calabresi, Brennan, & Sciolto, 1989). Surprisingly, collicular activations associated with IOR have not been detected when examined with functional neuroimaging techniques (Rosen et al., 1999). Instead, activations have been found in the frontal eye fields, anterior cingulate, superior parietal cortex, and thalamus.

To complement the neuroimaging findings, patient findings have revealed cortical involvement in IOR. Patients with frontal and parietal lesions have exhibited IOR impairments that vary as a function of task complexity (Stuss et al., 1999). Although right hemisphere lesions have little impact on IOR performance, patients with left parietal and left frontal lesions exhibit reduced effects on simple IOR tasks and less decline in IOR with increasing task complexity. Additional evidence for cortical involvement in IOR comes from research with commissurotomized (''split-brain'') patients (Tipper et al., 1997). When stimuli were rotated around the display in such a way as to stay in one visual field or to cross to the other visual field (an object-based IOR task), normal participants demonstrated intact IOR both within-field and between-fields, whereas split-brain patients demonstrated IOR within-field only. Patients did not exhibit IOR when the moving stimulus crossed the midline and the hemispheres could not communicate. Together, the evidence from patient studies suggests that subcortical areas are involved in simpler IOR tasks, and cortical areas are recruited for more complex tasks.

Aging and IOR Effects

Examining the effects of aging and AD on IOR patterns may shed light on the neural basis of IOR. Studies conducted thus far suggest that IOR is preserved with normal aging. Older adults exhibit significant IOR effects on both detection and discrimination tasks (Hartley & Kieley, 1995) and with intrinsic as well as extrinsic shifts of attention (Faust & Balota, 1997). When controlled for age-related cognitive slowing, IOR is of similar magnitude in younger and older normal adults (Faust & Balota, 1997; McDowd, Filion, Tipper, & Weaver, 2000), and the two groups exhibit a similar pattern of IOR reduction as the cue-target interval increases (Faust & Balota, 1997; Hartley & Kieley, 1995).

What is the potential relationship between older adults' performance on IOR tasks and age-related neural changes? The most obvious neural change that occurs with normal aging is loss of brain volume and weight, approximately 2 percent per decade after the age of 60 (Kemper, 1984; Raz, 2000). This atrophy seems to be due mainly to reductions in the association areas of the frontal, temporal, and parietal cortices (Boller & Duyckaerts, 1997; Raz et al., 1997). Primary sensory areas, including the visual pathways, are relatively less affected by age. The effects of aging on specific subcortical areas are presently unclear (Boller & Duyckaerts, 1997; Raz, 2000), but in general, aging effects are more prominent in cortical areas than in subcortical areas. Therefore, age-related IOR deficits that may be observed should be more likely on tasks thought to have stronger cortical involvement.

AD and IOR Effects

AD is characterized by the presence of neuritic plaques and neurofibrillary tangles that spread in a fairly predictable and consistent manner throughout the cortex (Braak et al., 1999; Farlow, 1998). The neuropathology is first seen in the entorhinal cortex and hippocampal formation and progresses into adjoining higher order association areas of the neocortex. The neocortical region

most likely to show reduced metabolism is the parietal association cortex, although significant reductions also appear in the temporal and frontal association areas (Parks, Haxby, & Grady, 1993). Along with the primary motor and sensory areas, subcortical areas such as the basal ganglia, thalamus, cerebellum, and superior colliculus are relatively spared until later in the course of the disease (Braak et al., 1999; Boller & Duyckaerts, 1997; Iseki et al., 1989; Leuba & Saini, 1995; Parks et al., 1993).

This pattern of neuropathology suggests that if cortical areas are involved in IOR effects on certain tasks, then AD patients should demonstrate selected patterns of IOR deficits. Findings are mixed regarding AD-related IOR patterns (Danckert et al., 1998; Faust & Balota, 1997). When a long interval rather than a second cue draws attention away from cued locations (Faust & Balota, 1997), AD patients produce facilitated rather than inhibited responses at cued locations, suggesting a failure to intrinsically return attention to fixation before the target appears. In contrast, using a similar single-cue paradigm, a different study found intact IOR effects in AD patients (Danckert et al., 1998). On a double-cue task with extrinsic shifts of attention, AD patients exhibited intact IOR effects, and the reduction in IOR with increasing cue-target interval did not vary between AD patients and an age-matched normal group (Faust & Balota, 1997).

It is important to note that, in the IOR studies just described, AD patients were tested on detection tasks. Findings from our laboratory (Fuentes, Langley, Overmier, Bastin de Jong, & Prod'Homme, 1998) indicate that AD patients exhibit IOR deficits on discrimination tasks. A categorization IOR task was combined with a semantic cuing task, so that the initial spatial cue served also as a semantic cue. AD patients exhibited diminished IOR effects on this task, but it is unclear whether this was due to the required discrimination response or to the added semantic demands of the task.

