

## BRIEF REPORT

# Differential Age Effects on Attention-Based Inhibition: Inhibitory Tagging and Inhibition of Return

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The purpose of this study was to determine whether 2 forms of attentional inhibition, inhibition of return (IOR) and inhibitory tagging, are differentially affected by the aging process. The authors tested 24 younger adults (mean age = 22 years) and 24 older adults (mean age = 69 years) on a combined IOR and Stroop task (Vivas & Fuentes, 2001). As predicted, younger adults' performance was consistent with inhibitory tagging of objects at inhibited locations. Although older adults demonstrated intact IOR, there was no evidence of inhibitory tagging. The results suggest that age deficits in inhibition are selective.

*Keywords:* aging, attention, inhibition of return, inhibitory tagging, Stroop effects

Visual attention serves to preferentially direct a person's focus to objects or locations that are salient or important to current goals. Aging has been associated with both preservation and impairment in attention (see reviews by Hartley, 1992; McDowd & Shaw, 2000). As an example of retained abilities, older adults benefit as much as younger adults from physical or symbolic cues that direct attention to the likely location or identity of upcoming target information (Greenwood & Parasuraman, 1994; Kramer & Strayer, 2001) and from constancies in distractor identity or placement that serve to facilitate target detection (Carlson, Hasher, Connelly, & Zacks, 1995; Langley, Overmier, Knopman, & Prod'Homme, 1998). However, when no such cues or constancies are present, or when cues are misleading, older adults find it difficult to identify target objects, particularly when targets overlap with distractors in physical or conceptual features (Humphrey & Kramer, 1997; Plude & Doussard-Roosevelt, 1989). Research has moved beyond simply describing age differences in attentional patterns to determining the cognitive mechanisms that are responsible for these differences.

### Aging and Inhibition

Hasher and Zacks (1988) proposed that inhibition was a cognitive mechanism that could account for a wide variety of age-related changes in cognition. To be specific, they hypothesized that if inhibition was a compromised cognitive mechanism in older adults, then task irrelevant information would not be prevented from entering working memory, thus leaving fewer resources available to process task relevant information. This proposal served as a catalyst for a variety of studies that focused on inhibitory deficits to explain older adults' selective attention performance. Although the research to date indicates that the relationship between aging, inhibition, and cognitive function is complex (see reviews by McDowd, 1997; Zacks & Hasher, 1997), inhibition has proved a useful explanatory construct with regard to cognitive aging.

One potential explanation for the observed difficulties in determining the relationship between aging and inhibition is that there exist independent varieties of inhibition with different susceptibilities to age effects. Kramer, Humphrey, Larish, Logan, and Strayer (1994) provided evidence consistent with this hypothesis. On a large battery of tasks thought to tap different inhibitory processes (e.g., Wisconsin Card Sorting Test, stopping paradigm, flanker task, and the negative priming task), the researchers found evidence for age deficits only in perseverative responses on the card sorting task and difficulty stopping a response once it was initiated. Furthermore, a pattern of weak correlations among measures of inhibition supported the idea of independent varieties of inhibition.

McCrae and Abrams (2001) provided further evidence for specific inhibitory deficits associated with age by using the inhibition of return (IOR) paradigm. In this paradigm, the viewer's attention is directed to spatial locations with the use of peripheral onset cues. Although a spatial cue usually facilitates responses to items sub-

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sequently presented at that location, if attention is drawn away before the item is presented (by a second cue or a long delay), then detection of items subsequently presented at the initially cued location is delayed compared with items presented at an uncued location (Posner & Cohen, 1984). This slowing is thought to reflect a slowed return of attention to explored but noninformative locations, thus promoting novelty in search (Klein, 2000; Posner & Cohen, 1984). A series of IOR studies conducted in the last decade have largely found age constancies in IOR (Faust & Balota, 1997; Hartley & Kieley, 1995; Langley, Fuentes, Overmier, Bastin de Jong, & Prod'Homme, 2001), suggesting that cue-induced inhibition in a visuospatial task is not disrupted in older adults.

