AGING AND OBJECT-BASED INHIBITION OF RETURN

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The Supervisory Committee certifies that this ***disquisition*** complies with North Dakota State University's regulations and meets the accepted standards for the degree of

MASTER OF SCIENCE

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ABSTRACT

Inhibition of return (IOR) is a cognitive mechanism to bias attention from returning to previously engaged items. While aging models have proposed deficits within select inhibitory domains, older adults have demonstrated preserved IOR functioning in previous studies. The purpose of the present study was to determine whether IOR associated with objects showed the same age patterns as IOR associated with locations. Both young and older adults produced significant location-based IOR in static and dynamic paradigms. In contrast, young adults produced object-based IOR in a dynamic paradigm, whereas older adults failed to produce significant object-based effects. The findings provide partial support for unique age-related inhibitory patterns associated with anterior and posterior attention systems.

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DEDICATION

This thesis is dedicated to my husband, Ben, for his never-ending support. This thesis is also dedicated to my parents, Abner and Yolanda, who showed me what a precious gift education is. This accomplishment would not have been possible without God's grace and the guidance from my wonderful parents.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Figure Page

LIST OF APPENDIX TABLES

INTRODUCTION

Visual attention mechanisms are essential to how we navigate and search through the environment, whether scanning a crowd to find a friend or noticing a motorcycle as it approaches an intersection. There are unique changes that occur in the aging process that impact the way older adults perceive and respond to their visual environment. While some attention mechanisms are preserved with age, some are sensitive to decline and impact search performance (Foster, Berhmann, & Stuss, 1995; Madden & Whiting, 2004; Verhaeghen & Cerella, 2002). In this thesis, I focused on age-related changes of two inhibitory mechanisms of exogenous visual orienting. The purpose of the present study was to assess whether there are greater age-related deficits in object-based compared to location-based inhibition. I will first review in the introduction orienting and inhibition of return (IOR) and how they change with age. I will distinguish between location- and object-based IOR and outline how testing for age patterns in these two types of inhibition informs theories of cognitive aging.

Orienting of Attention

Orienting is typically classified as exogenous or endogenous. When a salient or abrupt sensory event occurs, such as a stimulus entering the field of vision, an individual automatically orients their attention to the item. This reflects exogenous orienting, or a reflexive response to a salient stimulus. Second, orienting of visual attention can be driven by internal goals and expectancies (endogenous or volitional orienting). Exogenous and endogenous orienting systems seemingly work independently with some interaction depending on environmental circumstances (Chica, Bartolomeo, & Lupiáñez, 2013). A second and independent dimension by which orienting can be classified is covert and overt. Shifting attention covertly means with the absence of eye or head movement, whereas overt involves accompanying eye movements. Patterns of exogenous and endogenous orienting are for the most part consistent across covert and overt measures of orienting (Posner & Cohen, 1984; Posner, Snyder, & Davidson, 1980).

In a laboratory setting, orienting is assessed using a cueing paradigm in which a spatial cue is followed by a target (Posner, 1980). A visual cue (e.g. brightening of a peripheral object or onset of a central directional cue such as an arrow) is presented to direct attention to a particular location before a target is presented at one of the two or more peripheral locations (e.g. to the left, right, above, or below the central cue). The target (e.g. a solid square within a box) is then presented at one of the peripheral locations. Participants are instructed to respond rapidly to the target. Participants respond to the target by pressing a button as soon as they see it (detection response) or by responding to a particular feature of the target (e.g. location or identity discrimination). Participants can make the response with accompanying eye movements to the target (overt orienting) or while maintaining fixation at a central location (covert orienting).

Exogenous orienting is typically assessed using a peripheral cue that automatically captures attention. Endogenous orienting is assessed using a central symbolic cue that is often accompanied by an incentive to attend to the cue (e.g., the cue correctly indicates the location of the target on the majority of trials). For both types of cues, a target appearing in the same or indicated location (cued) is more quickly detected compared to a target presented at an uncued or non-indicated location (uncued). The facilitated response to a cued target is presumably due to attention previously being drawn to the location by the cue. Detecting a target at an uncued location requires disengaging and shifting attention from the cued location to the target and therefore takes longer. The time course of exogenous and endogenous orienting differs, with exogenous orienting benefits developing quickly (e.g., within 50 ms of cue onset) and also resolving quickly (e.g., by 300 ms of cue onset). Endogenous orienting develops more slowly (e.g., requiring at least 100 ms post-onset of cue) and is slower to resolve (in some cases, lasting several second; Posner & Cohen, 1984).

To distinguish the attentional benefits of a cued condition from the costs of an uncued condition, in some studies a neutral, non-directional cue (e.g., all peripheral location being brightened or a central double-headed arrow) is presented on some trials (Posner et al., 1980). Participants showed faster reaction times (RTs) to the cued condition compared to the neutral condition, reflecting the benefit of a cue directing attention to the target location. Responses are slower to the uncued conditions compared to the neutral condition, consistent with the cost of having to disengage attention from an uncued location and shift to the target location (Posner, 1980).

The present investigation used the aforementioned spatial cueing paradigm to assess age-related changes of inhibition in exogenous orienting, using a salient peripheral cue. As previously mentioned, when the target is presented within 300 ms of the cue onset, participants are faster to detect the target at the cued compared to the uncued location. However, for exogenous orienting, there is a biphasic pattern of cueing effects in the spatial cueing paradigm that reflects facilitation and inhibition (Posner & Cohen, 1984). When the target is presented more than 300 ms after the peripheral cue onset, participants are slower to detect the target at the cued compared to the uncued location. Posner and Cohen (1984) referred to this secondary effect as inhibition of return (IOR). They posited that this observed behavior was due to an attentional mechanism that biased attention to novel areas by orienting attention first towards the peripheral cue, followed by the removal of attention from that location. Attention can be disengaged voluntarily over the course of time or reflexively through the use of a second central cue (Zhou

& Chen, 2008). By drawing attention away from the peripheral cue, attention is inhibited from returning to that location.

Due to the findings that IOR is observed following peripheral onset cues but not central symbolic cues, IOR is considered an operation of exogenous attention, driven by a change in luminance or appearance and disappearance of objects at a peripheral location (Klein & Taylor, 1994; Maylor & Hockey, 1985; Rafal, Calabresi, Brennan, & Sciolto, 1989; Rafal & Henik, 1994; Taylor & Klein, 1998). It has been proposed that IOR is a motor response bias against the location of the cue, caused by oculomotor programming (Rafal et al., 1989; Taylor & Klein, 1998), although later evidence indicates that IOR is also an attentional phenomenon (Kingstone & Pratt, 1999; Klein, 2000). Since IOR can be observed with manual or saccadic responses, both cortical and subcortical areas are implicated in the effect, with oculomotor programming occurring in the superior colliculus and spatial information of the cue being processed in the parietal cortex (Taylor & Klein, 1998).

Object- and Location-based Inhibition of Return

In Posner's spatial cueing task, IOR is associated with locations. However, in real life events, such as driving, many of the objects in our environment do not remain stationary. This leads to the question of whether IOR is associated with objects as well as locations. The answer may impact the manner in which IOR assists visual search. Tipper, Driver and Weaver (1991) tested whether the IOR mechanism has qualities that respond appropriately to the moving nature of objects by modifying the spatial cueing task was modified to incorporate moving boxes. The center box remained fixed while the peripheral boxes rotated in a circle clockwise around it after one of the boxes was cued. A target was presented on one of the peripheral boxes, to which the participants made a speeded detection response. When the target appeared in the cued box (which was no longer in the cued location following rotation), participants were slower to detect the target than when the target was presented on an uncued object. These findings indicated that IOR was not solely tied to spatial locations but also attached to objects presented at those locations. An IOR effect for the dynamic display, calculated by subtracting uncued RTs from cued RTs, was compared against data from a static display in which the objects stayed in one place. A significant interaction of condition (static vs. dynamic) × cue (cued vs. uncued) indicated that greater IOR effects were produced under a static environment compared to a dynamic display. A two-component model would suggest that a summation of both object- and location-based IOR was what produced the larger IOR effect observed in the static spatial cueing paradigm (Jordan & Tipper, 1998).

Egly, Driver, and Rafal (1994) developed another cueing paradigm that could distinguish between location-based and object-based attention. Two rectangles, one on each side of a central fixation point, were presented to the participant. A peripheral cue appeared at one end of a rectangle. A target would then appear at the same location as the cue (cued-location), at the uncued end of the cued rectangle (cued-object), or at the uncued location (uncued) within the uncued rectangle that was an equal distance from the cued-location as the cued object. At a short cue-target SOA of 200 ms, participants detected cued-location targets more quickly than targets at the uncued and cued-object locations, showing facilitation effects. An analysis of the equidistant uncued and cued-object conditions indicated that participants detected the target more quickly when it appeared within the cued object compared to the uncued object. This finding was interpreted as a greater benefit in detecting the target when attention could shift within an object rather than cross boundaries to another object. Additionally, the design provided an opportunity to observe location-based (cued location) and object-based (uncued location within attended object) components of covert orienting in a single task (Egly et al., 1994). This paradigm has been used to test IOR in young adults by extending the cue-target interval to 400-1220 ms and has shown reliable location- and object-based IOR effects within this age group (Jordan & Tipper, 1999; List & Robertson, 2007; Reppa & Leek, 2003).

Aging and Inhibition of Return

Cognitive changes with age can be characterized in terms of preservations, declines, enhancements, and qualitative changes. In visual attention tasks, older adults experience a range of preserved and impaired functioning (Foster et al, 1995; Madden & Whiting, 2004; Verhaeghen & Cerella, 2002). Exogenous orienting is considered to be relatively stable in aging, whereas endogenous orienting demonstrates more instances of compromised functioning, particularly with increased task difficulty (Folk & Hoyer, 1992; Olk & Kingstone, 2009; Olk & Kingstone, 2015). This is consistent with the proposed theory of constancy in automatic processing compared to age-sensitive decline in controlled or effortful processes (Craik & Byrd, 1982; Hasher & Zacks, 1979). Older adults have been observed to produce magnitudes of IOR that are comparable to young adults (Faust & Balota, 1997; Hartley & Kieley, 1995) although they may not show IOR until a later time point compared to young adults when cue-target intervals are manipulated (Castel, Chasteen, Scialfa, & Pratt, 2003; Hartley & Kieley, 1995; Madden, 1990).

