AGING, OBJECT-BASED INHIBITION, AND ONLINE DATA COLLECTION

A Dissertation
Submitted to the Graduate Faculty
of the
North Dakota State University
of Agriculture and Applied Science

By

Asenath Xochitl Arauza Huether

In Partial Fulfillment of the Requirements
for the Degree of
DOCTOR OF PHILOSOPHY

Major Department:
Psychology

November 2020

Fargo, North Dakota

North Dakota State University
Graduate School

Title

Aging, Object-based Inhibition, and Online Data Collection

By

Asenath Xochitl Arauza Huether

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

DOCTOR OF PHILOSOPHY

SUPERVISORY COMMITTEE:

Dr. Linda Langley
Chair

Dr. Laura Thomas

Dr. Michael Robinson

Dr. Heather Fuller

Approved:

11/16/2020	Dr. Mark Nawrot
Date	Department Chair

ABSTRACT

Visual selective attention operates in space- and object-based frames of reference. Stimulus salience and task demands influence whether a space- or object-based frame of reference guides attention. I conducted two experiments for the present dissertation to evaluate age patterns in the role of inhibition in object-based attention. The biased competition account (Desimone & Duncan, 1995) proposes that one mechanism through which targets are selected is through suppression of irrelevant stimuli. The inhibitory deficit hypothesis (Hasher & Zacks, 1988) predicts that older adults do not appropriately suppress or ignore irrelevant information. The purpose of the first study was to evaluate whether inhibition of return (IOR) patterns, originally found in a laboratory setting, could be replicated with online data collection (prompted by the COVID-19 pandemic). Inhibition of return is a cognitive mechanism to bias attention from returning to previously engaged items. In a lab setting, young and older adults produced location- and object-based IOR. In the current study, both types of IOR were also observed within object boundaries, although location-based IOR from data collected online was smaller than that from the laboratory. In addition, there was no evidence of an age-related reduction in IOR effects. There was some indication that sampling differences or testing circumstances led to increased variability in online data.

The purpose of the second study was to evaluate age differences in top-down inhibitory processes during an attention-demanding object tracking task. Data were collected online. I used a dot-probe multiple object tracking (MOT) task to evaluate distractor suppression during target tracking. Both young and older adults showed poorer dot-probe detection accuracies when the probes appeared on distractors compared to when they appeared at empty locations, reflecting inhibition. The findings suggest that top-down inhibition works to suppress distractors during target tracking and that older adults show a relatively preserved ability to inhibit distractor objects. The findings across both experiments support models of selective attention that posit that goal-related biases suppress distractor information and that inhibition can be directed selectively by both young and older adults on locations and objects in the visual field.

ACKNOWLEDGMENTS

First and foremost, I thank God. This accomplishment would not have been possible without God's grace and strength. I would like to thank my advisor, Dr. Linda Langley, for her encouragement, guidance, mentorship, and support during the completion of this dissertation and doctoral program. Thank you for your advocacy and help coordinating incredible research and teaching opportunities that would open the door for me to stay in the Fargo-Moorhead area. I also want to recognize Dr. Jau-Shin Lou for his incredible mentorship. Thank you for giving me the invaluable opportunity to conduct Parkinson's research. I would also like to thank my committee members Dr. Laura Thomas, Dr. Michael Robinson, and Dr. Heather Fuller for their time, guidance, and willingness to mentor me throughout my Master's and Doctoral research. I am especially grateful to you, my committee, for your help brainstorming and providing guidance during a difficult transition to online data collection. I also would like to thank Enrique Vazquez for his programming of the experiments used in this dissertation. I am grateful for his patience and instruction as I collected data online for the first time.

To my husband, Ben, thank you for your never-ending love, patience, and support. Thank you for encouraging me when I felt like quitting and celebrating with me with each accomplishment. Words cannot express my gratitude. I am so grateful to God to have you as a husband! I love you!

To my parents, Abner and Yolanda, you have always been my inspiration. Thank you for your example of walking with the Lord and always putting your family first. Thank you for all the opportunities you provided for us to broaden our horizons, aspire for more, and dream bigger. To my sister, Ajor, I have always hoped for your confidence and adventurous spirit. I am so

grateful to have you as my big sister and I thank you for your support over the years. To my brother, Sergio, I miss you and I wish I could share the news of this accomplishment with you.

DEDICATION

Para mi familia, con mucho amor. To my family members who have passed on. Your memory lives on in the shared stories passed on from generation to generation and the dreams for a better future.

PREFACE

After my thesis committee approved the original dissertation proposal to assess bottom-up and top-down biases during object-based selective attention, in-person data collection was suspended by the 2020 coronavirus pandemic. As a result, I modified the dissertation project by adding a new goal of determining the feasibility of collecting cognitive data online. A concern with collecting attention data online is that the researcher has little control over the devices (e.g., PC, laptop, tablet, or phone) and operating systems participants use to complete the experiments, which may interfere with precise timing of stimulus presentation and responses. In addition, distraction within the testing environment is not under the experimenter's control with online testing. To assess comparability of lab-based and online data collection, the first experiment (Chapter 2) in this modified dissertation served to replicate a task from my master's thesis (assessing age differences in location-based and object-based IOR) but now with an online approach.

The intent of my originally proposed dissertation project was to compare age differences in the interplay of bottom-up and top-down inhibitory biases during object tracking. The background for this topic has been modified to include object-based inhibition measured by the IOR paradigm (Chapter 1). In the revised dissertation, I did not collect data for my originally proposed first experiment on bottom-up biases. However, the proposed study is included in the appendix of this dissertation. I hope to conduct this study at some point in the future but not in fulfillment of the dissertation.

A recurring theme in my thesis and dissertation projects has been my interest in investigating age differences in inhibitory processing and object-based attention. Therefore, I decided to conduct my proposed second experiment on top-down biases, with data collection occurring on an online platform. The findings of this project are described in Chapter 3.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDIX FIGURES

CHAPTER 1: AGING AND OBJECT-BASED ATTENTION

Visual attention is necessary for individuals to navigate and interpret the world around them. Attention allows one to identify and select stimuli from the numerous items in the visual field. A space-based frame of reference guides attention to the locations of objects, whereas an object-based frame guides attention to objects or details of those objects. In this dissertation, I focused on age differences in selective attention towards objects. To explain those differences, I focused on two theories. Per the biased competition account (Desimone & Duncan, 1995), selectivity occurs at hierarchical levels of processing through salient object representations and task-related expectations or goals. The inhibitory deficit theory is a complement to the biased competition model that accounts for age-related changes in object-based attention.