McCrae and Abrams (2001) found age-related deficits in a specific form of IOR called *object-based IOR*. As first demonstrated by Tipper, Driver, and Weaver (1991), IOR can be associated with moving objects (object-based IOR) as well as with stationary locations (location-based IOR). Using a modified paradigm in which the objects in the display moved after cue presentation, McCrae and Abrams found that both younger and older adults demonstrated location-based IOR (both groups were slower to detect items presented at the initially cued location compared with an uncued location). However, only younger adults demonstrated object-based IOR (they were slower to detect items presented within a cued but relocated object compared with an uncued object). This finding suggests that age deficits in inhibition are more evident for processing of object than of location information.

### IOR and Inhibitory Tagging

A recently reported inhibitory phenomenon that is thought to accompany IOR is inhibitory tagging. Fuentes, Vivas, and Humphreys (1999) proposed that within visuospatial tasks, inhibitory tagging is a secondary process that acts on stimuli presented at cued (inhibited) locations to hinder access to associated responses. Initial evidence for inhibitory tagging came from studies combining the IOR paradigm with semantic priming and flanker tasks. Fuentes et al. (1999) found that priming and flanker effects were reversed when the prime or flanker was presented at inhibited (cued) locations. For example, in a typical flanker task, performance is faster when a compatible flanker (a stimulus from the same category as the target) accompanies the target than when the target is paired with an incompatible flanker (a stimulus from a competing response category). However, Fuentes et al. found that when the flanker was presented to the cued (inhibited) location, flanker effects were reversed (participants were slower in the compatible than in the incompatible condition). The researchers explained their findings this way: An inhibitory tag at the cued location resulted in an inhibitory link between the flanker and its response. This tag slowed performance when the category of the target and flanker was the same, and it eliminated interference when the target and flanker belonged to different categories.

Additional evidence for inhibitory tagging has come from studies combining IOR with the Stroop task. Vivas and Fuentes (2001) found that Stroop interference (incongruent minus neutral condition) was reduced or eliminated when the target stimulus (e.g., the word RED printed in green) fell at a cued location relative to an uncued location. It is important to note that in the Stroop task, the task-irrelevant response (word naming) is the prepotent response (e.g., greater strength due to automatic activation or overlearning of the reading response). These results suggest that inhibitory

tagging is applied not only to relevant but also to irrelevant but prepotent dimensions of stimuli presented at locations subject to IOR.

### The Present Study

A further understanding of age susceptibilities to distinct forms of inhibition may play an important role in explaining age patterns of selective attention. Thus, the purpose of the present study was to use the combined Stroop-IOR paradigm to simultaneously examine age effects in two forms of inhibition: IOR and inhibitory tagging. On the basis of past research that has revealed location-based IOR effects are largely intact with age (Faust & Balota, 1997; Hartley & Kieley, 1995), we predicted that younger adults and older adults would produce IOR effects of similar magnitude. With regard to Stroop patterns, we predicted that older adults would demonstrate interference effects that were as large if not larger than those demonstrated by younger adults (Hartley, 1993; Spieler, Balota, & Faust, 1996; Verhaeghen & De Meersman, 1998). We were uncertain how age would affect inhibitory tagging, because this particular form of inhibition has yet to be studied in older adults. However, because there is some evidence (McCrae & Abrams, 2001) that stimulus-related inhibitory effects (e.g., object-based IOR) are more susceptible to age than location-related inhibitory effects (e.g., location-based IOR), we predicted that inhibitory tagging would be less evident in the performance of older adults. Thus, we predicted that the interaction between Stroop effects and IOR effects would be greater in younger adults compared to older adults, with younger adults demonstrating a more dramatic reduction in Stroop effects at the cued location.