There are two studies that examined age-related differences in object- and location-based IOR. In the first study, McCrae and Abrams (2001) conducted a series of experiments to study IOR in a static paradigm and object- and location-based IOR in dynamic paradigms. In the static double-cue task using the traditional Posner spatial cueing paradigm, both young and older adults produced reliable IOR effects in which responses were slower to targets at cued compared to uncued locations (Experiment 1). In an experiment to assess location-based IOR in a dynamic display (Experiment 4), the design was modified so that four boxes rotated 90° clockwise around the central fixation point between the presentation of the cue and target. Because the boxes rotated, the location-based cued condition consisted of a target presented at the cued location, now occupied by a new box. The target in the uncued condition was presented at the box located opposite from the cue location; the was target never presented at the other two boxes. In this experiment, both age groups produced location-based IOR effects, with older adults (*M* = 24 ms) producing larger effects compared to young adults (*M* = 9 ms). To measure object-based IOR, a similar paradigm was used but only two boxes on opposite sides of a fixation point were presented and again rotated 90° following a peripheral cue. Following the rotation, the object-based cued condition consisted of the target being presented in the originally cued box, now at a new location. The target in the uncued condition was presented at the box located opposite from the target location. In this experiment (Experiment 2), only young adults produced object-based IOR effects (*M* = 7 ms), whereas older adults produced facilitation effects to the object (*M* = 14 ms). Due to the age-related change in the time course of IOR (Langley et al., 2007), the possibility existed that older adults' inhibitory effects were missed because the time window of 467 ms did not accommodate this age-related change in the development of IOR. McCrae and Abrams (2001) conducted an additional experiment using the object-based paradigm, with four cue-target SOA intervals, 467, 1176, 2467, and 3967 ms. Although young adults produced IOR effects at the shortest SOA, older adults did not demonstrate inhibition effects at any of the SOA intervals (Experiment 3). The authors interpreted this finding as evidence for the lack of object-based IOR in older adults even when given additional time.

McAuliffe, Chasteen, and Pratt (2006) examined age differences in location- and object-based IOR using a static paradigm. The paradigm consisted of two placeholder boxes, left and right of the fixation point. A peripheral cue could be presented on either of the two boxes or on an empty space above or below the fixation point. The fixation point was cued to draw attention back to the center before the target was presented at one of the locations (above, below, left, or right of the fixation point). Location-based IOR was measured as the difference between RTs of the cued and uncued trials when the cue and target were presented at one of the empty spaces. IOR at cued objects was calculated as the difference between RTs of the cued and uncued trials when the cue and target were presented on the boxes. Object-based IOR was calculated as the difference between location-based IOR and IOR at cued objects. Location-based IOR was produced by both age groups. Object-based IOR was only produced by young adults, with older adults showing no significant inhibition to the object. Thus, across two studies (McAuliffe et al., 2006; McCrae & Abrams, 2001), older adults demonstrated intact location-based IOR and impaired object-based IOR.

Aging and Attentional Inhibition

According to the inhibitory deficit hypothesis of aging, age-related cognitive changes are explained by an inefficient inhibitory system that results in increased distraction by irrelevant items and impaired processing of relevant items (Hasher & Zacks, 1988). However, it is now more broadly accepted that inhibition is not uniformly affected by age. Rather, specific inhibitory processes are resistant to decline, while other components are more susceptible to age-related changes (Connelly & Hasher, 1993; Kramer, Humphrey, Larish, Logan, & Strayer, 1994; Verhaeghen, 2011). Consistent with an argument for independent inhibitory processes, Nigg (2000) proposed a taxonomic view of inhibition which distinguishes between executive and automatic inhibition. Tasks requiring executive inhibition would include the Stroop task, dual tasks, and go/no-go tasks because they involve interference control and response suppression. The neural components associated with these tasks are predominantly frontal and orbitofrontal networks, consistent with frontal lobe models of age-sensitive inhibitory systems (Arbuckle & Gold, 1993; Dempster, 1992; Hartley, 1993; Kramer et al., 1994). In contrast to executive control, the automatic inhibition class consists of attentional orienting tasks such as IOR. In accordance with frontal lobe models of aging, age-related impairments would be expected in executive inhibition but not automatic inhibition (Arbuckle & Gold, 1993; Dempster, 1992; Hartley, 1993; Kramer et al., 1994). While a frontal lobe model may support previous research of preserved IOR with age, it may not address age-related impairments of object-based IOR.

Posner and Petersen (1990) proposed a posterior and anterior attentional system based on neuroscientific evidence. The posterior regions (posterior parietal, thalamus, and superior colliculus) were considered fundamental to orienting attention to locations (Posner, Walker, Friedrich, & Rafal, 1984). Parietal areas play an important role in disengaging attention from their current location, whereas subcortical areas such as the superior colliculus and pulvinar are involved with shifting and engaging spatial attention (Chica et al., 2013). The anterior attentional system incorporates the fronto-parietal network and anterior cingulate cortex and is proposed to coordinate attentional components such as selection of relevant object features and linking an appropriate motor plan (Chica et al., 2013; Corbetta, Patel, & Shulman, 2008; Corbetta & Shulman, 2002). The prefrontal regions are involved less with spatial functioning and more with executive (e.g. allocating limited attentional resources) and modulating other brain areas (including the parietal regions; Madden, Whiting, & Huettel, 2005).

Findings of age-insensitive location-based IOR (Hartley & Kieley, 1995; McCrae & Abrams, 2001; McAuliffe et al., 2006), location-based negative priming (Tipper, Brehaut, & Driver, 1990), and expanding/contracting attention focus within the visual field (Hartley, Kieley, & McKenzie, 1992) support preserved inhibitory functioning associated with the posterior attentional system. In contrast, age-related impairments have been observed with tasks that incorporate the anterior attention system. These tasks include feature-based negative priming (Hasher, Stoltzfus, Zacks, & Rypma, 1991; McDowd & Oseas-Kreger, 1991) and object-based inhibitory tagging (Langley et al., 2007).

There is evidence that non-spatial IOR is associated with the anterior attention system. Zhou and Chen (2008) conducted a neuroimaging study investigating neural activity in location-based and non-spatial (color) IOR using the Posner cueing paradigm. For non-spatial trials, cues and targets were presented in a central box. The cue and target could present as the same (cued) or different (uncued) colors. Significant location- (42 ms) and color-based IOR (13 ms) effects were observed. The authors identified a central role of the bilateral precentral gyrus and frontal eye fields in both components of IOR, suggesting that these areas are involved with the bias of returning attention to the previously cued item. However, the authors were also able to identify that location-based and non-spatial inhibition were driven by differentiable neural correlates. Bilateral superior parietal activity was isolated to location-based IOR, consistent with the posterior attentional system and its role in processing spatial information (Corbetta & Shulman, 2002; Goodale & Milner, 1992; Posner & Petersen, 1990). In contrast, non-spatial inhibition was associated with activity of the left middle and inferior frontal gyrus and left ventral lateral and dorsal lateral prefrontal cortices, consistent with the anterior attentional system and its role in processing feature and object-related items (Goodale & Milner, 1992; Posner & Petersen, 1990).

If object-based IOR relies on the same frontal areas, one may conclude that the anterior attention system is involved in non-spatial forms of IOR.

The Present Study

The purpose of the present study was to further explore age differences in object-based IOR using dynamic and static displays. Based on the paradigm of McCrae and Abrams (2001; Experiment 4), the first experiment utilized a dynamic cueing display so that IOR associated with objects could be distinguished from IOR associated with locations. Whereas McCrae and Abrams (2001) evaluated object- and location-based IOR in separate experiments, I utilized a single paradigm that could compare both IOR components within the same experiment. I also utilized a cue-target SOA that may better accommodate age-related changes in the development of IOR. The second experiment assessed object-based IOR in a static environment, utilizing the Egly et al. (1994) paradigm. The aim was to build on these paradigms in order to measure both location- and object-based IOR in single experiments whereas previous studies have examined each component using the same paradigm but in separate experiments.

I predicted that both young and older adults would show significant location-based IOR with both the static and dynamic paradigms. I also predicted that young adults would show significant object-based IOR with both paradigms, whereas older adults would show impaired object-based IOR. A frontal lobe model (Arbuckle & Gold, 1993; Dempster, 1992; Hartley, 1993; Kramer et al., 1994) would suggest that the automatic processing of IOR is preserved with aging. However, a lack of object-based IOR with older adults cannot be fully explained by a basic frontal lobe model that distinguishes between automatic and executive forms of inhibition because there is no evidence that object-based IOR requires greater executive resources than location-based IOR. Instead, as Zhou and Chen (2008) identified distinct neural correlates involved in processing location-based and color-based IOR in young adults, a more appropriate aging model for explaining age-related impairments of object-based IOR may be one in which the posterior attention system (mediating location-based IOR and involving parietal and subcortical areas) is relatively preserved and the anterior attention system (mediating object-based IOR and involving frontal and cingulate areas) is relatively impaired by age.

EXPERIMENT 1

The goal of Experiment 1 was to examine age-related differences in location- and object-based IOR using a dynamic paradigm. As demonstrated in the landmark study by Tipper, Driver, and Weaver (1991), both forms of IOR can be examined in a display in which stimuli are moving. Thus, I based the IOR task used in the present experiment on the Tipper-inspired task developed by McCrae and Abrams (2001; Experiment 4), which used the structure of four peripheral boxes equally spaced around a central fixation point. McCrae and Abrams measured age differences in location- and object-based IOR in separate experiments (location-based IOR in Experiment 4 and object-based IOR in Experiments 2 and 3). Age differences in the two forms of IOR have yet to be assessed with concurrent measurement, although the two forms have been concurrently measured in young adults (Tipper et al.,1991; Tipper, Weaver, Jerreat, & Burak, 1994). Location- and object-based IOR are theoretically independent components, so age differences in the components should be observable in the same experiment.