Factors Involved in the Development of Object Effects

Prior to examining age-related changes in object-based attention, it is essential to review object effects in visual perception and selective attention. During early visual processing, stimuli are processed by parvocellular and magnocellular cells. Parvocellular cells in the retina respond to color, high contrasts, and high spatial frequencies. In contrast, the magnocellular cells respond to location, movement, and lower spatial frequencies. These parvocellular and magnocellular pathways feed forward information about what is in the environment and where it is located, respectively, to the cortical areas (Goodale & Milner, 1992). Parvocellular pathways project ventrally into the temporal cortex, associated with processing of objects, and the magnocellular pathway projects dorsally into the parietal cortex, associated with processing of spatial information (Goodale & Milner, 1992). As the pathways move towards their further cortical projections, the information undergoes more refined processing (Goodale & Milner, 1992; Perry & Fallah, 2014). Similar to visual processing, selective attention occurs in space- and object-based frames of reference. Space-based models propose that heightens processing of stimuli at locations (Eriksen & Yeh, 1985; Mozer & Vecera, 2005). Object-based models argue that attention heightens processing of features or perceived objects rather than regions of space.

The classification of an object can include: shape created by a boundary, elements comprising a larger object, and perceptual groupings that form an object (Baylis & Driver, 1992; Drummond & Shomstein, 2013; Duncan, 1984; Kahneman et al., 1992). In the remainder of the paper, an *object* will be defined as a part of the visual field united by the presence of a boundary or as a perceptual grouping comprised of one or more Gestalt principles – similarity, proximity, continuity, or closure (Chen, 2012; Kimchi et al., 2007; Wertheimer, 1923). For example, definitional criteria of an object would be met if four stimuli shared a distinct feature (e.g., color or movement) within an array of otherwise identical items; the subset of four stimuli would be perceived as a unitary object unless task goals required search for a feature contained within the four items. *Object-based effects* are defined as enhanced or impaired performance, measured by accuracy or reaction time (RT), due to attention being placed on or removed from a perceived object as compared to non-object stimuli.

When an object-based frame of reference is utilized, it tends to be driven by salient object features (e.g., perceptual grouping of four red items in large array of black items) or parameters of a task (e.g., instructions, expectancies) which require a discrimination between object features (Duncan, 1984; Lamy & Egeth, 2002; Shomstein & Behrmann, 2008; Watson & Kramer, 1999) Perceptual organization contributes to bottom-up selection of an object, and contextual information (i.e., spatial or temporal expectancy) contributes to top-down selection. Both bottom-up and top-down influences are flexible and dependent on the task. Neuroimaging research measuring the magnitude of attentional modulation across varying levels of salient stimuli supports a bottom-up and top-down interpretation. When salient stimuli (e.g., strong perceptual grouping to create illusion of an object) were available and competition was influenced by bottom-up biases, attentional modulation was attenuated. When bottom-up information could not resolve competition and top-down processes were necessary to guide attention, increased attentional modulation was observed (McMains & Kastner, 2011).

Biased Competition Model and Inhibitory Deficit Theory

The biased competition model (Desimone & Duncan, 1995) is based on neural and behavioral findings of selective attention and proposes how bottom-up and top-down processes influence spatial and object selection. Selectivity occurs through competition between visual stimuli at different hierarchical levels from sensory input to response production. While salient items may trigger an automatic selection response, competition can be biased towards events of high probability or that align with task relevant goals. When bottom-up information is insufficient for attentional selection or inconsistent with selection goals, top-down control mechanisms are employed to guide attention and behavior.

Duncan (1984) first proposed that information about objects must be processed hierarchically. For example, certain characteristics of a skyscraper (e.g., height of the building) would be relevant for one hierarchical level and other properties (e.g., crack in a window) would be more appropriate for a different level, depending on the task. Object representations separate a figure from the background in a parallel process prior to selection. This automatic response can be biased to select a different object through top-down control of expectancies and behavioral goals. In turn, behavioral goals, such as searching for a unique target amongst distractors or responding only to certain conditions, are proposed to be held in a *selection template* within working memory, which maintains and updates representations. The templates that guide top-down processes include a feature of an object (e.g., red), conjunction of features (e.g., red rectangles among different red shapes), and spatial location (e.g., on the left side of an array; Desimone & Duncan, 1995; Vecera & Behrmann, 2001). Bias to target features occurs through suppression of non-target neuronal populations across all hierarchical levels. This suppression enhances the representation of the relevant features, spatial attributes, and global object properties across the visual system (Deco & Rolls, 2004; Desimone & Duncan, 1995). The integral role of suppression in selective attention and evidence for age-related deficits in inhibitory processing require the consideration of the inhibitory deficit hypothesis (Hasher & Zacks, 1988) when predicting age patterns of object-based attention.

Whereas older adults do exhibit some forms of inhibition (such as the location-based inhibition discussed later in this review; see Kramer et al., 1994), the inhibitory deficit hypothesis (Hasher & Zacks, 1988) can be considered within the context of biased competition. A deficit of inhibition during selective attention means that irrelevant information may not be appropriately suppressed or ignored. As a result, there is not a clear “winner” from competition that occurs during early processing. At later stages, an impaired inhibitory system could prevent suppression of irrelevant representations in working memory. Together, an age-related decline in the efficiency of inhibitory processing could result in impairments across multiple hierarchical levels.

Based on the inhibitory deficit hypothesis, an impaired inhibitory system could be predicted to negatively impact perception and encoding of visual stimuli if task-irrelevant features or objects are not suppressed. The attentional system may process more information than necessary, perhaps reducing the advantages typically observed by having a perceptual object in the visual field (Hasher et al., 1999). In consideration with the biased competition model, selection templates during top-down bias may be inundated with irrelevant information and direct attention to unrelated stimuli.

Research on the inhibitory deficit hypothesis supports evidence for more than one inhibitory system. Connelly and Hasher (1993) suggested that at least two inhibitory systems operate to independently process locations and object identity. These separate systems were predicted to coincide with the dorsal and ventral visual pathways. However, in a series of tasks (spatial cueing, response compatibility, Wisconsin Card Sorting Task, negative priming, stopping paradigm) measuring different types of inhibition, Kramer et al. (1994) did not find age patterns of inhibitory functioning that could be sorted into spatial and object identity categories. Rather, the authors argued that age-related changes to the visual pathways likely influence behavior, but that models focusing on frontal lobe function could better explain performance on the more challenging inhibition tasks (Wisconsin Card Sorting Task, stopping paradigm). The authors suggested that aging impacts the different systems (ventral and dorsal pathways, frontal lobe) at different rates, therefore contributing to the complex pattern of results supporting preservation and impairment across different inhibitory processes.

Being that some age-related impairments in inhibitory processing align with theories of frontal lobe function, it is worth mentioning the cognitive control model (Braver & Barch, 2002). This aging theory contends that working memory and attention are responsible for maintaining and updating contextual information needed to influence thoughts and behaviors. Per this model, the dorsolateral prefrontal cortex (PFC) maintains representations of context information, and dopaminergic projections to the PFC are responsible for updates. Top-down feedback is directed by the PFC to bias competition in favor of a particular set of representations.