### Method

#### *Participants*

Twenty-four younger adults (14 women and 10 men) and 24 older adults (17 women and 7 men) participated in the study. Younger adults ( $M$  age = 21.5,  $SD$  = 4.0) were college students in psychology courses who received extra credit for participation; older adults ( $M$  age = 68.8,  $SD$  = 5.6) were recruited from the community and received \$15 for participation. All participants had attained at least a high school education ( $M$  = 14.5 years,  $SD$  = 1.3 for younger adults,  $M$  = 14.4 years,  $SD$  = 2.8 for older adults), and according to self-report on a health questionnaire (Christensen, Moyer, Armon, & Kern, 1992), they were free of serious medical conditions that could impair cognitive functioning (e.g., heart disease, cancer, stroke, dementia, depression, drug or alcohol abuse). All participants scored a 26 or higher ( $M$  = 29.3,  $SD$  = 0.7 for both younger and older adults) on the Mini-Mental State Examination (Folstein, Folstein, & McHugh, 1975) and a 45 or higher ( $M$  = 59.8,  $SD$  = 6.5 for younger adults;  $M$  = 68.5,  $SD$  = 8.4 for older adults) on the Vocabulary subscale of the Wechsler Abbreviated Scale of Intelligence (Wechsler, 1999). Corrected near visual acuity was 20/40 or better as assessed by a Snellen eye chart, and color vision was normal (i.e., 9 points or higher out of 11) as assessed by the Ishihara color plates. An additional 11 participants (6 younger adults, 5 older adults) were tested but did not meet these inclusion criteria and were thus replaced.

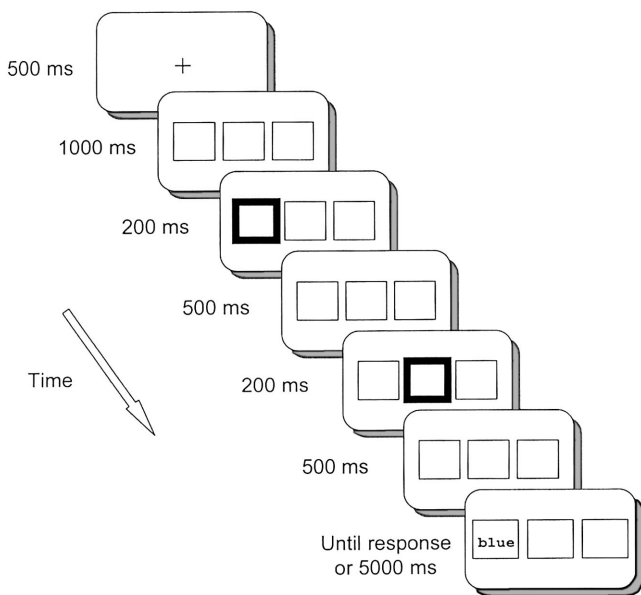
#### *Materials and Stimuli*

The experimental task was created using E-Prime (Version 1.1, Psychology Software Tools, Pittsburgh, PA). Stimuli were presented on a 17-in. color monitor controlled by a PC computer with a Pentium 4 processor. The stimulus display consisted of a black background with three white unfilled boxes arranged horizontally across the center of the screen. The

boxes, located  $15.0^\circ$  from the top of the viewing screen, subtended visual angles of  $4.3^\circ$  in width  $\times$   $2.9^\circ$  in height at a viewing distance of 40 cm, and the centers of the boxes were separated by  $6.4^\circ$ . Target stimuli consisted of neutral and incongruent Stroop stimuli. In the neutral condition, a string of four lowercase Xs was presented in red, green, or blue. In the incongruent condition, the words "red," "green," and "blue" were presented in an incongruent color of red, green, or blue. The stimuli, presented in Courier font, were  $1.1^\circ$  in height and an average of  $2.8^\circ$  in width (range  $2.2^\circ$ – $3.6^\circ$ ). With two levels of cue–target relation (cued and uncued) and two levels of Stroop condition (neutral and incongruent), there were four conditions in total. There were 48 trials per condition resulting in 192 trials. Within each condition, cues and targets were presented an equal number of times to the left and to the right. Participants responded by pressing one of three colored buttons on a PST Serial Response Box (Psychology Software Tools, Pittsburgh, PA).