McCrae and Abrams (2001), found reliable location-based IOR effects for young and older adults at a cue-target SOA of 467 ms (Experiment 4). However, only young adults produced object-based inhibitory effects when tested with the same SOA (Experiment 2). At SOA intervals 1167, 2467, and 3967 ms, young adults produced object-based IOR only at 467 ms, whereas older adults did not produce significant object-based effects at any SOA.

I argue that location- and object-based IOR should be assessed at a cue-target SOA that was not used by McCrae and Abrams (2001; between 467 ms and 1167 ms) because older adults have demonstrated the onset of location-based IOR at cue-target SOAs that were approximately 50-300 ms longer than those at which young adults demonstrated IOR (Castel, Chasteen, Scialfa, & Pratt, 2003). The SOAs over one second that were used by McCrae and Abrams may have been too long (i.e., IOR was already resolved for both age groups) to capture age differences in the time course of IOR. To optimize the cue-target SOA at which IOR could potentially be observed for older adults (Castel et al., 2003; Hartley & Kieley, 1995), I used a cue-target SOA of 698 ms.

I predicted that both young and older adults would produce significant location-based IOR due to preserved spatial inhibitory processes with age (Hartley & Kieley, 1995; McCrae & Abrams, 2001; Tipper et al., 1990). For the object-based condition, I predicted that older adults would show impaired inhibition, consistent with previous research supporting age-related impairments of object-based or object-feature inhibitory processes within the anterior attentional system (Hasher et al., 1991; McCrae & Abrams, 2001; McDowd & Oseas-Kreger, 1991).

Method

Participants

Thirty-five young adults (14 men, 21 women) with an age range of 18-22 years and thirty-five older adults (12 men and 23 women) with an age range of 60-86 years participated in the experiment. Young adults were undergraduate students from North Dakota State University and received course credit for their participation. I recruited older adults through advertisements in a senior newsletter, postings on campus staff and faculty list serves, and from a participant registry maintained by the lab. Older adults were paid $10/hour for their participation.

Participants completed a self-report health questionnaire (Christensen, Moye, Armson, & Kern, 1992), Snellen near visual acuity test (Precision Vision, La Salle, IL), Geriatric Depression Scale (GDS; Yesavage et al., 1983; validated in young adult sample, Ferraro & Chelminski, 1996), Mini-Mental State Examination (MMSE; Folstein, Folstein, and McHugh, 1975), and vocabulary subscale of the Wechsler Abbreviated Scale of Intelligence (WASI; Wechsler, 1999).

Participants were excluded if they had a visual acuity of 20/40 or worse to ensure that all participants could adequately see the stimuli presented on the computer task. I excluded participants with a GDS score of 10 or greater, consistent with symptoms of moderate to severe depression, which may negatively affect reaction time and cognitive function. Participants with an MMSE score of 25 or less, consistent with symptoms of dementia or cognitive impairment, were excluded because it may affect their measured reaction times and ability to follow task instructions. Participants completed the WASI Vocabulary subtest and questions about completed education to determine whether the young and older groups were approximately matched on crystallized intelligence and education level. Exclusions were not made based on the WASI assessment. Additional exclusions were based on health history of conditions that may affect participant measured reaction times, such as stroke, heart attack, and diagnosis of a neurodegenerative disease. Eight older adults were excluded (two for poor acuity, one for low MMSE, one for high GDS, and four for health conditions). Four young adults were excluded (four for high GDS and two for health conditions). Participant data for those who were excluded was replaced with new participants. Characteristics of the final sample are provided in Table 1.

Table 1

Participant Characteristics for Experiment 1

	Mean (SD)	
	Young Adults	Older Adults
Age (years)	18.7 (0.9)	72.5 (5.5)*
% Female	60%	66%
Education (years)	13.2 (0.7)	15.7 (2.5)*
WASI-V	55.3 (8.2)	61.1 (8.2)*
Snellen Acuity (20/_)	16.2 (3.0)	24.4 (5.9)*
MMSE	28.5 (1.0)	29.0 (1.0)*
GDS	1.7 (1.8)	1.1 (1.6)

Abbreviations: SD = standard deviation; WASI-V = Weschler Abbreviated Scale of Intelligence-Vocabulary (Wechsler, 1999). A maximum score of 80 can be obtained, with a higher score indicating better performance. Snellen Acuity = assessment of near vision acuity. A smaller value in the denominator indicates better visions. MMSE = Mini-Mental State Exam. A maximum score of 30 can be obtained, with a higher score indicating better performance. GDS = Geriatric Depression Scale. A maximum score of 30 can be obtained, with a higher score indicating greater symptoms of depression. *Indicates a significant difference between the age groups by independent t test, $p < .05$.

Apparatus and Stimuli

Stimuli were presented on a 33-cm CRT color monitor connected to a Windows 7 Optiplex 790 computer set to a refresh rate of 85 Hz. Stimuli were presented and reaction times were recorded using Presentation software (Version 18.0, Neurobehavioral Systems, Inc., Berkeley, CA). The participants were seated 34 cm from the computer monitor; the distance was held constant with the use of a chin rest. The basic stimulus display consisted of four unfilled boxes (1° x 1° visual angle), each 10° from a fixation cross in the center of the screen. All stimuli were presented in black on a light gray background. The peripheral cue consisted of a thickened border of a box. The central cue consisted of an enlargement of the cross from font size 30 to 36. The target was a filled black box (1° x 1°). Participants were instructed to press the space bar on the keyboard to make responses.

Procedure

Figure 1 illustrates the basic trial sequence. A trial began with the four-box display for 1,000 ms. A peripheral cue was presented for 90 ms, and upon its removal, the peripheral boxes rotated 90° in a clockwise direction. The total rotation occurred for a duration of 350 ms. When the peripheral boxes were 125 ms into rotation, the fixation cross was cued for 225 ms to draw attention back to the center. Once the stimuli finished rotating, the fixation cross remained cued for an additional 258 ms. The total cue-target SOA was 698 ms. The fixation cross returned to its initial uncued state as soon as the target appeared. Upon presentation of the target, participants had 2,000 ms to respond. To reduce target anticipation, 20% of trials were catch trials, in which no target was presented. Participants were instructed to keep fixated on the center cross and press the space bar as soon as they detected the target or to wait until the trial ended if no target was presented. If participants failed to respond to a target within the allotted time, or responded on a catch trial, an error tone (400 Hz for 700 ms) sounded. Following the response, a blank screen appeared between trials for 1,000 ms.

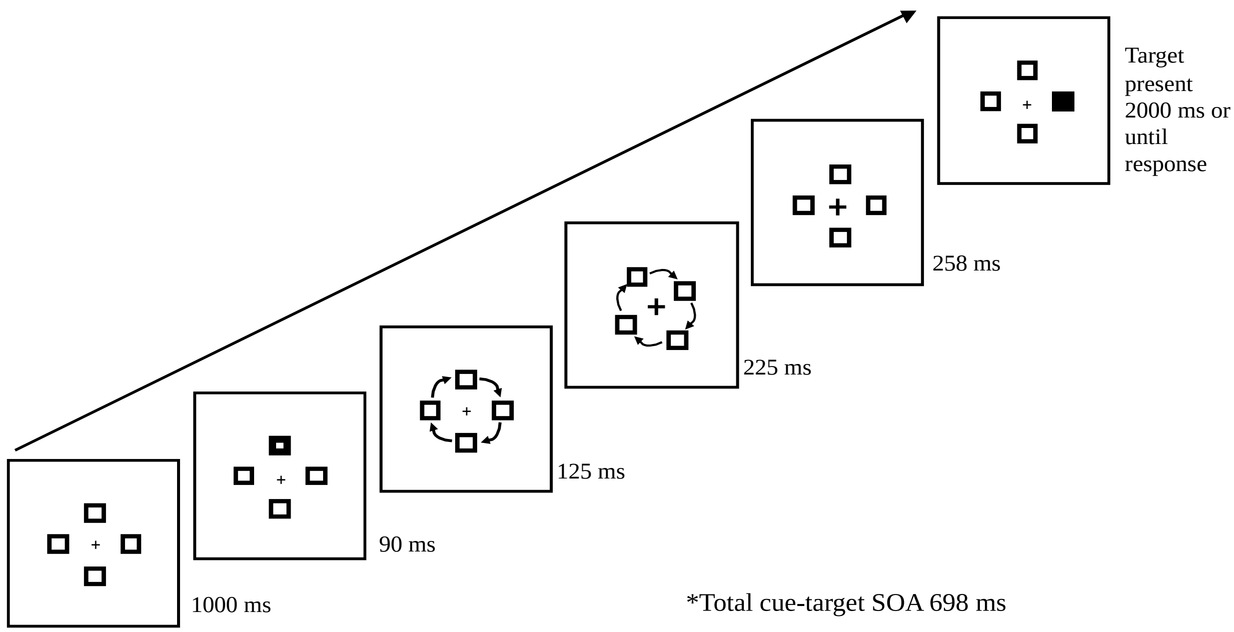

Figure 1. Experiment 1 trial sequence for cued-object condition.
Following a peripheral cue, the stimuli rotated 90° during which the central fixation cross was cued to draw attention back to the center. Following a 698 ms cue-to-target SOA, the target (a filled in black box) was presented at one of the four peripheral boxes. The present example is a cued-object trial.

The cue and target were equally and independently likely to appear in the four boxes. One quarter of non-catch trials (trials in which a target was presented) were cued-object (CO) trials, in which the target appeared in the original box that was cued (and had now rotated 90°). One quarter of the target trials were cued-location (CL) trials, in which the target appeared in the original location that was cued (now in a new box). The remaining half of target trials were uncued (UN) trials, in which the target appeared in a box that was not cued physically or spatially (either across from the cued location or one box counterclockwise from the cued location).

Each participant completed a practice block of 20 trials. During the practice block, the researcher monitored for error tones and provided the participant with additional instructions if needed. Following the practice block, there were 5 test blocks with 60 trials per block. Catch trials and target trials were randomly presented within a block of trials and all conditions were equally presented within a block. A screen presented between blocks instructed the participant to take a break, as needed, and press the space bar to proceed to the next block.