Braver and Barch’s (2002) cognitive control model allows the principles of the biased competition account to be applied to older adults by acknowledging the age-related changes in dopaminergic function and the PFC. However, the cognitive control model does not necessarily make unique predictions beyond the biased competition model and inhibitory deficit theory when addressing object-based attention. It is for this reason that I do not specifically reference the cognitive control model for the remainder of this dissertation.

Aging and Object-Based Selective Attention

In this dissertation, I used an inhibition of return (IOR) paradigm (Experiment 1) and a multiple object tracking (MOT) paradigm (Experiment 2) to examine age patterns of object-based selective attention. The IOR paradigm used in Experiment 1 required participants to maintain focus at a central fixation point while a spatial cue appeared on a placeholder in the display, and after a designated period of time, required that the participant respond to the appearance of a target at the same or different placeholder (Posner, 1980; Posner & Cohen, 1984). In MOT tasks, used in Experiment 2, participants track target objects from an array of identically-appearing objects moving in independent directions (Pylyshyn & Storm, 1988). I will introduce the IOR and MOT paradigms and discuss the literature on aging for each paradigm.

Inhibition of Return

In the traditional Posner cueing paradigm (Posner, 1980; Posner & Cohen, 1984), three placeholder squares were displayed along the center horizontal axis. A spatial cue appeared briefly at either the left or right square and was followed by a target, which appeared at the same location as the cue (cued condition) or at the other peripheral square (uncued condition). When the cue-target stimulus onset asynchrony (SOA) was less than 300 ms, participants were faster to respond to a target at the cued location than at an uncued location, representing facilitated detection due to attention at the cued location. In contrast, if the cue-target SOA was greater than 300 ms, participants were slower to detect a target at the cued location than at the uncued condition, representing slowed (inhibited) return of attention to a cued location. This effect is called inhibition of return (IOR) and is considered a delayed response to previously viewed items to encourage orienting towards new items (Posner & Cohen, 1984).

A dynamic variant of the spatial cueing paradigm (Tipper et al., 1991) permits evaluation of two components of IOR: location-based and object-based. Therefore, while utilizing a spatial task, object-based attention can be evaluated. Similar to the traditional spatial cueing task, three placeholder squares are presented in the display. A peripheral square is cued and before the target appears, the peripheral squares rotate around the fixation point. This allows for a measure of response times to targets presented at the cued location and to targets presented at the cued object (the square, now at a different location). Significant location- and object-based IOR has been observed in young adults using this or similar designs (Tipper et al., 1991; Tipper et al., 1994).

Object-based IOR has been tested in older adults using static (Huether, 2018; Huether & Langley, manuscript in revision; McAuliffe et al., 2006) and dynamic (Huether, 2018; Huether & Langley, manuscript in revision; McCrae & Abrams, 2001) variants of the spatial cueing paradigm. In my master's thesis, I measured location- and object-based IOR using static and dynamic paradigms (Huether, 2018). McCrae and Abram (2001) measured location- and object-based IOR in separate experiments using a dynamic task (with moving objects upon which cued and targets were presented). I used an adapted version of McCrae and Abram's tasks to include conditions to measure both location- and object-based IOR in the same experiment. I found that while both young and older adults produced location-based IOR, object-based IOR was produced only by young adults, with older adults trending towards facilitation to the object (Huether, 2018). In a subsequent study using a static task (Huether & Langley, manuscript in revision), I adapted the Egly et al. (1994) two-rectangle design to extended the cue-target SOA (1380 ms) and manipulate object presence (modeled after List & Robertson, 2007). I found that both young and older adults produced location-based IOR and object-based IOR.

The findings of my thesis and follow-up study (Huether, 2018; Huether & Langley, manuscript in revision) provided evidence for preserved location-based IOR in older adults and relative preservation of object-based IOR. Object-based IOR was found for young adults only in the dynamic task, although there are several methodological differences and additional attentional mechanisms involved which could have influenced behavioral patterns for older adults. In the dynamic task, the moving objects may result in attentional momentum, resulting in bias along the trajectory in which the object was moving (Pratt et al., 1999). A dynamic task also involves working memory for the object file. An object file holds the representation of an object's identity and updates the representation across changes in attributes (e.g., rotation, color) or spatial location (Kahneman et al., 1992). Lastly, the cue-target SOA for the static paradigm was significantly longer (1380 ms) compared to the dynamic task (698 ms). While the cue-target SOAs were selected carefully for each paradigm based on previous research on aging patterns in IOR and the design used (McAuliffe et al., 2006; McCrae & Abrams, 2001), there is the potential that for the dynamic task, a longer duration was needed during object movement or between the central fixation cue and target onset to observe inhibition in older adults' performance (List & Robertson, 2007).

Multiple Object Tracking

In MOT tasks, participants track target objects from an array of identically appearing objects moving in independent directions (Pylyshyn & Storm, 1988). Selective attention plays a critical role in multiple object tracking, as it works to select and track targets, while ignoring distractors (non-target objects). Visuospatial working memory also contributes to tracking performance by maintaining and updating the object files of the targets as they are in motion. The standard MOT paradigm consists of an array with identical stimuli. A select number of items are revealed as targets and then return to their original identity. Participants track the targets as they move among distractors. Once all items stop moving, participants indicate the locations of the targets by pointing to them with a computer mouse, finger touch, or by indicating whether a probe appears on one of the targets (Meyerhoff et al., 2017). Previous research has identified age differences in MOT performance (Sekuler et al., 2008; Störmer et al., 2013; Trick et al., 2005). Trick et al. (2005) found that young adults were able to track more targets compared to older adults (4 and 3 targets, respectively). The authors suggested that age differences in tracking were likely due to a compromised ability to maintain representations in working memory until a response is given or due to task demands of tracking multiple independently moving items.

In an MOT paradigm in which targets and distractors moved at one of two speeds for either a long or short duration (Sekuler et al., 2008), older adults performed increasingly worse than young adults as the number of targets increased, and they experienced greater costs when the duration of movement was longer and when the speed of movement was faster (but see Störmer et al., 2011). A serial analysis measured accuracy for each sequential response during target identification. The first two targets identified by older adults were accurately tracked, but accuracy dropped significantly for the third and each subsequent target. The finding that older adults could track fewer targets and were particularly impacted by the speed and duration of tracking, may be related to impairments in attending to multiple items that move independently of each other.