Present Study

The preceding review demonstrates that there is cortical as well as subcortical involvement in IOR, particularly on more demanding tasks. The detection tasks on which AD patients have been tested may not have been complex enough to reveal deficits in IOR. To address this, we assessed younger and older normal adults and AD patients on a categorization task as well as a detection task. As a further analysis of age- and AD-related patterns of IOR effects, we explored performance at two cue-target intervals. As described earlier, IOR diminishes over time and at a faster rate for more complex tasks. To determine whether reductions in IOR magnitude varied across tasks and groups, we included both a short (950 ms) and a long (3500 ms) stimulus onset asynchrony (SOA) between the first cue and the target. We chose a particularly long SOA to maximize the likelihood of IOR resolution.

We made the following predictions regarding IOR patterns. First, because subcortical mechanisms are thought to subserve IOR on detection tasks, we expected that AD patients, older normal adults, and younger normal adults would exhibit equivalent IOR effects when detection responses were required. Second, based on the early cortical neuropathology of AD and recent evidence of cortical involvement in more demanding IOR tasks (Stuss et al., 1999; Tipper et al., 1997), we predicted that AD patients would exhibit reduced IOR on the categorization task. Third, we expected that all three groups would exhibit reduced IOR effects at the longer SOA (Cheal et al., 1998; Faust & Balota, 1997; Hartley & Kieley, 1995). This reduction would be greater on the categorization task than on the detection task, as other studies have found greater reductions with greater task complexity (Klein, 2000; Lupiáñez et al., 1997; Lupiáñez & Milliken, 1999; Tipper & Weaver, 1998).

METHOD

Participants

Eighteen younger normal adults, 15 older normal adults, and 12 AD patients participated. The younger normal adults were undergraduate students from the University of Minnesota participating for course extra credit. The older normal participants were spouses of AD patients and volunteers from the

community. AD patients were recruited from the University of Minnesota Alzheimer's Clinic and the Johns Hopkins Alzheimer's Disease Research Center, referred by the directors of the clinics. All participants were native English speakers. AD patients were diagnosed by a neurologist according to the guidelines of the National Institute of Neurological and Communicative Disorders and Stroke, and the Alzheimer's Disease and Related Disorders Association (NINCDS-ADRDA, McKhann et al., 1984). None of the participants had histories of heart condition, stroke, head injury, psychiatric illness, learning disability, or drug abuse as reported on a self-report health-screening questionnaire (Christensen, Bowes, Armson, & Kern, 1992). Median visual acuities were 20/15 (range 20/15–20/20), 20/25 (range 20/15–20/50), and 20/25 (range 20/15–20/60) for younger normal adults, older normal adults, and AD patients, respectively.

Mean ages for younger normal adults, older normal adults, and AD patients (with SDs in parentheses) were 21.5 years (3.2), 70.8 years (8.3), and 73.4 years (9.5), respectively. Older normal participants and AD patients did not differ significantly in age. Years of education did not vary significantly between the younger normal participants ($M = 13.3$ years, $SD = 1.0$), older normal participants ($M = 13.9$ years, $SD = 2.2$), and AD patients ($M = 13.3$ years, $SD = 2.9$), $F < 1$. Younger normal adults' scores ($M = 29.2$, $SD = 0.7$) on the Mini-Mental State Examination (MMSE; Folstein, Folstein, & McHugh, 1975) did not differ from those of older normal participants ($M = 28.6$, $SD = 0.9$). AD patients had significantly lower MMSE scores ($M = 22.2$, $SD = 2.8$) than both younger and older normal participants, $ps < .05$. AD patients' scores ranged from 17 to 26, indicating mild to moderate levels of cognitive impairment.

Stimuli and Apparatus

Stimuli were presented on a color monitor of an IBM/PC compatible computer. Displays were white and red on a black background. Target stimuli consisted of the words *horse*, *lion*, *cat*, *dog*, *elm*, *oak*, *pine*, and *maple* printed in lowercase. Letters subtended an average of .48° by .38° of visual angle at a viewing distance of 60 cm. The target words were presented in three white unfilled boxes arranged horizontally across the vertical center of the screen. The boxes subtended viewing angles of 5.4° by 1.3°, and the inner sides of the two peripheral boxes were located 4.9° from fixation. As a spatial cue, one of the three boxes turned from white to red. Participants' responses were recorded via a button box interfaced with the parallel port of the computer. Two buttons were arranged vertically on the box with a label positioned immediately above each button (*Animal* and *Tree*). The assignment of buttons to responses was counterbalanced across participants.

Procedure

A trial proceeded as follows (see Figure 1). A fixation cross was presented in the center of the screen until the researcher initiated the trial. The fixation cross was replaced by three white boxes that remained on the screen for the remainder of the trial. After 1000 ms, the left or right peripheral box changed to red for 300 ms, serving as the initial spatial cue. The boxes then reverted to white for 200 ms, after which the center box changed to red for 300 ms (the central cue). The interstimulus interval between the second cue and the target was 150 ms or 2700 ms. Thus, the SOA from the first cue to the target was either 950 or 3500 ms. The target word was presented in the location of the initial peripheral cue (the Cued condition) or in the other peripheral box (the Uncued condition), and the target remained on the screen until the participant responded. The target was an exemplar of one of the two response categories (*Animal* or *Tree*).