### Procedure

The session (including consent, screening, and computer task) lasted approximately 1.5 hr. The experimenter explained the computer task to participants by using verbal instructions and a drawn representation of stimulus events. After 36 practice trials, participants completed 2 test blocks of 96 trials. The trial sequence, presented in Figure 1, began with a fixation cross presented for 500 ms. The fixation was replaced by three white boxes that remained on the screen for the duration of the trial. After 1,000 ms, the outline of the left or right box increased in width (from 2 to 8 points) for 200 ms, serving as the initial spatial cue. After 500 ms, the center box increased in width for 200 ms (the central cue). The interstimulus interval (ISI) between the central cue and target was 500 ms. The target stimulus appeared either in the location of the initial cue (the cued condition) or in the other outer box (the uncued condition), and it consisted of an incongruent or a neutral Stroop stimulus. The target remained on the screen until a response or 5 s had elapsed. Participants pressed a button corresponding with the color in which the target stimulus was presented. Speed was emphasized but not over accuracy.



*Figure 1.* Sequence of events for a sample trial. Stimuli are not scaled to size. In the experiment, white outlined boxes were presented against a black background, and target stimuli were presented in a red, green, or blue font color.

### Results

Mean RTs and error rates are reported in Table 1. Response times that were less than 250 ms or more than 3,000 ms were removed as outliers, which eliminated less than 1% of trials for each age group. Median RTs (correct trials only) were then calculated for each combination of task condition and participant and submitted to a  $2 \times 2 \times 2$  mixed analysis of variance (ANOVA) with age group (younger adults and older adults) as the between-subjects factor and Stroop condition (neutral and incongruent) and target location (cued and uncued) as the within-subjects factors. All main effects were significant: age group,  $F(1, 46) = 43.16$ , Stroop condition,  $F(1, 46) = 91.41$ , and target location,  $F(1, 46) = 18.74$ , all  $ps < .0001$ . Older adults were slower than younger adults (1,066 ms vs. 670 ms, respectively), the Stroop effect was evidenced by slower responses to incongruent targets than to neutral targets (928 ms vs. 808 ms, respectively), and the IOR effect was evidenced by slower responses to targets at the cued location than at the uncued location (885 ms vs. 852 ms, respectively). In addition, we observed significant two-way interactions of age group with Stroop condition,  $F(1, 46) = 24.59$ ,  $p < .0001$ , and age group with target location,  $F(1, 46) = 15.38$ ,  $p < .001$ . Both Stroop effects (incongruent RTs minus neutral RTs) and IOR effects (cued RTs minus uncued RTs) were significantly greater for older adults ( $M$  Stroop effect = 181 ms;  $M$  IOR effect = 63 ms) compared with younger adults ( $M$  Stroop effect = 57 ms;  $M$  IOR effect = 3 ms). Finally, it is important to note that these two-way interactions were modified by a significant three-way interaction of age group, Stroop condition, and target location,  $F(1, 46) = 6.50$ ,  $p < .05$ .

To examine the three-way interaction, we conducted separate  $2 \times 2$  ANOVAs for each age group. For younger adults, there was a main effect of Stroop condition,  $F(1, 23) = 21.98$ ,  $p < .0001$ , consistent with the traditional Stroop effect (incongruent RT > neutral RT). There was no effect of target location ( $F < 1$ ), but there was a significant interaction between target location and Stroop condition,  $F(1, 23) = 13.17$ ,  $p < .01$ . The Stroop effect was significantly smaller at the cued location compared with the uncued location (29 ms vs. 87 ms, respectively). For older adults, there were main effects of Stroop condition,  $F(1, 23) = 69.42$ ,  $p < .0001$ , and target location,  $F(1, 23) = 31.98$ ,  $p < .0001$ , reflecting Stroop effects and IOR effects, respectively. However, the interaction was not significant ( $F < 1$ ). Contrary to the pattern found for younger adults, there was no reduction in the magnitude of older adults' Stroop effects at cued compared with uncued locations (195 ms vs. 168 ms, respectively).