Results

Mean RTs as a function of age group and cue condition are presented in Table 2. Trials with RTs less than 150 ms, greater than 2,000 ms, or greater than 2.5 *SD* from an individual's mean RT were excluded from the analysis. Trials that were deleted for errors (false alarms or misses) were low for both age groups: 2% for young adults and 2% for older adults. Mean RTs for correct trials were submitted to a 2 (age group: young and older adults) × 3 (conditions: cued-location, cued-object, and uncued) mixed ANOVA, with age as the between-subjects variable and cue condition as the within-subjects variable. A main effect was found for age group, $F(1, 68) = 25.96$, $p = .0001$, with young adults showing significantly faster RTs ($M = 392$ ms) compared to older adults ($M = 454$ ms). A main effect was also found for cue condition $F(2, 68) = 9.17$, $p = .0002$, with cued-location showing the longest RTs ($M = 426$ ms), followed by cued-object ($M = 423$ ms), and uncued ($M = 419$ ms). Analysis using a Student-Newman-Keuls (SNK) post hoc test showed significant differences of (a) cued-location and cued-object and (b) cued-location and uncued. A significant group × condition interaction was also found $F(2, 68) = 5.33$, $p = .006$.

To investigate the interaction, one-way ANOVAs examining cue condition effects were conducted within each age group. For young adults, there was a main effect for condition, $F(2, 34)= 9.51$, $p = .0002$. Using an SNK test, cued-location RTs ($M = 395$ ms) and cued-object RTs ($M = 395$ ms) were not significantly different from each other, but both were significantly slower than uncued RTs ($M = 386$ ms), *p*s < .05. For older adults, a main effect was also found for condition, *F*(2, 34) = 5.03, *p* = .009. Cued-location RTs (*M* = 458 ms) were significantly slower than uncued (*M*=452 ms) and cued-object RTs (*M*=451 ms) but cued-object RTs were not significantly slower than uncued RTs.

Table 2

Mean Reaction Times (ms) and Standard Deviations for Experiment 1

	Mean RTs (SD)	
	Young Adults	Older Adults
Cued-location	394.8 (54.5)	458.2 (55.7)
Cued-object	395.1 (50.4)	450.8 (49.3)
Uncued	385.9 (48.9)	452.5 (49.7)

Raw reaction times for the three critical conditions for young and older adults. Abbreviations: RT = reaction time; SD = standard deviation.

The IOR effects were measured as slower responses to a cued locations or objects than to uncued locations or objects. For each participant, the mean RT for the uncued condition was subtracted from the mean cued-location and cued-object RTs separately. These means were submitted to one-way within-subjects ANOVAs to assess age differences In IOR effects. For location-based IOR, there was no significant main effect for age group *F*(1, 68) = .91, *p* = .34, with young adults showing 9 ms and older adults showing 6 ms of location-based IOR. For object-based IOR, a significant effect for group was found *F*(1, 68)= 13.86, *p* = .0004, with younger adults showing an 9 ms effect and older adults showing a -1.6 ms effect.

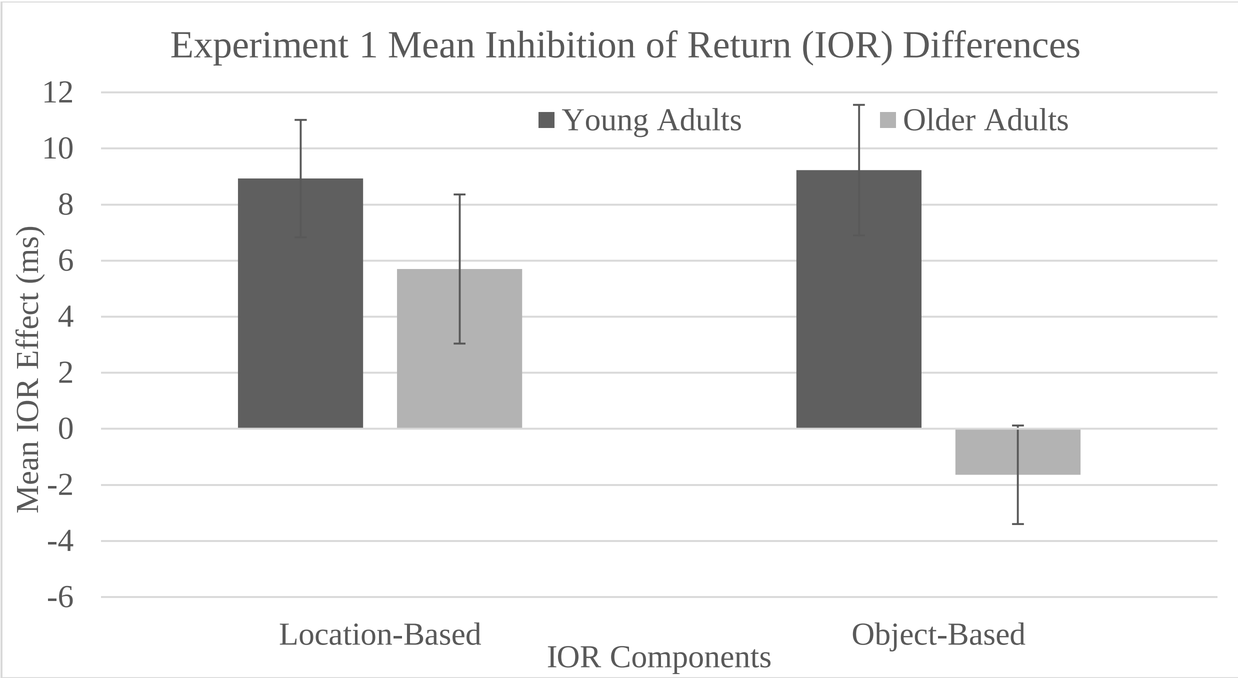

Figure 2. Experiment 1 mean inhibition of return (IOR) differences for young and older adults. IOR effects for young and older adults in a dynamic paradigm. Error bars represent one standard error.

Discussion

In Experiment 1, I had predicted location-based IOR for both age groups and this prediction was supported. Older adults were predicted to show location-based IOR due to preserved spatial inhibitory processes mediated through the posterior attention system. Location-based IOR has been reliably observed in dynamic paradigms with young adults (McCrae & Abrams, 2001, Experiment 4; Tipper et al., 1991; Tipper et al., 1994) and in a single study with older adults (McCrae & Abrams, 2001, Experiment 4). The finding was replicated in the present experiment, and the magnitude of IOR did not differ significantly as a function of age.

I had predicted that young adults would produce object-based IOR based on findings from other studies using a dynamic paradigm (McCrae & Abrams, 2001, Experiment 2; Tipper et al., 1991). In contrast, I predicted that object-based IOR would be diminished in older adults due to age-related changes in non-spatial inhibitory processes mediated by the anterior attention system (Zhou & Chen, 2008). As predicted, there was object-based IOR for young adults, but not for older adults.

It has been proposed that object-based IOR may dissipate more quickly than location-based IOR (Tipper & Weaver, 1998). Additionally, older adults typically produce IOR over a longer time course compared to young adults (Castel et al., 2003; Greenwood, Parasuraman, & Haxby, 1993; Madden, 1990). Although the SOA of the current experiment was lengthened compared to that of McCrae and Abrams (2001, Experiment 4), there exists the possibility that the appropriate interval was not assessed to be able to observe object-based IOR effects for older adults. Future research should incorporate multiple SOA intervals, to observe object-related effects in older adults more comprehensively. While I cannot conclude whether object-based IOR can be observed in the performance of older adults, I can conclude that there are age differences in the nature, or at least the timing, of object-based IOR.

In summary, I investigated location- and object-based inhibitory effects for young and older adults in a dynamic paradigm. Both age groups produced location-based IOR. Only young adults produced object-based IOR. Consistent with my second prediction, older adults did not produce reliable object-based effects. For young adults, location- and object-based IOR effects of similar magnitude were measured in the same dynamic paradigm. This suggests that both components of IOR can be simultaneously observed. The lack of older adults' object-based IOR in midst of significant location-based IOR suggests that there were age-related changes in the inhibitory processes associated with orienting to objects. This is consistent with previous findings by McCrae and Abrams (2001) and fits within a model in which older adults experience greater impairment in non-spatial inhibitory processes associated with the anterior attentional system (Connelly & Hasher, 1993; Zhou & Chen, 2008).

EXPERIMENT 2

The goal of Experiment 2 was to examine age-related differences in location- and object-based IOR using a static paradigm. To do so, I modified the object-based cueing paradigm by Egly and colleagues (1994). In the original two-rectangle design, one end of a rectangle was briefly cued before a target was presented either at the same location as the cue, on the opposite end of the cued rectangle, or at one of the ends of the uncued rectangle. Egly et al. observed that spatial cues led to both location- and object-based facilitation. Following a short 200 ms SOA, participants responded quickest to the targets presented at the cued locations. Participants also showed a benefit in response times to the targets presenting at the cued objects relative to the uncued object, suggesting that there was a facilitatory benefit to shifting attention within the cued object than shifting attention the same distance to locations in the uncued objects. The design has been used extensively to measure facilitation (e.g., Hecht & Vecera, 2007; Marino & Scholl, 2005; Shomstein & Behrmann, 2008), and a few studies have used the paradigm to measure IOR (Jordan & Tipper, 1999; Leek, Reppa, & Tipper, 2003), but this paradigm has not yet been used to measure age-differences in object-based IOR.

Following the lead of Leek and colleagues (2003), I made three changes to the Egly et al. (1994) task to encourage IOR to both locations and objects. First, the central fixation point was cued prior to target presentation to reorient attention back to center and to encourage IOR (Leek et al., 2003; List & Robertson, 2007), whereas the original paradigm (Egly et al., 1994) measured facilitation and did not include a double-cue interval. The second change was that the cue-target SOA was lengthened in order to encourage inhibitory effects. Finally, I included trials without the objects (the rectangles) to compare object-absent trials with object-present trials and ensure that RT differences to uncued targets presented within the rectangles reflected inhibitory effects due to boundaries of the objects.