The detection task and the categorization task were completed in separate blocks of trials. Participants completed 90 practice trials and 90 experimental trials of each task. The experimenter explained the tasks to participants using a drawn representation of the stimulus events. Participants were told that the color changes associated with the spatial cues would not help predict the location of the target. They were asked to keep their eyes focused in the center of the screen for the duration of the trial. For the detection task, participants rested a thumb on the top button of the response box (held in the palms of their hands) and pressed the button as soon as they detected the target word. For the categorization task, participants rested one thumb on the top button and the other thumb on the bottom button and categorized the target word as an *Animal* or a *Tree* by pressing the corresponding button. Participants were encouraged to respond as quickly as possible while avoiding errors. The order of task completion (detection task versus categorization task first) was counterbalanced across participants. An equal number of short (950 ms) and long (3500 ms) SOA trials was included in each task, and the order of trials was randomly determined. For each task, the correct response was *Animal* on half the trials and *Tree* on the other half. The eight target words were presented an equal number of times in each task, and the cues and targets were presented an equal number of times in the left and right peripheral boxes.

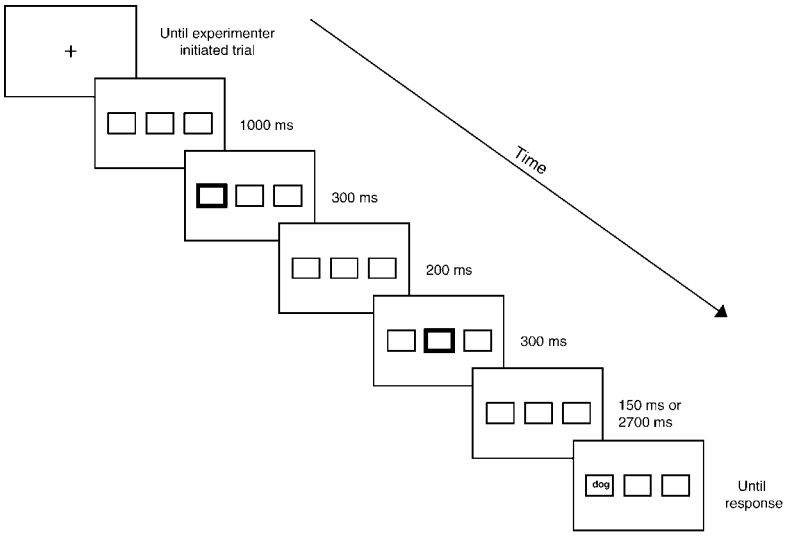

Fig. 1. Sequence of events for a sample trial in the Cued condition. Note that in the experiment, stimuli and boxes were presented in white on a black background, and spatial cues were presented in red. On detection trials, participants pressed a button as soon as the target was detected. On categorization trials, participants pressed one of two buttons corresponding to the category (*Animal* or *Tree*) to which the target belonged.

RESULTS

Reaction Times (RTs)

General Analysis

Mean RTs and derived IOR effects as represented by difference scores (Cued condition RTs minus Uncued condition RTs) are presented in Table 1. RTs were submitted to a $3 \times 2 \times 2 \times 2$ mixed ANOVA with group (younger normal participants, older normal participants, and AD patients) as the between-subjects variable and task (detection and categorization), SOA (950 ms and 3500 ms), and location (cued and uncued) as the within-subjects variables. There were main effects of group, $F(2, 42) = 26.13$, $MSE = 529{,}061$, $p < .0001$, task, $F(1, 42) = 117.72$, $MSE = 177{,}017$, $p < .0001$, and location, $F(1, 42) = 33.68$, $MSE = 4{,}536$, $p < .0001$. Bonferroni *t*-tests indicated that AD patients were significantly slower ($M = 1136$ ms) than both older normal adults ($M = 591$ ms) and younger normal adults ($M = 463$ ms), $ps < .05$. Older normal participants were slower than the younger normal participants but not significantly so. As anticipated, participants were slower on the categorization task ($M = 917$ ms) than on the detection task ($M = 454$ ms). Averaged across task and SOA, participants responded more slowly to targets presented at the Cued location ($M = 706$ ms) than to targets presented at the Uncued location ($M = 665$ ms), reflecting IOR effects. The Group $\times$ Task interaction was the only significant interaction, $F(2, 42) = 6.78$, $MSE = 177{,}017$, $p < .01$. All three groups were slower on the categorization task than on the detection task, but the magnitude of the difference between tasks (Categorization RT – Detection RT) varied between groups, $F(2, 42) = 6.57$, $MSE = 184{,}497$, $p < .01$. AD patients had a greater mean difference score ($M = 454$ ms) than did either the older normal adults ($M = 243$ ms) or the younger normal adults ($M = 204$ ms), $ps < .05$.

The above results have important implications for the interpretation of IOR effects. Although the goal of this study was to investigate group differences in IOR effects, the above analyses suggest that the groups differed in their baseline (i.e., uncued) RTs.[1] This difference is consistent with a systematic linear relationship often found

[1]An analysis of uncued RTs demonstrated significant group differences in baseline RTs, $F(2, 42) = 26.38$, $MSE = 257182.9$, $p < .0001$. Uncued RTs of AD patients ($M = 1112$ ms) were significantly greater than those of younger normal adults ($M = 444$ ms) and older normal adults ($M = 573$ ms), $ps < .05$.