Age differences in Stroop and IOR effects were further examined with proportional change scores to reduce the effects of age-related generalized slowing. Stroop effects (calculated by dividing incongruent–neutral difference scores by neutral RTs) were significantly greater for older adults compared with younger adults at the cued location (.21 and .05, respectively),  $F(1, 46) = 20.63$ ,  $p < .0001$ , but not at the uncued location (.18 for older adults, .14 for younger adults),  $F(1, 46) = 0.97$ ,  $p > .20$ . IOR effects (calculated by dividing cued–uncued difference scores by uncued RTs) were significantly greater for older adults compared with younger adults when targets were incongruent Stroop stimuli (.08 and  $-.03$ , respectively),  $F(1, 46) = 14.20$ ,  $p < .001$ , but not when they were neutral Stroop stimuli (.06 for both younger and older adults;  $F < 1$ ).

Table 1  
Reaction Times (RTs; ms) and Error Rates (%)

Target location	Younger adults			Older adults		
	Inc	Neut	Stroop	Inc	Neut	Stroop
RT means (ms)						
Cued	686	657	29 <sup>a</sup>	1195	1000	195 <sup>a</sup>
Uncued	712	625	87 <sup>a</sup>	1119	951	168 <sup>a</sup>
IOR	-26	32 <sup>a</sup>		76 <sup>a</sup>	49 <sup>a</sup>	
RT SDs (ms)						
Cued	146	146	51	285	254	137
Uncued	165	146	88	283	244	118
IOR	75	51		103	72	
Error means (%)						
Cued	1.9	1.6	0.3	3.2	1.1	2.1
Uncued	1.7	1.6	0.1	2.7	0.7	2.0
IOR	0.2	0.0		0.5	0.4	

Note. Inc = incongruent Stroop condition. Neut = neutral Stroop condition. Stroop = incongruent RT - neutral RT (mean difference score). IOR (inhibition of return) = cued RT - uncued RT (mean difference score).

<sup>a</sup>The difference score was significantly different from 0 by *t* test,  $p < .05$ .

Mean error rates (see Table 1) were low overall (1.7% for younger adults, 1.9% for older adults). Errors were submitted to the same  $2 \times 2 \times 2$  mixed ANOVA used for the RT analysis. The only significant effect was for the Stroop condition,  $F(1, 46) = 4.68$ ,  $p < .05$ , with slightly higher error rates in the incongruent condition (2.4%) than in the neutral condition (1.3%).

## Discussion

The purpose of the present study was to investigate age patterns in two inhibitory processes: IOR and inhibitory tagging. With a combined Stroop and IOR paradigm, we found that both age groups demonstrated location-based IOR when responding to neutral Stroop stimuli, and the magnitude of IOR did not differ between groups. Thus, older adults were as likely as younger adults to slow the return of attention to recently attended locations. These results add to growing evidence that basic IOR patterns are preserved with age (Faust & Balota, 1997; Hartley & Kieley, 1995). In addition, Stroop effects were observed in the performance of both age groups. Younger and older adults were slower to name a word's ink color when the word named an incongruent color. At locations not subject to inhibition (the uncued location), Stroop effects were greater for older adults compared with younger adults, but this age difference was no longer significant with a proportional analysis. These results are consistent with an increased susceptibility to Stroop interference with age that can be accounted for in part by generalized slowing (McDowd & Shaw, 2000; Verhaeghen & De Meersman, 1998).