Previous research has shown that both young and older adults produce reliable location-based IOR in a static environment (Connelly & Hasher, 1993; Hartley & Kieley, 1995; McAuliffe et al., 2006; McCrae & Abrams, 2001, Experiment 1). In static paradigms, young adults have produced reliable object-based IOR effects (Jordan & Tipper, 1999; Leek et al., 2003; McAuliffe et al., 2006; McCrae & Abrams, 2001), while older adults have not shown significant object-based IOR effects, even with an SOA extended to 1,000 ms (McAuliffe et al., 2006). I predicted that in the present experiment, both age groups would respond more slowly to a target presented at cued compared to uncued locations in both the object-present and object-absent trials, reflecting location-based IOR and consistent with preservation of spatial inhibitory processes with age. Furthermore, young adults would respond more slowly to targets presented at the uncued end of a cued rectangle compared to either end of the uncued rectangle, reflecting object-based IOR. I predicted that older adults would produce impaired object-based IOR due to frontally-mediated changes in non-spatial inhibitory processes of the anterior attentional system.

Method

Participants

Thirty young adults (ages 18 – 23 years; 17 men and 13 women) and 30 older adults (ages 60 – 91 years; 4 men and 26 women) participated in the experiment. The same recruiting and screening techniques described in Experiment 1 were used for Experiment 2. Six older adults were excluded (three for low MMSE, one for high GDS, and two for health conditions). Ten young adults were excluded (three for high GDS and seven for health conditions). Participant data for those who were excluded was replaced with new participants. Characteristics of the final sample are provided in Table 3.

Table 3

Participant Characteristics for Experiment 2

	Mean (SD)	
	Young Adults	Older Adults
Age (years)	19.2 (1.2)	70.6 (7.3)*
% Female	43%	87%
Education (years)	13.4 (0.8)	15.5 (2.5)*
WASI-V	55.9 (5.4)	62.3 (6.9)*
Snellen Acuity (20/_)	15.9 (2.8)	24.5 (5.3)*
MMSE	28.9 (1.2)	29.0 (1.4)
GDS	1.5 (2.1)	2.4 (2.1)

Abbreviations: SD = standard deviation; WASI-V: Wechsler Abbreviated Scale of Intelligence-Vocabulary (Wechsler, 1999). A maximum score of 80 can be obtained, with a higher score indicating better performance. Snellen Acuity = assessment of near vision acuity. A smaller value in the denominator indicates better visions. MMSE = Mini-Mental State Exam. A maximum score of 30 can be obtained, with a higher score indicating better performance. GDS = Geriatric Depression Scale. A maximum score of 30 can be obtained, with a higher score indicating greater symptoms of depression. *Indicates a significant difference between the age groups by independent t test, $p < .05$.

Apparatus and Stimuli

Stimuli were presented on a 33-cm PC monitor running Presentation software that was 34 cm from the participant. All stimuli were presented in black on a light gray background. There were two display conditions: object-present and object-absent. Cues and targets on object-present trials were presented within two unfilled rectangles (10° x 3°), with each center point 3.5° in distance from a fixation cross in the center of the screen. The rectangles were presented in either a vertical or horizontal orientation. The corners of each rectangle occupied approximately the same location (7.7° from central fixation), regardless of the orientation. The peripheral cue was an unfilled, superimposed square (equal width to that of the rectangle), with thickened borders, on one of the four ends of the rectangles. The central cue consisted of an enlargement and thickening of the fixation cross. The target was a filled square (equal width to that of the rectangle) superimposed on one of the four ends of the rectangles.

On object-absent trials, the same cues and targets were presented on a screen without the rectangles. The cues and targets appeared in the same locations and with the same dimensions as the object-present conditions. In both the object-present and object-absent conditions, participants used a space bar on the keyboard to make responses.

Procedure

Figure 3 illustrates the task sequence for object-present trials and Figure 4 for object-absent trials. For the object-present condition, the trial began with the two-rectangle display for 1,000 ms. A cue was presented within a rectangle for 90 ms at one of the four corner locations. After the cue was removed, the initial display screen was presented for 330 ms. The fixation cross was then cued for 90 ms to draw attention back to center. The target was presented immediately following central cue offset and remained until the participant responded (for a maximum of 2,000 ms). The cue-target SOA between the peripheral cue and the target was 510 ms. For the object-absent conditions, the sequence was the same except there were no rectangles (objects) on which the cue and target were presented. On catch trials, the sequence remained the same, except no target was presented and the display remained for 2,000 ms following the central cue offset. Participants were instructed to press the space bar as soon as they detected the target or wait until the next trial if no target was presented. If the participant failed to detect the target, or responded on a catch trial, an error tone (400 Hz for 700 ms) would sound. Following the participant's response, a blank screen appeared between trials for 1,000 ms. Participants were instructed to keep fixated on the center cross throughout the trial, but eye movements were not monitored.

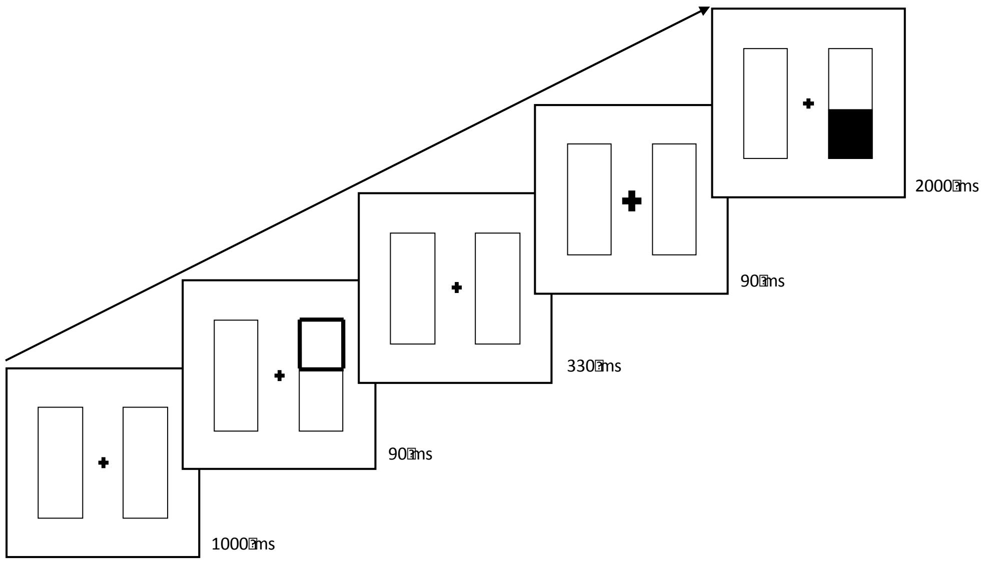

Figure 3. Experiment 2 trial sequence for object-present cued-object condition. Experiment 2 trial sequence for the cued-object condition. After a 90 ms peripheral cue, the initial display was presented. The central fixation cross was then cued to draw attention back to the center. Following a 510 ms SOA from the peripheral cue, a target was presented on 80% of the total trials.

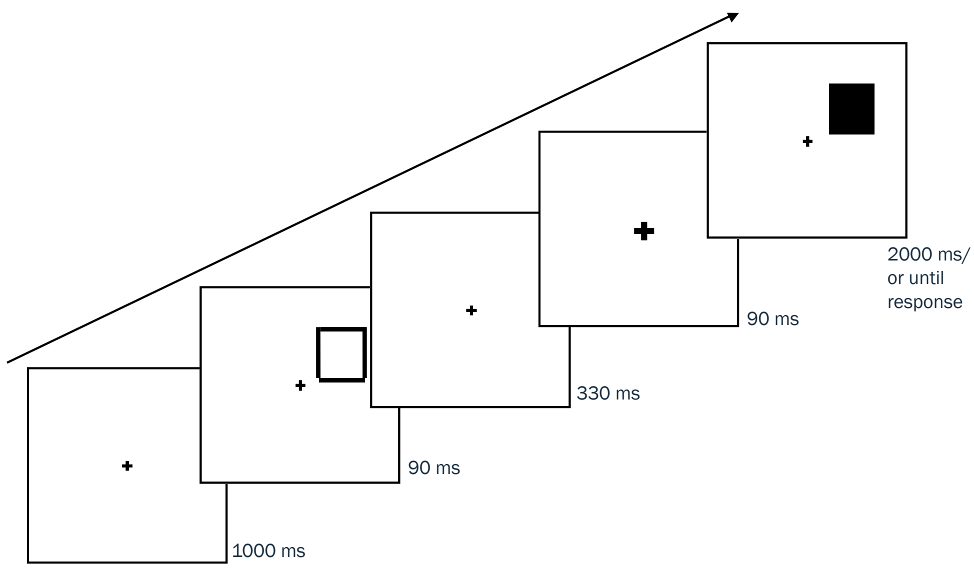

Figure 4. Experiment 2 trial sequence for object-absent cued-location condition. Experiment 2 trial sequence for the cued-location condition. After a 90 ms peripheral cue, the initial display was presented. The central fixation cross was then cued to draw attention back to the center. Following a 510 ms SOA from the peripheral cue, a target was presented on 80% of the total trials.

Cues and targets were equally and independently likely to appear at the four locations. The conditions were labeled based on the target's position relative to the cue (Figure 5). Thus, for the object-present condition, one quarter of the trials were cued-location (CL) trials, in which the target would appear in the original location that was cued. One quarter of the target trials were cued-object (CO) trials, in which the target appeared in the opposite end of the rectangle that was originally cued. An uncued-equal (UE) trial was one in which the target appeared in the uncued rectangle but at an equal distance from the cue as a cued-object target. An uncued-unequal (UU) trial occurred when the target appeared in the uncued rectangle at the end opposite the cue (and thus at a longer distance from the cue than a cued-object target). For the object-absent conditions, although there were no rectangles (objects) on which the cue and target were presented, the trials were yoked to the object-present trials and were labeled with the same four cue conditions to allow for comparison between the conditions (see analysis in Leek et al., 2003). Although condition labels remained the same for object-absent trials, without the rectangles there was no difference between cued-object and uncued-equal trials.