In an MOT study using a paradigm similar to the one I used in Experiment 2, young and older adults tracked two targets among four static distractors and four moving distractors (Störmer et al., 2013). The researchers presented probes during the tracking period which could appear on the targets, on moving distractors, or on static distractors. Because the study recorded neural electrophysiological responses during the task, the probe served as a time point from which the researchers could evaluate amplitude and latency modulations associated with the distinct object identities (i.e., target or distractor). They recorded event-related potentials (ERP) to investigate age differences in peaks associated with top-down attentional modulation during selective attention. The behavioral data showed that young adults were faster and more accurate to indicate if a probe at an object was a target compared to older adults; however, behavioral data was not reported for accuracy of identifying a probe at a moving versus static distractor. More importantly, electrophysiological responses suggested that enhancement of the target representation (early phase of P1 component) was preserved in older adults, while suppression of moving distractors was delayed (N1 component) and attenuated (P1 amplitude modulations). Young adults and older adults showed suppression (P1 component) of static distractors. The authors concluded that significant noise during early processes could affect the efficiency of attentional modulation and that variability in suppression patterns could better be explained by differentiating between high and low performing older adults.

The MOT literature suggests that older adults are able to successfully focus on select target objects for tracking but are limited in the number of objects they can track, especially as task parameters become more demanding. The MOT task requires components of top-down biases to maintain and update target object files and to suppress distractors. Age-related impairments in inhibitory processes (Hasher & Zacks, 1988) can contribute to poorer suppression of distractor objects. Poor suppression of distractors could lead to increased load on the observer during target tracking and ultimately lead to poorer tracking accuracy. Per the biased competition model, participants would be expected to rely on top-down control in order to track target objects, which following a reveal of their identity (salient bottom-up cue to draw attention), now look identical to the moving distractors. Attenuated performance in older adults could arise from impaired ability to maintain and update the object files during tracking.

Visual Search

In the MOT task, participants track targets as they move amongst identical distractors. Target selection among identical or similar distractors can be observed in the visual search paradigm. In visual search tasks, the salience of the target stimulus relative to other items in the display plays a significant role in search success. In a feature task, a target with a feature distinct from the distractors automatically draws attention (e.g., a red car in a parking lot of white cars) and eliminates the need to conduct a thorough search of each item (parallel search). Young and older adults demonstrate robust abilities to efficiently conduct this parallel search process (Plude & Doussard-Roosevelt, 1989). In a conjunction task, the target is defined by two or more features that are shared with the distractors, such as a red car in a parking lot of red trucks and white cars (Treisman & Gelade, 1980). As a result, a conjunction task requires that participants serially inspect items to identify the target. Due to the serial search, participant RTs are slower and increase with the number of distractors in the search array. Two conditions are compared: a target absent and target present condition. On average, search time approximately takes twice as long for participants to determine that a target is absent, as the participant must exhaustively search the items. While both age groups show significant increases in their search time as the number of distractors increase, older adults exhibit much steeper costs and especially in the target absent condition (Plude & Doussard-Roosevelt, 1989).

In a mixed parallel-serial task, or guided search task, a limited number of distractors share an identifying feature with the target (e.g., two red truck distractors and a target red car amongst white trucks and white cars). In this type of task, participants parcel out a perceptual group of distractors (e.g., all white items) and then conduct a serial search of the potentially relevant items (e.g., search only among the red items for the car). No age differences have been found in these mixed parallel-serial or guided search tasks (Madden et al., 1999; Plude & Doussard-Roosevelt, 1989) unless task difficulty is made significantly more challenging (e.g., search parameters varying across trials; Gottlob, 2006).

These findings suggest that during visual search, older adults show preserved pre-attentive processing of features but exhibit impairments in the serial processing of similar stimuli. Age-related impairments in integrating the stimulus features during a serial search (Treisman & Gelade, 1980) are potentially caused by inefficient search strategies, impaired spatial localization, or generalized slowing of information processing (Plude & Doussard-Roosevelt, 1989). Considering object-based attention, older adults are able to benefit from bottom-up processing of salient features or perceptual grouping to facilitate visual search.

Visual Marking

Inhibitory selection processes work to suppress distractor information in order to enhance relevant representations (Deco & Rolls, 2004; Desimone & Duncan, 1995). The EEG findings from an aging study on MOT suggested that suppression of distractors was impaired in older adults compared to young adults (Störmer et al., 2013). To my knowledge, there has not yet been behavioral evidence of older adults' impaired suppression during MOTs. The allocation of inhibition during target selection has been examined by assessing visual marking. Visual marking is a similar form of suppression during visual search that is proposed to use top-down inhibition to ignore a previewed group of distractors (Watson & Humphreys, 1997).

Visual marking is proposed to use top-down inhibition to ignore a group of distractor items which are presented prior to the target (Watson & Humphreys, 1997). The temporal gap between the first set of irrelevant distractors and the second set of distractors improved search efficiency, as measured in reaction time. The incorporation of dynamic stimuli in the second set of items did not interrupt the visual marking effect unless changes (e.g., rotation, luminance) were simultaneously made at the location of the first set of static distractors (Watson & Humphreys, 1997; Watson & Humphreys, 1998). The authors argued that top-down control could prioritize inhibition to dynamic or static stimuli, but that this goal state was subject to a limited resource capacity. A secondary task could reduce the available resources and lead to poorer maintenance of the goal state and ultimately reduce marking efficiency (Watson & Humphreys, 1997).

Visual marking by older adults showed a more complex pattern. While visual marking of static stimuli has been found with older adults (Kramer & Atchley, 2000), the authors suggested it was the demands on cognitive load which slowed reaction time when the second set of stimuli were presented. Further, significant age-related impairments were observed with the inclusion of moving items, as older adults showed no evidence of visual marking of the old items. Age deficits are suggested to arise from the demand on attentional resources by moving stimuli on an already impaired top-down inhibitory system (Watson & Maylor, 2002).

The Present Study

The purpose of the present study was to explore age differences of inhibitory processes during object-based attention. For Experiment 1, I used a task which allowed for the comparison of location-and object-based components of IOR (Egly et al., 1994) to examine automatic inhibitory processing towards previously inspected locations and objects. Experiment 1 also served as a replication study to compare the suitability of online data collection methods with traditional in-person testing in a laboratory setting. Therefore, I predicted that the data online would replicate the IOR patterns observed in the laboratory-based study, in which significant location- and object-based IOR would be observed for young and older adults and the magnitude of the effects would be similar for both data collection methods. For Experiment 2, I paired an MOT task with a dot-probe detection task, borrowed from the methodology of Pylyshyn et al. (2008) to examine the role of inhibitory processing to suppress distractors. I predicted that evidence of suppression during selective attention would be observed as poor probe detection on moving distractors compared to probes on targets and empty locations. I also predicted that age differences would be observed with probe detection of the different distractor conditions, as older adults were predicted to show poor suppression of relevant distractors (moving) or potentially the misplacement of suppression on irrelevant distractors (static).