Table 1. Mean Reaction Time as a Function of Group, Task, Cue-Target SOA, and Target Location.

	Detection Task					
	Short SOA (950 ms)			Long SOA (3500 ms)		
Group	Cued	Uncued	C-U	Cued	Uncued	C-U
Younger normal adults (N = 18)						
RT (msec)	320	278	42*	299	288	11
(SD)	(67)	(52)	(25)	(48)	(48)	(28)
Older normal adults (N = 15)						
RT (msec)	432	407	25*	375	343	33*
(SD)	(46)	(61)	(32)	(75)	(71)	(40)
AD patients (N = 12)						
RT (msec)	815	748	67*	785	738	47*
(SD)	(383)	(378)	(113)	(410)	(411)	(73)

	Categorization Task					
	Short SOA (950 ms)			Long SOA (3500 ms)		
Group	Cued	Uncued	C-U	Cued	Uncued	C-U
Younger normal adults (N = 18)						
RT (msec)	659	593	67*	652	617	35*
(SD)	(78)	(59)	(45)	(76)	(70)	(45)
% Errors	2.4	4.2	−1.8	2.1	1.4	0.7
Older normal adults (N = 15)						
RT (msec)	828	753	75*	802	789	14
(SD)	(93)	(97)	(39)	(118)	(136)	(81)
% Errors	2.1	1.7	0.4	1.3	0.8	0.5
AD patients (N = 12)						
RT (msec)	1519	1478	41	1525	1480	46
(SD)	(801)	(777)	(205)	(657)	(626)	(202)
% Errors	3.1	3.7	−0.6	5.2	2.1	3.1

Note: No errors were possible on the detection task. C-U = Cued Location; RT – Uncued Location; RT (inhibition of return difference scores). AD = Alzheimer's disease; SOA = stimulus onset asynchrony; RT = reaction time. *Significantly different from 0 as indicated by t-test, $p < .05$.

between the response latencies of younger normal adults, older normal adults, and AD patients (Madden, in press; Nebes & Brady, 1992; Nebes & Madden, 1988; Salthouse, 1985). For example, the Brinley function (i.e., the monotonic increase in the task condition mean RTs of older normal adults, as a function of the corresponding task condition means of younger normal adults) is often found to increase with a slope of approximately 1.50 (Cerella, 1985; Lima, Hale, & Myerson, 1991; Myerson, Ferraro, Hale, & Lima, 1992). The Brinley function relating AD patients' RTs to those of younger normal adults has been found to be even steeper, with a slope of approximately 2.25 (Madden, Welsh-Bohmer, & Tupler, 1999; Nebes & Brady, 1992).[2] As a result of this monotonic relationship, older normal adults and AD patients may produce larger condition effects than younger normal adults independent of the influence of the particular cognitive process under investigation. As Faust and Balota (2000) demonstrate, group differences in cognitive processing

[2] Similar relationships were found in the present data. For both the detection task and the categorization task, the uncued RTs of older normal adults were approximately 1.3 times those of younger normal adults (1.33 for the detection task, 1.27 for the categorization task). The uncued RTs of AD patients were approximately 2.5 those of younger normal adults (2.63 for the detection task, 2.44 for the categorization task).

speed may exaggerate some group interactions but obscure others. Generalized slowing may actually mask Group × Condition interactions related to particular cognitive processes when an impairment that exists in the slower group is hidden by linearly increased RTs.

Limitations to using RT to assess group differences in specific components of cognitive functioning have motivated the development of RT transformations that take into account the contribution of group differences in baseline cognitive speed (Faust, Balota, Spieler, & Ferrara, 1999; Madden, in press). One such transformation divides individuals' condition RTs or condition difference scores by their baseline RTs. As a result, these proportionally transformed scores identify task-specific group differences that are independent of baseline RT differences, and they allow within-group comparisons of performance across conditions with different baseline RTs. Such transformed scores have proven instrumental in IOR studies for comparing effects across groups and task conditions (Chasteen & Pratt, 1999; Faust & Balota, 1997; Stuss et al., 1999).

Faust et al. (1999) have encouraged performing analyses on transformed response latencies as well as on raw response latencies, noting that interesting information can be gained from identifying discrepancies between the two. Therefore, we proceeded with analyses on transformed IOR scores, calculated for each participant using the following formula: (Cued RT – Uncued RT)/ Uncued RT × 100. This formula identifies the percentage slowing in the Cued condition relative to the Uncued condition. As noted in Table 1, the transformed IOR effects exhibited the same IOR patterns as the untransformed data within each group.