Participants completed the object-present and object-absent trials in separate blocks. For counterbalancing purposes, half the participants completed the object-present trials first, and half the participants completed the object-absent trials first. For each type of trial (object-present and object-absent), participants completed a practice block of 20 trials before completing 5 blocks of 40 test trials. In total, participants completed 400 test trials. Twenty percent of all trials were catch trials, in which a cue but no target was presented. Catch trials and target trials were randomly presented within a block of trials and functioned to reduce predictability of the target appearance. For the object-present trials, rectangle alignment was randomly determined, with the rectangles vertically aligned on half the trials and horizontally aligned on the other half.

Alignment was independent from cue condition. A screen presented between blocks instructed the participant to take a break, as needed, and press the space bar to proceed to the next block.

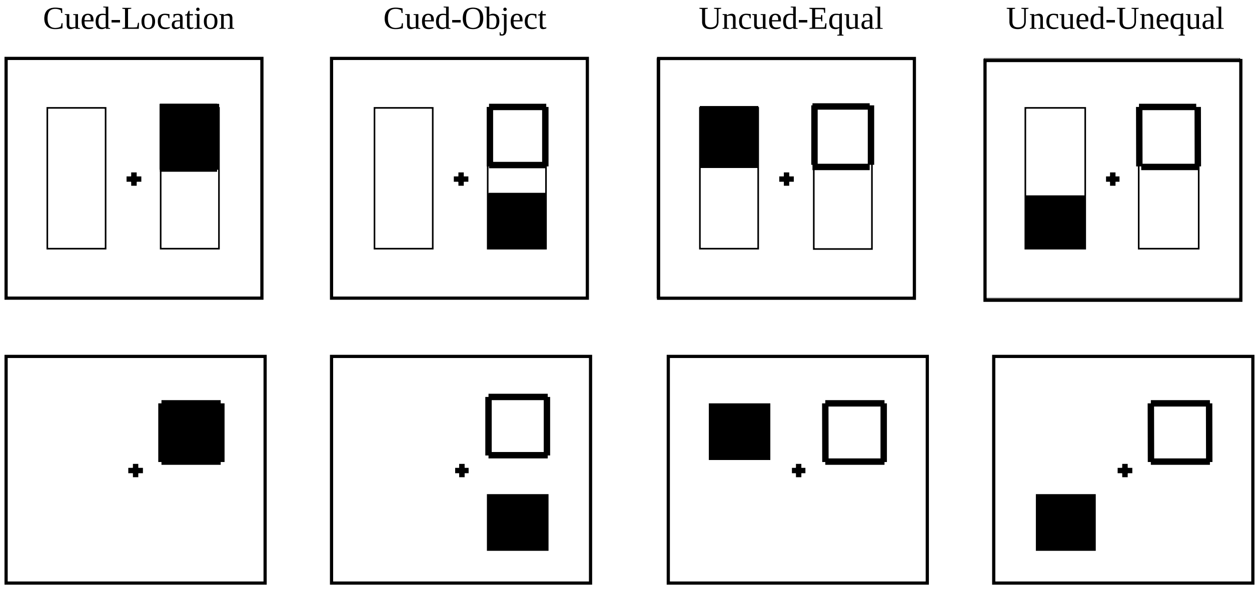

Figure 5. Examples of cue-target conditions of object-present and object-absent trials in Experiment 2.
The conditions are labeled based on the target's position relative to the cue. In the cued-location condition, the target appeared at the same location that was cued. In the cued-object condition, the target was presented in the same rectangle as the cue, but at the uncued end. In the uncued-equal conditions, the target presented in the uncued rectangle at a location equidistant from the peripheral cue as the cued-object target. In the uncued-unequal condition, the target was presented in the other end of the uncued rectangle, diagonal from the cue. The same conditions were presented in the object-absent trials, however there was no qualitative difference between cued-object trials and uncued-equal trials.

Results

Trials with RT responses less than 100 ms, greater than 2,000 ms, or greater than 2.5 *SD* from an individual's condition (e.g. cued-location) mean were excluded from the analysis. Trials that were deleted for errors (false alarms and misses) were low for both age groups (3% for young adults and 2% for older adults).

The orientation of rectangles (horizontal or vertical) was not a central variable of interest in the present experiment, but I was concerned that it might interact with the variables of interest, so I conducted a preliminary analysis with orientation as an independent variable. If there was no interaction between orientation and cueing effects, I planned to collapse the orientation conditions for further analyses. Limiting the analysis to the object-present trials (when rectangles were present), mean RTs for correct trials were submitted to a 2 (age group: young and older adults) × 2 (orientation: horizontal and vertical) × 4 (cue condition: cued-location, cued-object, uncued-equal, and uncued-unequal) mixed ANOVA. Focusing on the effects involving orientation, there were no significant effects for orientation $F(1, 58) = 1.09$, $p = .30$, or age group × orientation × cue condition $F(3, 58) = 1.82$, $p = .15$. However, there were significant interactions for age group × orientation, $F(1, 58) = 4.24$, $p = .04$, and cue condition × orientation, $F(1, 58) = 4.72$, $p = .003$. The significant interaction of age group × orientation resulted from older adults responding more slowly to horizontal orientations ($M = 412$ ms) compared to vertical orientations ($M = 408$ ms), whereas young adults responded more slowly to vertical orientations ($M = 331$ ms) compared to horizontal orientations ($M = 329$ ms). However, within each age group, responses to the two orientations were not significantly different from one another, Fs < 3.5, ps > .09.

The significant interaction of orientation and cue condition was explored by examining cue condition effects within each orientation. There were significant cue effects for the horizontal orientation, $F(3, 58) = 29.74$, $p = .001$, and the vertical orientation, $F(3, 58) = 84.28$, $p = .001$, which were further analyzed via SNK post-hoc tests. The relative ordering of RTs across cue conditions was the same for both orientations, with cued location RTs being slower than all other condition RTs. In both orientations, cued-object RTs were significantly slower than uncued-unequal RTs but not uncued-equal RTs. The difference in cue effects across orientations centered on the uncued conditions; in the horizontal orientation, the two uncued conditions were not significantly different from one another, whereas in the vertical orientation, the uncued-equal RTs were slower than the uncued-unequal RTs. Because the interaction was largely driven by the relative positioning of the two uncued conditions, which did not directly impact the hypotheses regarding IOR, the vertical and horizontal orientations were collapsed for further analysis and labeled jointly as object-present trials.

For the overall analysis, mean RTs were submitted to a 2 (age group: young and older adults) × 2 (object presence: present and absent) × 4 (cue condition: cued-location, cued-object, uncued-equal, and uncued-unequal) mixed ANOVA. Mean RTs as a function of age group, object presence, and cue condition are presented in Table 4 (Figure 6). A main effect was found for age group, $F(1, 58) = 24.86$, $p = .0001$, with young adults showing significantly faster reaction times ($M = 333$ ms) compared to older adults ($M = 395$ ms). The main effect for object presence, $F(2, 58) = 12.53$, $p = .0008$, was due to faster RTs for object-absent ($M = 358$ ms) trials compared to object-present ($M = 371$ ms) trials. A main effect for cue condition, $F(3, 58) = 146.23$, $p = .0001$, reflected the following ordering of RTs (cued-location = 384 ms, cued-object = 362 ms, uncued-equal = 361 ms, and uncued-unequal = 350 ms). Significant interactions were found for age group × object presence, $F(2, 58) = 23.76$, $p = .0001$; age group × cue condition, $F(3, 58) = 8.23$, $p = .0001$; and object presence × cue condition, $F(6, 58) = 2.69$, $p = .0479$. Contrary to my predictions, the age group × object presence × cue condition interaction was not significant $F(3, 58) = 1.68$, $p = .174$.

Table 4

Mean Reaction Times (ms) and Standard Deviations for Experiment 2

	Mean RTs (SD)	
	Young Adults	Older Adults
Object-Present		
Cued-location	351.0 (36.8)	435.0 (60.6)
Cued-object	327.3 (28.4)	408.7 (65.3)
Uncued-equal	325.0 (30.1)	405.8 (61.7)
Uncued-unequal	319.3(33.1)	392.1 (66.4)
Object-Absent		
Cued-location	347.5 (38.4)	403.4 (63.8)
Cued-object	332.2 (39.5)	380.1 (65.6)
Uncued-equal	335.1 (36.5)	376.1 (63.2)
Uncued-unequal	326.9 (39.0)	361.5 (61.3)

Abbreviations: RT = reaction time; SD = standard deviation.

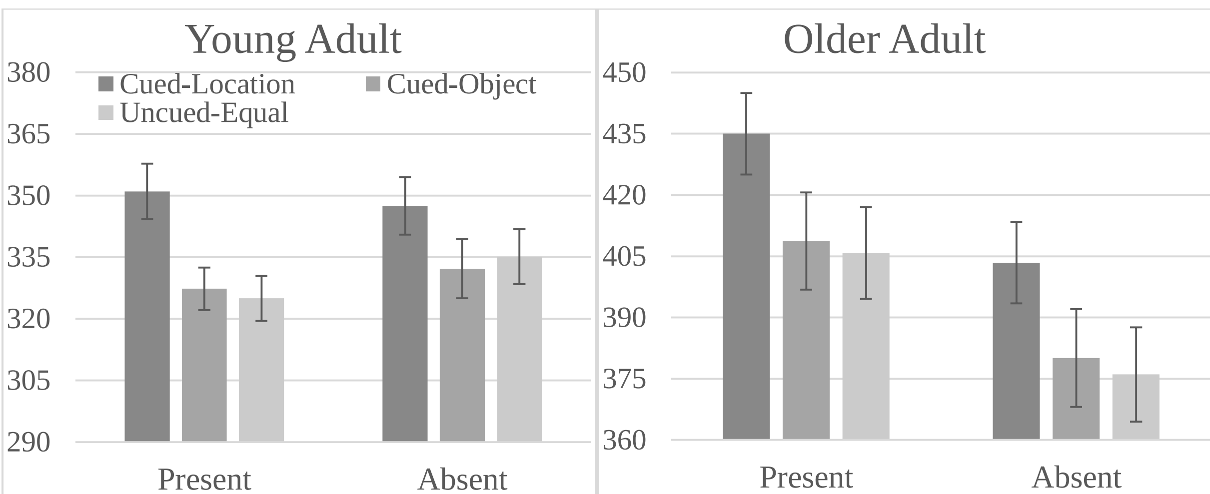

Figure 6. Mean reaction times for young adult and older adults as a function of cue condition (cued-location, cued-object, and uncued-equal) and object presence (present and absent).