CHAPTER 2: EXPERIMENT 1, ONLINE DATA COLLECTION

Traditionally, cognitive psychological research has occurred in lab settings. Over the last two decades, extensive research has been done on the reliability, methods, and platforms for collecting data online (Buhrmester et al., 2016; Germine et al., 2012; Granello & Wheaton, 2004). Crowdsourcing websites, such as Amazon Mechanical Turk (MTurk or AMT), have numerous advantages including low compensation costs and access to large, diverse samples in the United States and worldwide (Buhrmester, et al., 2016; Crump et al., 2013). This accessibility allows for quicker data collection, especially when very large sample sizes are needed. Online data collection also has several disadvantages, including high dropout rates, biased samples, and inattentiveness by participants. Some methods for addressing these issues include payment upon satisfactory completion and intermittent attention checks to eliminate potential bots or distracted participants.

For online cognitive studies, the lack of control over the operating software and monitor size used by a participant increases variability in the precise parameters of stimulus presentation and reaction time measurements. With increased variability of web browsers and devices, a processing lag up to 20 ms and reaction time recording errors up to 45 ms can occur (Bridges et al., 2020). Crump et al. (2013) addressed these concerns by replicating multiple lab-based attention tasks (sorted into broad categories: reaction time, rapid stimulus presentation, and learning tasks) online. While MTurk served as the interface through which participants were recruited and paid, the attention tasks appeared on an html web page and were run using JavaScript code. One of the experiments used the aforementioned Posner cueing paradigm (Posner, 1980; Posner & Cohen, 1984). With stimulus onset asynchronies (SOA:100, 400, 800, 1200 ms) between the cue and target, 50 participants showed a target-detection performance that replicated the biphasic facilitatory and inhibitory patterns obtained in lab-based studies (Lupiañez et al., 1997; Posner & Cohen, 1984). With the methodological concerns associated with accurate timing for short stimulus presentations and recording reaction times, it is notable that Crump et al. found significant cueing effects that were as small as 15 ms.

Similar successful replications of cognitive tasks (e.g., go/no-go, 2-back) measuring RTs were found using the programs Millisecond Inquisit4Web (Miller et al., 2018) and JavaScript in jsPsych (Kochari, 2019). Among studies comparing online and lab-based data collection, Chetverikov and Upravitelev (2016) replicated RT patterns on a visual search task that varied set sizes but observed a disproportionately high amount of noise from the web-based tasks. To have sufficient statistical power, the authors tested ten times as many participants in the web-based task compared to data collected in the lab. The authors attributed the substantial variability with online data collection being a result of varying central processing units (CPU), operating systems, web browsers used to complete the attention task, and participant distractedness (i.e., inattentiveness, multi-tasking). Despite the strides that have been made with replicating cognitive findings online with young adults, there is limited research testing older adults on cognitive tasks using virtual methods.

Studying Cognitive Aging Using Web-based Studies

A majority of web-based aging studies have focused on practical application. Despite the increased use of internet in daily life, a disproportionately low number of older adults use computers and feel confident in their skills to navigate the web (Hunsaker & Hargittai, 2018). With telehealth and virtual medical appointments implemented to improve patient accessibility, research has focused on older adults' user experience to improve literacy of health-related websites and programs (Chung & Nahm, 2015; Xie, 2012). Studies have also focused on web-based interventions to improve health outcomes (Tomasino et al., 2017), to investigate virtual cognitive training programs (Corbett et al., 2015), and to validate online versions of cognitive screening assessments (Koo & Vizer, 2019; Saxton et al., 2009).

In a review of aging literature comparing online and in-person data collection, I found one replication of an attention study. The study evaluated age differences in inattentional blindness (Stothart et al., 2015). White and black Ls and Ts randomly moved around the screen and participants were directed to fixate on a central point and count the number of times any white letter crossed a central horizontal blue line. At a random time, a light gray cross could travel across the screen right to left at one of six possible distances from the center horizontal axis. At the end of the trial, participants were required to state if they saw anything unusual, describe the unexpected object, and complete a series of questions regarding the display. Logistic regression was performed to calculate the probability of noticing an unexpected object as a function of participant age and spatial distance from the horizontal line. Consistent with previous studies in which data was collected in-person (Graham & Burke, 2011), the authors found that inattentional blindness increased as age increased and as the stimulus appeared further from the area of attentional focus. A limitation noted in this study was the challenge of recruiting adults over the age of 60 through MTurk. In an attempt to collect data for an independent analysis of the pre-registered report, they were able to recruit only 25 older adults over the age of 60 compared to 198 young adults ages 18-35.

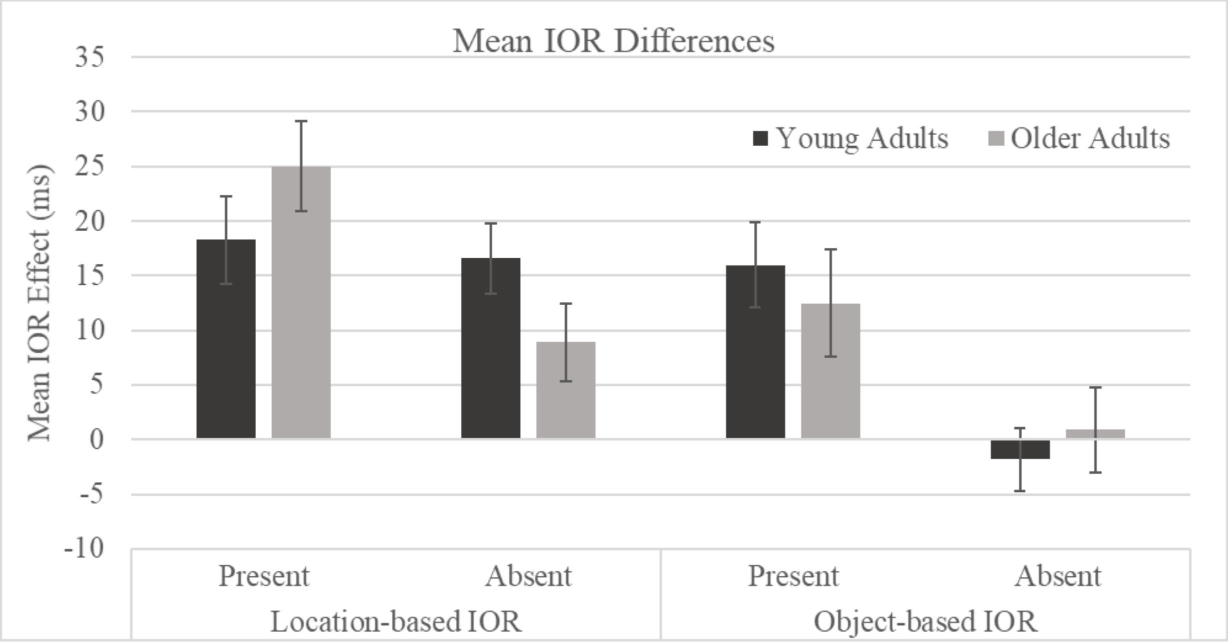
Evidence from online replication studies testing young (Crump et al., 2013) and older adults (Stothart et al., 2015), although preliminary, suggest that attentional phenomena, even those with small effects, can be measured online. Limitations noted throughout the studies indicate the loss of experimental control with online data collection. There are several ways in which the researcher can minimize the variability from participants using different devices. Some crowdsourcing sites, such as Prolific, allow the researcher to set criteria for which devices can be used (e.g., no tablets, no mobile devices). Notes can also be added to provide participants with additional suggestions and instructions (e.g., "task works best with Google Chrome or Firefox"). Increased number of trials and larger samples sizes have been proposed as methods to compensate for the variability in reaction time data caused by different devices, web browsers, and CPUs. However, if the diversity of these technological parameters is equally split (e.g., 50% of sample uses OS X and 50% of sample uses Windows XP/Vista), then increased trial number or sample size would not effectively counteract the negative impacts on statistical power. The concern with increased diversity of technological parameters, is that one operating system can yield a different mean RT and distribution shape than a different operating system (Chetverikov & Upravitelev, 2016).