Transform IOR Scores

IOR effects as represented by percentage change scores are presented in Figure 2 as percentage change scores. Individuals' transformed IOR scores were submitted to a 3 × 2 × 2 mixed ANOVA with group (younger normal adults, older normal adults, and AD patients) as the between-subjects variable and task (detection and categorization) and SOA (950 and 3500 ms) as the within-subjects variables. There were main effects of task, $F(1, 42) = 5.04$, $MSE = 88.92$, $p < .05$, and SOA, $F(1, 42) = 6.33$, $MSE = 101.17$, $p < .05$. Averaged across groups, IOR effects were significantly greater on the detection task ($M = 9.28\%$) than on the categorization task ($M = 6.41\%$), and IOR effects were significantly greater at the short SOA ($M = 9.98\%$) than at the long SOA ($M = 5.71\%$). The magnitude of IOR effects, averaged across task and SOA, did not differ between younger normal adults ($M = 9.12\%$), older normal adults ($M = 7.50\%$), and AD patients ($M = 6.37\%$), but importantly, there was a significant Group × Task × SOA interaction, $F(2, 42) = 3.77$, $MSE = 71.53$, $p < .05$.

To explore the three-way interaction, patterns of IOR effects were examined within each group. Percentage change IOR scores were submitted to a 2 (task) × 2 (SOA) repeated measures ANOVA. For younger normal adults, there was a main effect of SOA, $F(1, 17) = 17.56$, $MSE = 67.50$, $p < .001$, but not task, $F < 1$, and the Task × SOA interaction was not significant, $F(1, 17) = 2.08$, $MSE = 62.01$, $p = .17$. IOR effects were similar on the detection task ($M = 9.68\%$) and the categorization task ($M = 8.55\%$). Paired t-tests indicated that younger normal adults' IOR effects declined significantly from the short SOA to the long SOA on both the detection task, $t(17) = -3.71$, $p < .001$, and the categorization task, $t(17) = -2.25$, $p < .05$. Analyses using *t*-tests for the amount of change from zero indicated that younger normal participants exhibited significant IOR effects on the detection task at the short SOA, $t(17) = 8.07$, $p < .0001$, but only marginal IOR effects at the long SOA, $t(17) = 1.92$, $p = .07$. On the categorization task, younger normal participants showed reliable effects at both the short SOA, $t(17) = 6.66$, $p < .0001$, and the long SOA, $t(17) = 3.37$, $p < .01$.

For older normal adults, there was no main effect of task or SOA, Fs < 1, but there was a significant Task × SOA interaction, $F(1, 14) = 6.16$, $MSE = 69.68$, $p < .05$. Paired *t*-tests revealed a significant decline in IOR from the short SOA to the long SOA on the categorization task, $t(14) = 2.76$, $p < .05$, but not on the detection task, $t(14) < 1$. As indicated by t-tests for the amount of change from zero, older normal adults' IOR effects were significant on the detection task