To investigate the significant age group × cue condition and age group × object presence interactions, further analyses were conducted within each age group. When examining cue condition effects with one-way ANOVAs, a main effect of cue condition was found for young adults, $F(3, 29)= 59.50$, $p = .0001$, and older adults, $F(3, 29) = 87.93$, $p = .0001$. SNK post-hoc test showed the same pattern for both age groups, that cued-location was significantly slower than all other cue conditions, and uncued-equal and cued-object were significantly slower than uncued-unequal but not from one another. While the uncued-equal and cued-object conditions were not significantly different from each other for either age group, the pattern indicated the young adults had slightly slower RTs for uncued-equal (0.3 ms difference from cued-object) trials, whereas older adults had slightly slower RTs for cued-object (3 ms difference from uncued-equal) trials. The interaction appeared to be driven by the opposite pattern of the uncued-equal and cued-object conditions between the age groups. For the age group × object presence interaction, a main effect for object presence was significant for older adults, $F(2, 29) = 24.31$, $p = .0001$, but not for young adults, $F(1, 29)= 1.64$, $p = .2109$. Older adults responded more slowly on object-present trials ($M = 410$ ms) compared to object-absent trials ($M = 380$ ms).

The significant object presence x cue condition interaction was explored by conducting one-way ANOVAs for cue effects within each object presence condition. For object-present trials, there was a significant main effect for condition, $F(3, 59) = 82.02$, $p = .0001$. The post-hoc test showed cued-location ($M = 393$ ms) RTs were significantly slower than the other three conditions, cued-object ($M = 368$ ms) and uncued-equal ($M = 365$ ms) RTs were significantly different from uncued-unequal ($M = 356$ ms), but not from each other. For object-absent trials, there was also a main effect for cue condition, $F(3, 59) = 75.38$, $p = .0001$. The post-hoc analysis showed cued-location ($M = 375$ ms) RTs were significantly slower than the other three conditions, cued-object ($M = 356$ ms) and uncued-equal ($M = 356$ ms) RTs were significantly different from uncued-unequal ($M = 344$ ms) RTs, but not from each other. The interaction appeared to be driven by the size of location-based slowing effects, which were slightly larger for the object-present condition compared to the object-absent condition.

Inhibition of return is measured as a slower response to a cued location or object than to an uncued location or object. To further explore the age × cue condition interaction, location-based IOR was measured by subtracting from cued-location RTs the average of cued-object and uncued-equal condition RTs (for methodology, see List & Robertson, 2007). Due to the lack of a significant age group × object presence × cue condition interaction, object present and object absent conditions were collapsed to calculate location-based IOR. I did not calculate object-based IOR because cued-object and uncued-equal conditions were not significantly different from each other. Location-based IOR difference scores were submitted to a one-way ANOVA with age group (young and older adults) as the between-subjects factor. The location-based IOR effect was significantly larger for older adults (27 ms) compared to young adults (20 ms), $F(1, 59) = 4.03$, $p = .049$ (Figure 7).

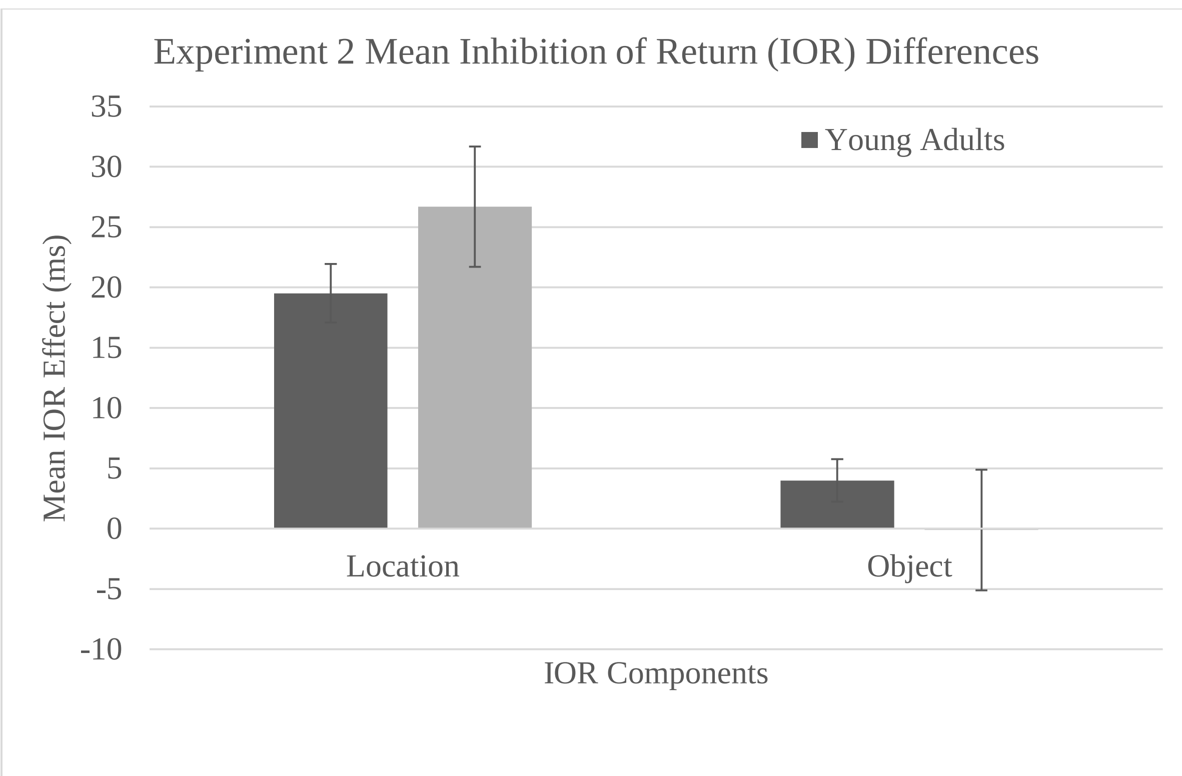

Figure 7. Experiment 2 mean inhibition of return (IOR) differences for young and older adults. IOR effects for young and older adults in a dynamic paradigm. Error bars represent one standard error.

Discussion

The results from Experiment 2 showed a pattern of location-based IOR for both age groups, which supported my first prediction. Older adults showed greater IOR effects (27 ms) than young adults (20 ms), although general slowing may have contributed to this age difference (Cerella, 1990). This finding is consistent with previous research that both young (Jordan & Tipper, 1998; Leek et al., 2003; McAuliffe et al., 2006) and older adults (McAuliffe et al., 2006) produce location-based IOR using a static paradigm.

The lack of object-based IOR (slower RTs for the cued-object condition relative to the uncued-equal condition) for young adults was inconsistent with my second prediction and with previous findings (Leek et al., 2003; List & Robertson, 2007). Older adults did not show any significant object-based inhibition either, but it cannot be interpreted as an age-related deficit given the performance of young adults. Rather, a task design issue may have led to the absence of object-based IOR effects. I focused on two aspects of the current design: object orientation and the selected cue-target asynchrony.

Egly, Driver, and Rafal (1994) observed robust object-based facilitation in a two-rectangle paradigm, alternating between vertical and horizontal orientations. However, Tassinari, Aglioti, Chelazzi, Peru, and Berlucchi (1994) identified that attentional orienting was affected by the hemifields in which cues and targets were presented. Four boxes were presented along the horizontal meridian, two on each side of the vertical meridian, an equal distance from the central fixation point with one closer to and one further from the center. In the cueing task, the cue-to-target SOAs varied between 0 to 900 ms. Consistent with the previous findings (Tassinari, Aglioti, Chelazzi, Marzi, & Berlucchi, 1987), Tassinari and colleagues (1994) found that on a facilitatory cueing task (cue-target SOA was less than 65 ms), the participants benefitted from the target being presented within the same hemifield as the cue as well as at the same location. In addition, when the SOA was greater than 300 ms, the inhibitory effect showed a cost to the entire hemifield in which the cue was initially presented. Tassinari and colleagues (1994) proposed that this cost was based on the oculomotor system in covert orienting. The instructions to keep fixated on the center cross created a bias of the motor system to keep eye movement away from the cue. Upon the target presenting in the opposite hemifield, the motor system would be quicker to respond compared to the hemifield in which there existed a suppressive command. To disentangle hemifield effects from object effects, two studies have modified the Egly paradigm by re-orienting the vertical and horizontal rectangles to +/- 45 degrees (Jordan & Tipper, 1999; List & Robertson, 2007). With the rectangles at a 45-degree angle, the cues and targets were presented along the vertical and horizontal meridians, and participants did not need to shift attention across a hemifield to attend to both the cue and target of a trial. The current experiment should be replicated using a ± 45-degree orientation rather than vertical and horizontal.

The second factor that may have influenced object-based IOR in the present experiment was the selected cue-target SOA. The SOA of 510 ms is within the parameters to observe IOR (Klein, 2000; Maylor, 1985; Taylor & Klein, 1998), however it may not have been long enough to detect measurable object-based IOR in this paradigm. List and Robertson (2007) conducted a series of experiments with a double-cue IOR task modifying the SOA between (a) the initial peripheral cue and the second central fixation cue and (b) the central fixation cue and the target. While location-based IOR was consistently observed in all experiments, object-based IOR was more sensitive to the time interval since the last cue. The authors recommended that in order to observe reliable object-based IOR effects, the time interval between the most recent cue (whether peripheral or central) and the target should be longer than 400 ms, due to a delay in the object-based attentional selection and subsequently slower rise in inhibition. The current experiments should be replicated using a longer cue-target SOA, specifically lengthening the amount of time between the central cue and target from 90 ms.