Replication of Lab-Based Study

In Experiment 1, I attempted an online replication of the findings from a laboratory-based study (Huether & Langley, manuscript in revision) on location- and object-based IOR. Because I compared the in-person laboratory data of my master's thesis with the online data of Experiment 1, I provide here some details from the laboratory study. Twenty-four young adults (*M* = 18.8 years) and 24 older adults (*M* = 71.5 years) were tested on the task (additional participant characteristics are provided in Table 1). Young adults ages 18 – 35 were recruited from introductory psychology courses at North Dakota State University and older adults ages 60 - 86 were recruited from the community. To measure object effects, the target could appear at the cued end or at the uncued end of a cued object (one of the two rectangles), or at a location equal distance from the cued location but on the other rectangle. Participants were slower to detect a target that appeared on the cued object, compared to an equidistant target on the uncued object. We included object-absent trials (removing the rectangles) to confirm that object patterns were only observed within object boundaries and not due to proximity (modeled after List & Robertson, 2007). Using this paradigm, with an extended cue-target SOA of 1380 ms, we found that young and older adults produced both location- and object-based IOR (Figure 1; Huether & Langley, manuscript in revision).

Figure 1

Mean inhibition of return (IOR) difference scores for young and older adults in a laboratory experiment



Note. Location-based IOR was calculated by subtracting the average of cued-object and uncued-equal condition RTs from cued-location RTs. Object-based IOR was calculated by subtracting the uncued-equal condition RTs from the cued-object condition RTs. Error bars represent one standard error (±1 SE). Difference scores were significantly different than zero for all conditions shown except for object-based IOR in object-absent conditions.

Experiment 1 Overview

The purpose of the present experiment was to evaluate online platforms as a method for data collection in the study of cognitive aging. The experimental design used in this study was recently used to collect data in a laboratory setting and resulted in significant location- and object-based IOR for both young and older adults (Huether & Langley, manuscript in revision). The study used a static task modeled after the Egly et al. (1994) paradigm. Therefore, the aim of the current study was to replicate the patterns observed with the data collected in-person. The methodological concerns associated with the presentation of stimuli and the collection of reaction time data may contribute to greater variability of the recorded participant responses. To address this, I put in place several restrictions and instructions to minimize significant device-related variance. Additionally, several studies have successfully replicated behavioral patterns for attention tasks using online data collection, suggesting that the small RT difference scores between critical conditions should be calculable (Crump et al., 2013). In addition to evaluating age-related differences in location- and object-based IOR using online data collection, I also included analyses to compare the IOR effects when tested online and in-person.

I predicted that both young and older adults would show significant location-based IOR with the data collected online. I also predicted that both young and older adults would show significant object-based IOR for object-present trials. The object presence manipulation served the purpose of differentiating between effects associated with object borders (object-present condition) and proximity (object-absent condition). Lastly, I predicted that the difference scores reflecting IOR for data collected online would not differ in magnitude compared to data collected in a laboratory setting.

Method

Participants

Twenty-six young adults in the age range of 18-35 years and 26 older adults in the age range of 60-76 years participated in the experiment. Participants were recruited through the

Prolific crowdsourcing website (https://prolific.co/), the site serves as a platform through which workers complete certain tasks for financial awards. Participants were paid at a rate of $10 per hour for their participation.

During the creation of a Prolific account, participants completed a self-report profile including demographic and health information. These profile items were used to screen participants and exclude participants who reported a health history of conditions that may affect cognitive functioning (e.g., neurodegenerative disease, mild cognitive impairment, heart attack, stroke, significant visual impairments). Additional characteristic measures were collected to characterize the demographics of the sample (e.g., years of education, gender, use of glasses), but were not used to exclude participants. When a study is "opened" for recruitment, eligible participants receive notice of the study and can choose to accept the contract. Individuals who agreed to participate were first directed to Qualtrics to complete the informed consent process. In Qualtrics, participants completed the Geriatric Depression Scale (GDS; Yesavage et al., 1983; validated in young adult sample: Ferraro & Chelminski, 1996; Guerin et al., 2018) and Mini-Cog (Borson et al., 2000), a brief mental status test. Participants were excluded if they had a GDS score of 12 or greater (out of 30 points), consistent with symptoms of moderate to severe depression (Wancata et al., 2006), which may negatively affect reaction time and cognitive function. Participants were excluded if they had a Mini-Cog score of 2 or less (out of 5 points), consistent with symptoms of cognitive impairment. To study healthy aging, participants with risk of cognitive impairment were excluded. Additionally, if participants have cognitive impairment, it may affect their measured reaction times and ability to follow task instructions. Twelve young adults and eight older adults were excluded for a GDS score of 12 or greater and four older adults were excluded for a Mini-Cog score of 2 or less. Excluded participants were replaced with individuals who met the screening criteria. Participant characteristics of the final sample are provided in Table 1.

Table 1

Participant Characteristics for Experiment 1

Data Collection	**Online**		**Laboratory**	
	Mean (SD)			
	Young Adults	Older Adults	Young Adults	Older Adults
N	26	26	24	24
Age (years)	25.0 (4.0)	65.3 (4.6)*	18.8 (1.0)	71.5 (6.4)*
% Female	46%	65%	71%	71%
Education (years)	15.2 (2.5)	15.1 (2.1)	12.7 (1.1)	15.8 (2.8)*
Mini-Cog	4.5 (0.7)	4.6 (0.7)	N/A	N/A
GDS	4.4 (3.3)	3.5 (3.0)	1.8 (1.9)	1.4 (2.2)

Note. Abbreviations: SD = standard deviation; Mini-Cog = Mini-Cognitive Assessment. A maximum score of 5 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; evaluated within each data collection method.