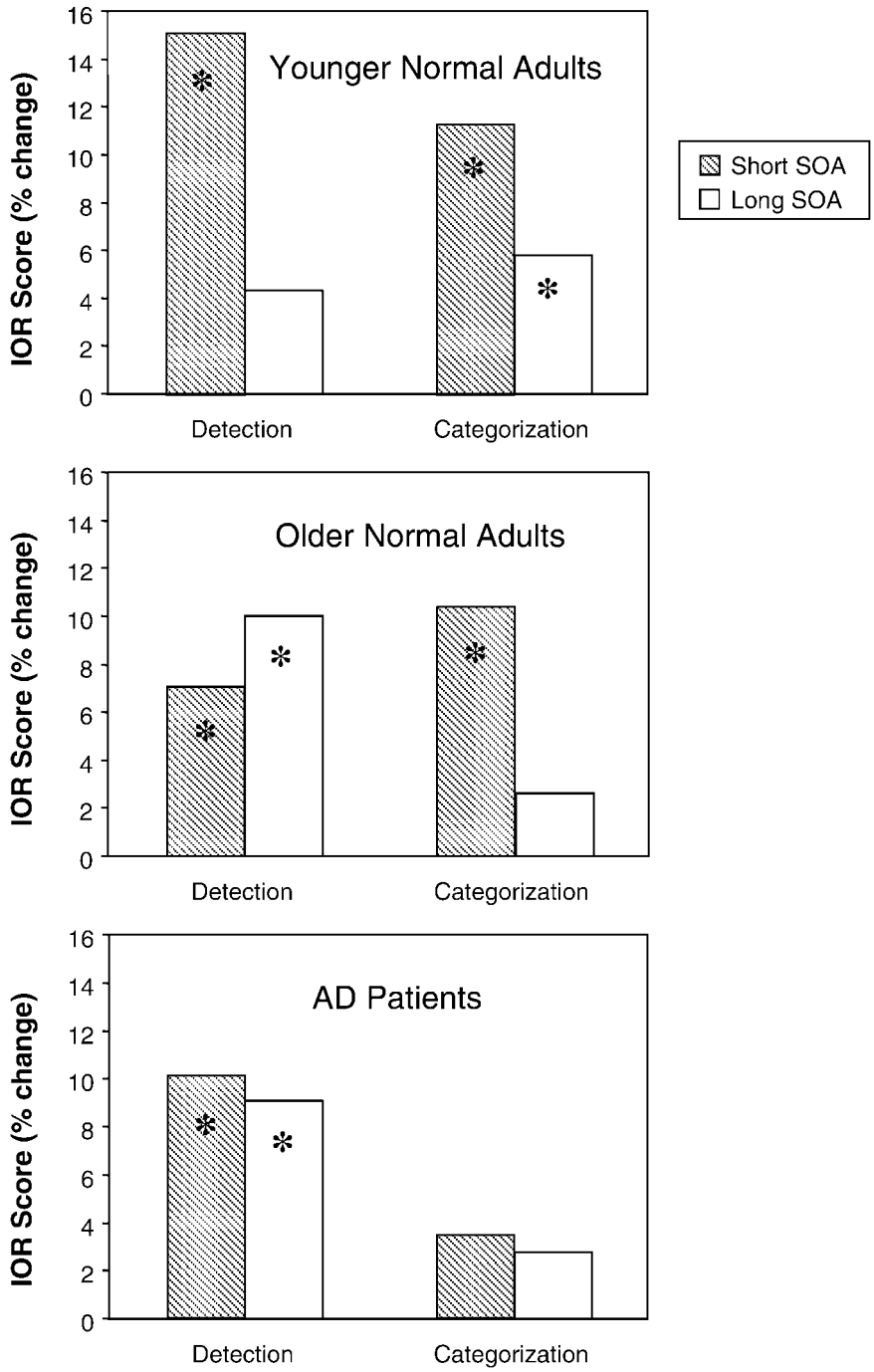

Fig. 2. Inhibition of return (IOR) scores as a function of group (younger normal adults, older normal adults, and AD patients), task (detection and categorization), and cue-target SOA (950 ms and 3500 ms). IOR scores were calculated using the following formula: (Cued RT – Uncued RT)/Uncued RT × 100. *Significantly different from 0 as indicated by t-test, $p < .05$.

at both the short SOA, $t(14) = 3.20$, and the long SOA, $t(14) = 3.29$, $ps < .01$, whereas IOR effects on the categorization task were significant at the short SOA, $t(14) = 7.07$, $p < .0001$, but not at the long SOA, $t(14) = 1.08$, $p = .30$.

For AD patients, there was a marginal effect of task, $F(1, 11) = 3.35$, $MSE = 161.00$, $p = .074$, but not SOA, $F < 1$, and there was no Task × SOA interaction, $F < 1$. Although the main effect of task was not reliable, *t*-tests for the amount of change from zero indicated that IOR effects were significant on the detection task at both the short SOA, $t(11) = 2.66$, $p < .05$, and the long SOA, $t(11) = 3.11$, $p < .01$, but IOR effects were not significant on the categorization task at either the short SOA or the long SOA, $ts < 1$. The magnitude of IOR did not differ between the short and long SOA for either task, $ts(11) < 1$.

In comparing the magnitude of effects between groups, performance on the two tasks was examined separately. A 3 (group) × 2 (SOA) mixed ANOVA for the detection task indicated no main effect of either group, or SOA, but there was a Group × SOA interaction, $F(2, 42) = 4.78$, $MSE = 86.78$, $p < .05$. One-way ANOVAs at each SOA indicated that the groups differed marginally at the short SOA of the detection task, $F(2, 42) = 2.86$, $MSE = 95.39$, $p = .069$. Younger normal adults had significantly greater IOR scores than older normal adults, $p < .05$, but older normal adults and AD patients did not differ. The groups did not differ significantly in IOR effects at the long SOA of the detection task, $F(2, 42) = 1.42$, $MSE = 109.17$, $p = .25$.

On the categorization task, there was a significant effect of group, $F(2, 42) = 3.21$, $MSE = 68.32$, $p < .05$, and SOA, $F(1, 42) = 5.52$, $MSE = 85.91$, $p < .05$, but there was no Group × SOA interaction, $F < 1$. Averaged across SOA, Bonferroni *t*-tests indicated that the IOR effects of younger normal adults ($M = 8.55\%$) were greater than those of AD patients ($M = 3.12\%$), $p < .05$. IOR effects were larger at the short SOA ($M = 8.88\%$) than at the long SOA ($M = 3.95\%$). One-way ANOVAs indicated that groups differed significantly at the short SOA, $F(2, 42) = 3.76$, $MSE = 64.57$, $p < .05$. Younger and older normal adults exhibited significantly more IOR than AD patients, $ps < .05$, but the younger and older normal adults did not differ in the magnitude of IOR. At the long SOA, the three groups did not differ in IOR effects, $F < 1$.

Errors

A 3 (group) × 2 (SOA) × 2 (location) mixed ANOVA was performed on error rates. Analyses were limited to the categorization task because errors did not occur on the detection task. Although error rates were low for each group ($M = 2.52\%$, 1.46%, and 3.52% for younger normal adults, older normal adults, and AD patients, respectively), there was a significant main effect of group, $F(2, 42) = 3.74$, $MSE = 15.25$, $p < .05$. Bonferroni t-tests indicated that error rates were greater for AD patients than for older normal adults. There were no other significant effects, including error patterns reflecting IOR effects.