To address the factors mentioned above, I piloted a new experiment on 24 young adults that made the following modifications to the present experiment: rectangle orientation was changed to ±45° instead of vertical and horizontal, and the peripheral cue-target SOA was lengthened from 510 ms to 1380 ms. The time interval between peripheral and central cue was lengthened from 420 ms to 690 ms and the central cue to target interval was lengthened from 90 ms to 690 ms. I observed significant location- and object-based IOR (17 ms and 15 ms, respectively) in the object-present trials. Consistent with my predictions for object-based effects, only location-based IOR (13 ms) was produced in the object-absent trials, while RTs for all other conditions (cued-object, uncued-equal, and uncued-unequal) were not significantly different from each other (see Appendix). I will next test older adults on this task to evaluate age-related changes of object-based IOR in a static paradigm.

To conclude, both age groups produced location-based inhibition in the present experiment. My second prediction was not supported by the current findings, with neither age group showing object-based IOR. The lack of object-based IOR in young adults suggests that the design of the experiment was not suitable for addressing age differences. What is also of future interest is why cue-target timing is critical for observing IOR. Data collection is underway with a modified version of the task to assess age differences in location- and object-based IOR.

GENERAL DISCUSSION

In two experiments, I explored age patterns in inhibition associated with orienting, focusing on spatial and non-spatial forms of inhibition. I proposed that the two forms of inhibition were mediated by different attention systems and were therefore uniquely susceptible to age effects. The posterior attention system (parietal lobe, pulvinar, and superior colliculus) is involved in location-based IOR, whereas the anterior attention system (frontal lobe, anterior cingulate) is involved in object-based IOR (Zhou & Chen, 2008). Because aging impacts the anterior system more than the posterior system, I predicted that object-based IOR would show greater age-related deficits than location-based IOR. My first prediction of significant location-based IOR for both age groups was supported in the dynamic (Experiment 1) and static (Experiment 2) paradigms. These findings support previous evidence that location-based IOR is preserved with age (Hartley & Kieley, 1995; Langley et al., 2007; McAuliffe et al., 2006; McCrae & Abrams, 2001). My prediction for young adults to produce reliable object-based IOR effects was observed only in the dynamic paradigm (Experiment 1), which replicated previous findings (McCrae & Abrams, 2001; Tipper et al., 1994). However, the lack of young adults' object-based IOR in a static paradigm (Experiment 2) was not consistent with previous findings (Jordan & Tipper, 1999; Leek et al., 2003; McAuliffe et al., 2006) and hampered efforts to evaluate older adult object-based effects in a static paradigm.

Previous research has shown that object-based IOR is sensitive to experimental design elements such as the cue-target SOA (Castel et al., 2003; List & Robertson, 2007). Based on the findings of Experiment 2, I have started collecting data for an experiment using 45° object orientations and a longer SOA. As demonstrated in the pilot study (Appendix), young adults demonstrated significant object-based IOR effects with these modifications. The next step is to test older adults. If older adults do not show object-based IOR, it will provide support for age-related changes in non-spatial inhibitory processes. If older adults do produce significant object-based IOR, it would suggest that timing for object-based IOR is different than that for location-based IOR.

Two limitations of my studies were the variability in age range between the two groups and the high representation of women in my older adult samples. Young adult participants are undergraduate students and therefore the age range is largely within 18-24, with a mean age of 19 years. In contrast, older adults are recruited from the community and the participants have a much wider range of ages, roughly from 60-90 years. A consideration would be to incorporate a maximum age limit in which older adults can participate or to create young-old and old-old age groups for comparison. Another possibility is to recruit a community sample of young adults that better matches the range of ages and education of the older adult sample. The second limitation was that the older adult sample was predominantly female, particularly for Experiment 2. In order to evaluate age effects, and not gender effects, the sample should be comprised of roughly the same number of males and females. Recruiting additional men ensures that the observed cognitive patterns are not specific to women. Additional men will be recruited for testing on the modified Experiment 2.

For older adults, there are limited studies that have investigated object-based IOR effects. Between the two aging studies using a dynamic (McCrae & Abrams, 2001) and static (McAuliffe et al., 2006) paradigm, older adults did not show inhibition in the object-based conditions, whereas young adults showed significant object-based IOR effects. Of the aging models I discussed and considered, I was able to eliminate one possibility. The differentiation between age-related changes of executive versus automatic inhibition (Nigg, 2000) is not supported by my data. If this model explained my findings, then IOR, which is driven by exogenous orienting, should have been produced by older adults regardless if it was object- or location-based. Additionally, a model characterized by age-related changes of the frontal lobe (Arbuckle & Gold, 1993; Dempster, 1992; Hartley, 1993; Kramer et al., 1994) may not adequately support the findings of this thesis. Due to the fact that older adults show selective impairments of object-based IOR, a more appropriate model should incorporate age-related changes of neural correlates involved with processing of object-features.

A model of age-selective sensitivities within the attentional systems may provide some insight to the preserved location-based IOR and compromised object-based IOR in older adults and best supports my data from Experiment 1 (Posner & Petersen, 1990). The anterior attention system, which includes the prefrontal cortex and anterior cingulate cortex are involved in the processing of non-spatial IOR (Zhou & Chen, 2008). In contrast, location-based IOR produced significant neural activity in the parietal lobe, a component of the posterior attention system. This distinction between the two systems and the IOR components associated with neural correlates within each system could support the data in Experiment 1. Future studies should also further examine the extent of impaired object-based IOR in older adults: if the impairment extends to any non-spatial feature or if it is limited to the object structure itself. Zhou and Chen (2008) found that young adults produce color-based IOR and location-based IOR in a single paradigm. If older adults do have impaired processing of the anterior attentional system, we would expect to see a deficit in object-based IOR across other object-features that are processed in these same neural areas.

Ultimately, it is important to see how inhibitory effects translate to real-world scenes. Although the real environment provides an individual with numerous cues to guide attention and navigation, it is important to evaluate if an object-based inhibition deficit results in real-word consequences, such as driving or finding a friend in a crowd.

If older adults do not produce object-based IOR, this may result in failure to inhibit the return of attention to irrelevant objects in their view, leading to a less efficient search. When holding attention to too many irrelevant items their ability to detect a critical event may be hindered, especially when driving. Future research may provide insight to age-related object-based inhibitory impairments through additional behavioral research and neuroimaging evidence. Understanding the physiological changes driving these impairments would allow for the ability to test targeted training interventions.

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APPENDIX. YOUNG ADULT DATA FROM MODIFIED EXPERIMENT 2 DESIGN

I tested 24 young adults using the same paradigm as in Experiment 2, however orientation was changed to ±45° instead of vertical and horizontal and the cue-target SOA was lengthened from 510 ms to 1380 ms. The time interval between peripheral and central cues was lengthened from 420 ms to 690 ms and the central cue to target interval was lengthened from 90 ms to 690 ms.

I conducted a preliminary analysis to determine that cueing effects did not interact with orientation, because rectangle orientation (-45° or +45°) was not a central variable of interest. Limiting the analysis to the object-present trials, mean RTs for correct trials were submitted to a 2 (orientation: -45° or +45°) ×4 (condition: cued-location, cued-object, uncued-equal, and uncued-unequal) within-subjects ANOVA. There were no significant effects found for orientation, $F(1, 23) = 0.04$, $p = .85$, or orientation × condition $F(3, 23) = 1.57$, $p = .20$, so the -45° and +45° orientations were collapsed in further analyses and labeled as object-present trials.

For the overall analysis, mean RTs were submitted to a 2 (object presence: present and absent) × 4 (cue condition: cued-location, cued-object, uncued-equal, and uncued-unequal) within-subject ANOVA. The object effect was not significant, $F(1, 23) = 0.24$, $p = .63$. A main effect for cue condition, $F(3, 23) = 29.04$, $p = .0001$, reflected an expected relative ordering of RTs (cued-location = 359 ms, cued-object = 348 ms, uncued-equal = 341 ms, and uncued-unequal = 336 ms). A significant interaction was found for object presence × cue condition, $F(3, 23) = 5.02$, $p = .003$.

To investigate the interaction, separate one-way ANOVAs to examine cue condition effects for each object presence condition. For object-present trials, there was a significant main effect for condition, $F(3, 23) = 25.93$, $p = .0001$. Cued-location RTs ($M = 364$ ms) were significantly slower than the other three conditions. Cued-object RTs (*M* = 354 ms) were significantly slower than uncued-equal (*M* = 339 ms) and uncued-unequal (*M* = 334 ms) RTs, which were not significantly different from each other. For object-absent trials, there was a main effect for cue condition, $F(3, 23) = 7.61$, $p = .0002$. Cued-location RTs (*M* = 355 ms) were significantly slower than the other three conditions; uncued-equal (*M* = 344 ms), cued-object (*M* = 341 ms), and uncued-unequal (*M* = 338 ms) RTs, which were not significantly different from each other.

Table A1

Mean Reaction Times(ms) and Standard Deviations for Young Adults on Modified Experiment 2

	Mean (SD)
	Young Adults
Object-Present	
Cued-location	363.6 (47.1)
Cued-object	353.7 (48.4)
Uncued-equal	338.8 (46.2)
Uncued-unequal	333.7 (46.3)
Object-Absent	
Cued-location	355.2 (53.1)
Cued-object	341.4 (48.9)
Uncued-equal	343.9 (52.6)
Uncued-unequal	337.7 (47.7)

Raw reaction times for the four critical conditions for young adults. Abbreviations: RT = reaction time; SD = standard deviation.

For each participant, location-based IOR was measured by subtracting from cued-location RTs the average of cued-object and uncued-equal RTs (for methodology, see List & Robertson, 2007). Object-based IOR was measured by subtracting uncued-equal RTs from cued-object RTs. For object-present trials, young adults produced 17 ms of location-based IOR and 15 ms of object-based IOR. For object-absent trials, young adults produced 13 ms of location-based IOR and -3 ms of object-based IOR.