Apparatus and Stimuli

The primary changes of the online task compared to the laboratory task was the variety of testing computers and monitors, length of the task, and different programming and presentation software. The online task was shortened by reducing practice trials from 20 to six and by removing one test block (40 trials) from each of the object conditions (object present, object absent). There were 400 total test trials in the laboratory task and 320 test trials in the online task. The task was programmed using JavaScript (PsychoJS) and task sequences were executed on the platform Pavlovia (https://pavlovia.org/), as PsychoJS was the most precise online package (Bridges et la., 2020). Participants were instructed to use a laptop or desktop computer so that responses could be made via a keyboard and so that the task would be presented on a larger screen, and with a larger device memory. However, Prolific did not prevent participants from completing the task on a tablet or phone. Participants were encouraged to use Firefox or Google Chrome browsers. The visual angle dimensions reflect the programmed specifications for a 32 cm x 32 cm monitor at a distance of 34 cm but may have varied across the different monitor sizes and device operating software.

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 -45° or +45° orientation (Tassinari et al., 1987; Tassinari et al., 1994). The corners of each rectangle occupied approximately the same locations (7.7° above, below, to the left, and to the right of 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 dimensions to that of the peripheral cue) superimposed on one of the four ends of the rectangles. On object-absent trials, the cues and targets were presented at the same locations on the screen and with the same dimensions but without the framing rectangles. In both the object-present and object-absent conditions, participants used the space bar on the keyboard to make responses.

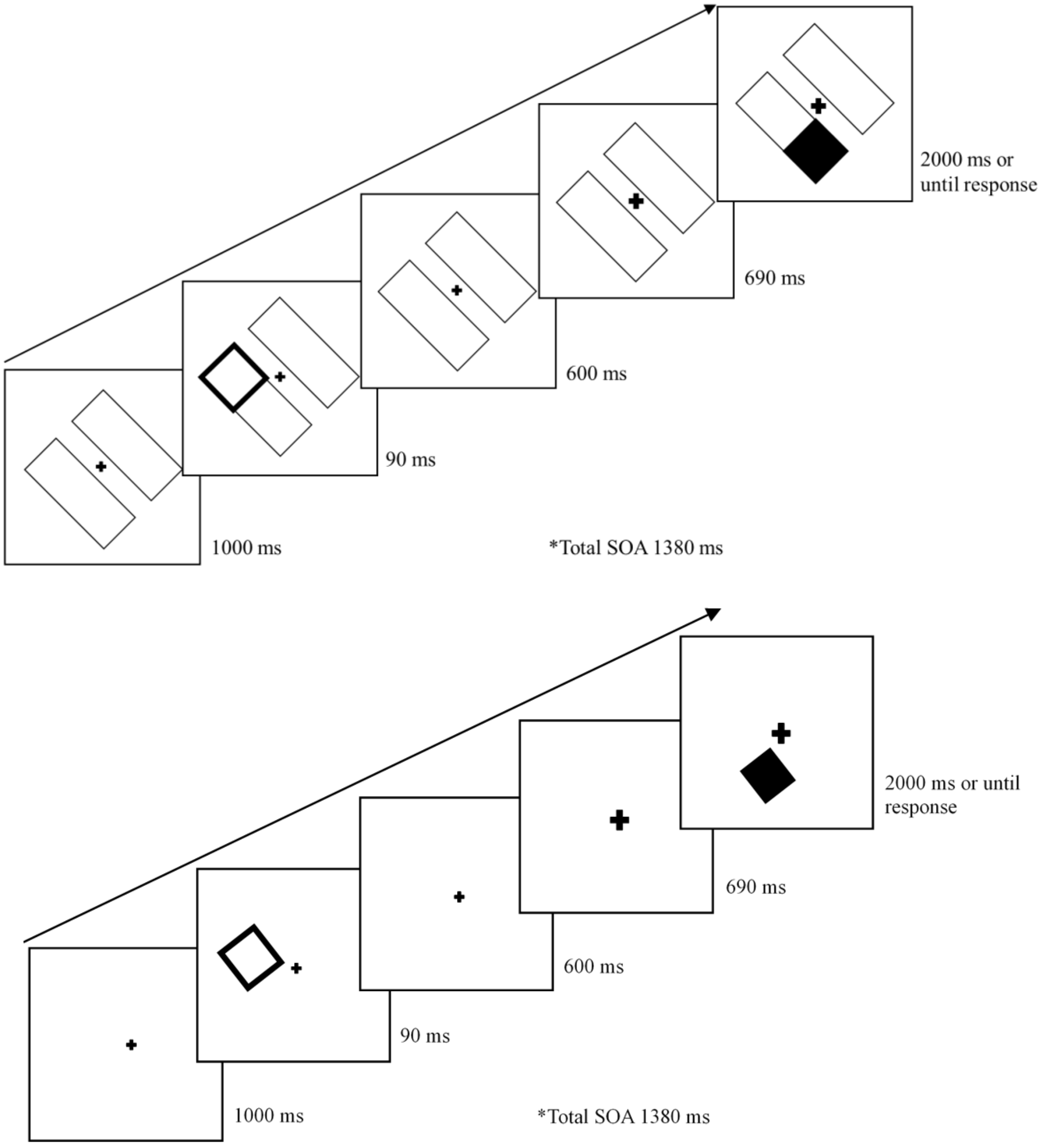
Procedure

Participants who initiated the study through Prolific were first directed to Qualtrics, where informed consent, the GDS, and Mini-Cog were administered. Following a brief video providing task instructions, the Qualtrics site transferred participants to an html site for the computer task. Figure 2 illustrates the task sequence for object-present and 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 end locations. After the cue was removed, the initial display screen was presented for 600 ms. The fixation cross was then cued to draw attention back to center and stayed enlarged for the remainder of the trial. The target was presented 690 ms following central cue onset 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 1,380 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) sounded. Following the participant's response, a blank screen appeared between trials for 1,000 ms. Participants were instructed to keep their eyes fixated on the center cross throughout the trial, but eye movements were not monitored. Participants were also encouraged to close all other programs and browser windows and to complete the task without distractions (e.g., television, phones, and noisy environments).