Turning to Stroop interactions, we found evidence for inhibitory tagging in the performance of younger adults. Their Stroop scores were significantly reduced at cued (inhibited) locations relative to uncued locations, replicating findings by Vivas and Fuentes (2001). The present results can be explained in terms of inhibitory tagging of responses associated with the word-level representation of Stroop stimuli. As suggested earlier, it appears that tagging, initiated by location-based inhibition of return, temporarily suppressed the *prepotent* response associated with the stimulus. In

most cases, the prepotent response is also the relevant response, but under these conditions it was not. Further evidence that tagging is associated with the prepotent response for Stroop stimuli could be gathered by switching the demands of the task to reading the word (now the *prepotent* and *relevant* response) and ignoring the color. This change in task demands should lead to increased rather than decreased Stroop interference at the cued compared with the uncued location if the relevant response is tagged. On the other hand, if tagging is under some form of top-down control that identifies distraction based on task goals, then it is possible that switching the demands of the Stroop task to reading the word will lead to inhibitory tagging of color naming. Continued exploration is needed to further specify the nature of inhibitory tagging.

An important finding from this study is that older adults did not demonstrate inhibitory tagging. For this age group, there was no interaction between Stroop effects and the location of the stimulus. The magnitude of older adults' Stroop effects, although at least as great in magnitude compared to those of younger adults, did not diminish from uncued to cued locations. To summarize, within a single task we found separate age patterns for two inhibitory processes. Older adults successfully inhibited the return of attention to recently attended locations, demonstrating the same IOR pattern as younger adults. However, older adults' performance did not reflect inhibitory tagging of stimuli at inhibited locations. This dissociation is consistent with the proposal by Kramer et al. (1994) that age does not similarly affect all forms of cognitive inhibition and supports findings from other studies (Connelly & Hasher, 1993; McCrae & Abrams, 2001) that indicate location-based inhibitory processes are more resistant to aging than stimulus-based inhibitory processes. Of course, future studies will need to determine whether selective deficits in inhibition best explain the present age pattern. An alternative explanation worth considering is an age deficit in information transmission rather than inhibition. Because tagging is initiated by IOR, it is dependent on input from spatial processing areas of the brain. Thus, inhibitory tagging may be intact with age, but because of a breakdown in information transfer, brain areas responsible for initiating tagging may not receive the appropriate signals from brain areas responsible for IOR.

Although the present study does not address the neural basis of inhibitory mechanisms, the results can be considered in light of previous neuropsychological findings. Patients with parietal lobe lesions (Vivas, Humphreys, & Fuentes, 2003), frontal lobe lesions (Vivas, Fuentes, & Humphreys, 2004), and schizophrenia (Fuentes, Boucart, Vivas, Alvarez, & Zimmerman, 2000) have all been tested on the Stroop-IOR paradigm. Together the evidence from these studies suggests that IOR, modulated by the posterior parietal cortex, provides a signal to anterior frontal areas that sets a temporary inhibitory link between stimuli at inhibited locations and their responses (see review by Fuentes, 2004). Older adults in the present study exhibited the same inhibitory pattern as two patient groups with known frontal lobe impairments. Several theories of cognitive aging confer a prominent role to altered frontal lobe functioning to explain age-related cognitive deficits (Braver & Barch, 2002; Cabeza, 2002; West, 1996). It is unlikely that a simple frontal aging hypothesis can capture the full complexity of cognitive changes that accompany aging (Band, Ridderinkhof, & Segalowitz, 2002; Greenwood, 2000), but nevertheless, specific changes within the frontal lobes may account for a subset of observed inhibitory deficits. In fact, the present findings are con-

sistent with the pattern of inhibitory deficits observed by Kramer et al. (1994). They found preserved negative priming and IOR effects in older adults, which they argued are mediated by non-frontal visual processing areas, but performance on Wisconsin Card Sorting Tasks and stopping tasks was impaired, which they argued are mediated by frontal areas.

In conclusion, this study offers support for differential inhibitory patterns with age. Measured within the same task, older adults demonstrated normal location-based IOR effects, but they did not display stimulus-linked inhibitory tagging effects. These findings are consistent with two models of aging and inhibition (that themselves may be compatible). One model argues that location-based inhibition is more resistant to age than object-based inhibition; the other model argues that inhibition mediated by nonfrontal brain areas is more resistant to aging than frontally mediated inhibition. Although the present study cannot distinguish between the two models, the findings do argue against generalized inhibitory deficits with age.

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