DISCUSSION

Since 1984, when Posner and Cohen first described the IOR effect, several aspects of the phenomenon have been examined, including the conditions under which IOR occurs, the cognitive processes involved, and the neural basis. The evidence points to IOR as a general and pervasive mechanism of visual search. Although IOR is observed under a variety of experimental conditions, the magnitude and timing of IOR varies as a function of task demands (see review by Klein, 2000). As task complexity increases, IOR tends to become smaller in magnitude, slower to develop, and faster to resolve. This suggests that IOR may be associated with distinct neural mechanisms. The superior colliculus is strongly associated with simple IOR tasks and processes of spatial localization (Posner et al., 1985; Rafal et al., 1988). Cortical areas (e.g., the frontal eye fields, the anterior cingulate, or the posterior parietal cortex) appear to contribute to performance on more complex IOR tasks (Rosen et al., 1999; Stuss et al., 1999; Tipper et al., 1997), perhaps associated with inhibitory processes of feature processing.

Examining the patterns of IOR performance exhibited by AD patients and older normal participants may further inform the nature of IOR. Both AD and aging are associated with changes in

the brain, with greater involvement of cortical areas than subcortical areas. Of course, the degree of cortical impairment is greater in AD patients than in nondemented older adults. To assess the effects of task manipulation on AD- and age-related patterns of IOR performance, we tested AD patients, older normal participants, and younger normal participants on IOR tasks that manipulated both response requirements and stimulus timing. We expected that AD patients would demonstrate relatively intact IOR on a detection task, thought to tap subcortical mechanisms of IOR. Based on patient findings (Stuss et al., 1999; Tipper et al., 1997), we expected AD patients would exhibit relatively reduced IOR effects on a categorization task, thought to tap cortical mechanisms of IOR. Normal older adults were expected to exhibit relatively mild impairments in IOR if any at all. We predicted that all three groups would show reductions in IOR with an increasing cue-target interval, consistent with the resolution of IOR over time.

Because of group differences and task differences in response latency, we transformed RT data so that IOR scores represented the percentage change in RT in the Cued condition relative to the Uncued condition. This transformation reduced the influence of cognitive speed on group differences and task differences in IOR magnitude. Transformed scores revealed a group interaction in IOR effects that was not observed with untransformed scores, suggesting that differences in cognitive speed obscured underlying group differences in the cognitive process of interest, namely IOR. This finding underscores the importance of examining RT data of populations known to differ in general cognitive speed using data transformations that take into account these baseline differences (Faust et al., 1999; Faust & Balota, 2000). Otherwise, group-specific impairments in specific cognitive processes may be overlooked.

Consistent with predictions, AD patients demonstrated significant IOR effects on the detection task at a cue-target interval that typically reveals IOR effects. This result indicates that the brain areas responsible for inhibition of spatial localization appear to be functional in AD. The likely neural candidate is the superior colliculus, part of the pathway responsible for visual saccades, and a midbrain area that is relatively resistant to early AD-related changes.

Although older normal participants exhibited significant IOR effects at the short cue-target interval of the detection task, they unexpectedly exhibited smaller IOR effects than younger normal adults. Other studies have not reported such an age-related reduction in IOR (Faust & Balota, 1997; Hartley & Kieley, 1995). One possible explanation is that the transformed data revealed a deficit in the present study that was obscured by age-related cognitive slowing in other studies. However, Faust and Balota used a proportional transformation similar to the transformation used in the present study and found no age differences in the magnitude of IOR effects at a similarly short SOA (800 ms) or at longer SOAs (1300 and 1800 ms). Hartley and Kieley analyzed absolute RT data. Although estimating group proportional scores using the group untransformed mean RTs is only a rough approximation of the group mean of individual proportional scores, doing so with the reported means from Hartley and Kieley provided no indication of age-related reductions in IOR effects at a similarly short SOA (750 ms). Therefore, there is no indication that slowing effects obscured age-related reductions in IOR effects in other studies that used detection tasks and short SOAs.

Perhaps the discrepancy between the expected and the observed age-related pattern of IOR effects is due to a delay in the build-up of inhibitory effects for older normal adults rather than to a reduction in IOR magnitude. Consistent with this hypothesis, IOR effects actually increased slightly from the short to the long cue-target interval for older normal adults, whereas they decreased for younger normal participants. Klein (2000) has demonstrated that as RT increases, there is a linear increase in the time point at which IOR is first observed. Perhaps there is a common mechanism for age-related cognitive slowing processes and processes of build-up of IOR effects (e.g., changes in subcortical nuclei or white matter tracts). This hypothesis can be addressed in the future by testing younger and older normal adults with a wider range of cue-target SOAs to determine in closer detail the age-

related patterns of build-up and decline in IOR effects over time.

In addition to the detection task, younger and older normal participants exhibited significant IOR effects on the categorization task at the short cue-target interval. It is evident from these results that IOR effects occur on target discrimination tasks as well as on target localization tasks. Responses on the categorization task required processing of the semantic properties of the target word. IOR effects have been demonstrated in past studies when discriminations required processing of the physical properties of the target word. Target discriminations have been based on color (Fuentes, Boucart, Vivas, Alvarez, & Zimmerman, 2000; Lupiáñez et al., 1997; Lupiáñez & Milliken, 1999), orientation (Cheal et al., 1998; Handy, Jha, & Mangun, 1999), and identity (Cheal & Chastain, 1999; Pratt, 1995; Pratt & Abrams, 1999; Kingstone & Pratt, 1999). Findings from this study indicate that IOR effects are evident even when the discrimination is based on non-physical dimensions (see also Fuentes, Vivas, & Humphreys, 1999), thus extending the generality of the IOR phenomenon.

In AD patients, a significant IOR effect was found on the detection task but not on the categorization task. The overall task effect for AD patients was marginal, so it is not possible to affirm that IOR effects differed between the tasks. Despite this limitation, it is worth noting that the implied differential pattern of IOR effects was observed within a single group of AD participants on two tasks that varied *only* in the required response. Consistent with task differences in IOR effects, AD patients' IOR scores were significantly smaller than those of younger and older normal participants only on the categorization task, not on the detection task. The AD-related reduction in IOR magnitude on the categorization task replicates previous findings from our laboratory in which an IOR task was combined with a semantic cuing task (Fuentes et al., 1998). Paralleling the present pattern of results, AD-related attentional deficits as a function of task demands are revealed on another spatial orienting task, namely spatial cuing. AD patients exhibit difficulties disengaging attention from spatial locations on discrimination tasks but not on detection tasks (Oken et al., 1994; Parasuraman et al., 1992). The commonality of AD-related impairments across spatial attention tasks deserves further investigation. One possibility for attention deficits that are associated with task difficulty is that the neural mechanisms involved in spatial attention vary as a function of task characteristics. Cortical areas that are impaired early in the course of AD (e.g., parietal or frontal areas) may be more greatly involved in complex attention tasks. Another possibility is that the neural mechanisms that are responsible for discrimination performance influence or block the neural mechanisms involved in spatial attention (inhibition or disengagement) in AD in a way that does not occur in normal aging.

Regarding timing effects, we expected that IOR would decrease in magnitude as the cue-target interval increased. This time-related reduction in IOR may represent an adaptive function of visual search that allows attention to eventually return to previously explored locations. Younger normal adults exhibited the predicted reduction in IOR with increased SOA on both the detection and categorization tasks. Older normal adults exhibited this IOR reduction on the categorization task but not on the detection task. AD patients as well as older normal adults failed to exhibit an SOA-related reduction in IOR on the detection task. A similar maintenance of IOR effects after a long cue-target interval has been exhibited by schizophrenic patients (Fuentes & Santiago, 1999), which suggests that certain cortical changes may be associated with altered timing characteristics of IOR. With aging and AD, slowed resolution of IOR may lead to the maintenance of inhibition when it no longer aids visual search performance.

There is an alternative interpretation of the demonstrated pattern of reduced IOR effects with increased cue-target SOA for younger normal adults but not for older normal adults or AD patients on the detection task. The groups may have differed in the strategies used to perform the detection task. Although when designing the study we believed that the inclusion of two SOAs would dissuade anticipatory responses, anticipation was possible at the long cue-target interval. Because the timing of the target's appearance was

predictable once the target did not appear at the short SOA, a detection response at the long SOA could have been made based on anticipating the target's appearance. If this strategy were employed, inhibitory effects associated with the cued location would have had little influence on responses because the target would not have needed to be localized. Therefore, IOR effects would be diminished at the long SOA compared to the short SOA due to anticipation rather than to resolution. This strategy would not be effective on the categorization task because semantic aspects of the target would have had to be processed before a response could be made. Thus the observed SOA-related reduction in IOR effects on the categorization task for the younger and older normal groups could not be attributed to anticipatory responding.

Younger normal adults may have used a target anticipation strategy at the long SOA of the detection task to enhance RTs, whereas older normal adults and AD patients may have relied on the appearance of the stimulus. This would alternatively account for group differences in the reduction of IOR effects. In fact, older normal adults' pattern of SOA performance was more consistent with predictions than younger normal adults' performance. We expected that SOA disparities in IOR effects would be greater on the categorization task than on the detection task because IOR reductions are greater on complex tasks than on simple tasks (Klein, 2000; Lupiáñez et al., 1997; Lupiáñez & Milliken, 1999; Tipper & Weaver, 1998). Whereas younger normal adults exhibited similar SOA-related reductions in IOR on both the detection and the categorization tasks, older normal adults exhibited the expected pattern of greater SOA-related IOR reductions on the categorization task than on the detection task. This may have been due to group differences in performance strategy. Future studies with a greater variety of SOAs and the inclusion of catch trials should further differentiate group differences in the timing of IOR effects versus strategy differences.

In conclusion, this study offers further support for (a) the influence of task demands and stimulus timing on IOR effects, and (b) the effect of age and AD on IOR patterns. Although IOR appears to be a pervasive and general component of visual search, evidence is beginning to accumulate that suggests there are distinct neural bases of IOR. The present evidence suggests that IOR effects that are associated with different cognitive demands are differentially affected by aging and AD. Although IOR effects on detection tasks, associated with subcortical mechanisms, appear relatively resistant to age- and AD-related effects, IOR effects on categorization tasks, associated with cortical mechanisms, are vulnerable to the effects of AD. Aging may lead to a slower build-up of IOR, and both aging and AD may lead to a slower resolution of IOR. Further examination of age- and AD-related IOR patterns will help determine under what conditions this inhibitory mechanism of spatial attention is resistant to the effects of age and AD.

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