Figure 2

Sample trial sequence for Experiment 1

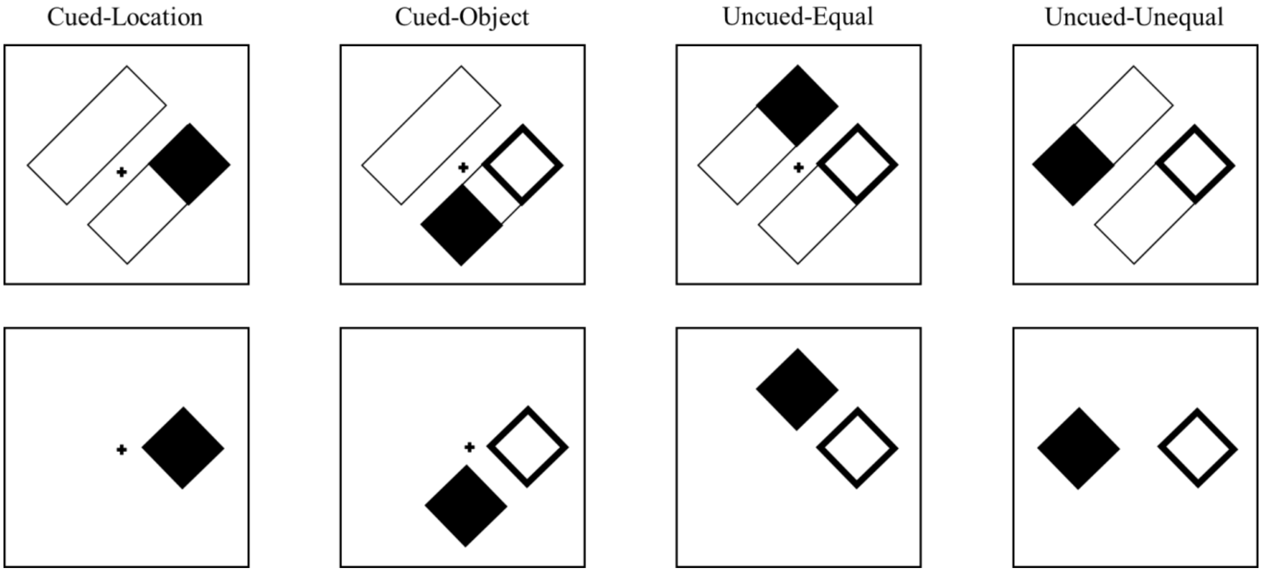


Note. Object-present trials are presented in the top sequence, and object-absent trials are presented in the bottom sequence. After a 90 ms peripheral cue, the central fixation cross was cued (increased in size) to draw attention back to the center. Following a 1,380 ms SOA from the peripheral cue, a target was presented on 80% of the trials. For object-absent trials, the sequence and cue-target distances remained the same but there were no object placeholders.

Cues and targets were equally and independently likely to appear at the four locations. The cue conditions were labeled based on the target's position relative to the cue (Figure 3). 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 trials were cued-object (CO) trials, in which the target appeared in the opposite end of the rectangle that was 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.

Figure 3

Examples of cue-target conditions for Experiment 1



Note. The conditions are labeled based on the target's position relative to the cue. In the cued-location condition, the target (filled square) appeared at the same location that was cued (unfilled square). In the cued-object condition, the target was presented in the same rectangle as the cue, but at the opposite end. In the uncued-equal conditions, the target was presented in the uncued rectangle at a location equidistant from the cue as the cued-object condition. In the uncued-unequal condition, the target was presented at the other end of the uncued rectangle, diagonal from the cue. The same conditions were presented in the object-absent trials, but in the absence of the rectangles, thus there was no qualitative difference between cued-object trials 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 6 trials before completing 4 blocks of 40 test trials per block. In total, participants completed 320 test trials. Twenty percent of all trials were catch trials, in which a cue but no target appeared. 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 -45° aligned on half the trials of a block and +45° 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. The Qualtrics screening and computer task lasted about 45 minutes in duration.

Results

Reaction Times

Trials with RT responses less than 100 ms, greater than 2,000 ms, or more than 2.5 *SD* from an individual's cue 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 (<1% for young and older adults). No participants were excluded for high errors or incomplete sessions.

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 2. A main effect for cue condition, $F(3, 50) = 4.31$, $p = .006$, reflected the following ordering of RTs (cued-location = 438 ms, cued-object = 435 ms, uncued-equal = 431 ms, and uncued-unequal = 428 ms). Using an SNK post-hoc test, comparisons indicated that a) cued-location was significantly slower than uncued-equal and uncued-unequal conditions and b) cued-object was not significantly different from any of the other conditions. There was no main effect found for age group, $F(1, 50) = 2.34$, $p = .13$, or object presence, $F(1, 50) = 0.38$, $p = .54$. No significant interaction was found for age group × cue condition, $F(3, 50) = 0.78$, $p = .51$, or age group × object presence × cue condition, $F(3, 50) = 0.72$, $p = .54$. A significant interaction was found for age group × object presence, *F*(1, 50) = 10.27, *p* = .002, and object presence × cue condition, *F*(3, 50) = 8.01, *p* < .0001.

Table 2

Mean Reaction Times and Standard Deviations for Experiment 1

	Mean RTs (SD)	
	Young Adults	Older Adults
Object-Present		
Cued-location	414.8 (94.5)	476.6 (76.1)
Cued-object	409.4 (90.7)	468.5 (71.6)
Uncued-equal	404.1 (98.9)	457.0 (69.3)
Uncued-unequal	400.0 (96.8)	449.3 (71.9)
Object-Absent		
Cued-location	422.4 (115.3)	438.8 (67.3)
Cued-object	422.3 (123.3)	441.0 (67.3)
Uncued-equal	420.7 (115.1)	441.7 (64.5)
Uncued-unequal	425.4 (117.8)	438.1 (66.8)

Note. RT = reaction time; SD = standard deviation.

To investigate the significant age group × object presence interaction, independent t-tests examining age effects were conducted within each object presence condition. For the object-absent condition, young adults (*M* = 423 ms) and older adults (*M* = 440 ms) were not significantly different from each other, *t*(50) = 0.66, *p* = .51. For the object-present condition, young adults (*M* = 407 ms) responded significantly faster than older adults (*M* = 463 ms), *t*(50) = 2.44, *p* = .02. In comparison, this interaction was not significant in the lab-based study, with young adults showing significantly faster reaction times compared to older adults across all conditions.

To investigate the significant object presence × cue condition interaction, one-way ANOVAs examining cue condition effects were conducted within each object presence condition. For the object-present condition, there was a main effect for cue condition, *F*(3, 50) =

11.22, *p* < .0001. The post-hoc analysis showed that a) cued-location RTs (*M* = 446 ms) and cued-object RTs (*M* = 439 ms) were not significantly different from each other, b) uncued-equal (*M* = 431 ms) and uncued-unequal (*M* = 425 ms) RTs were not significantly different from one another, and c) both cued conditions were significantly different from both uncued conditions. Similar patterns were observed with data collected in the lab, although cued-location RTs were also significantly slower than cued-object RTs. For the object-absent condition, there was no main effect for cue condition, *F*(3, 50) = 0.04, *p* = .99, with no one condition being significantly different from another. Data collected in the lab had resulted in cued-location having the slowest RTs, with no significant differences between the other conditions.

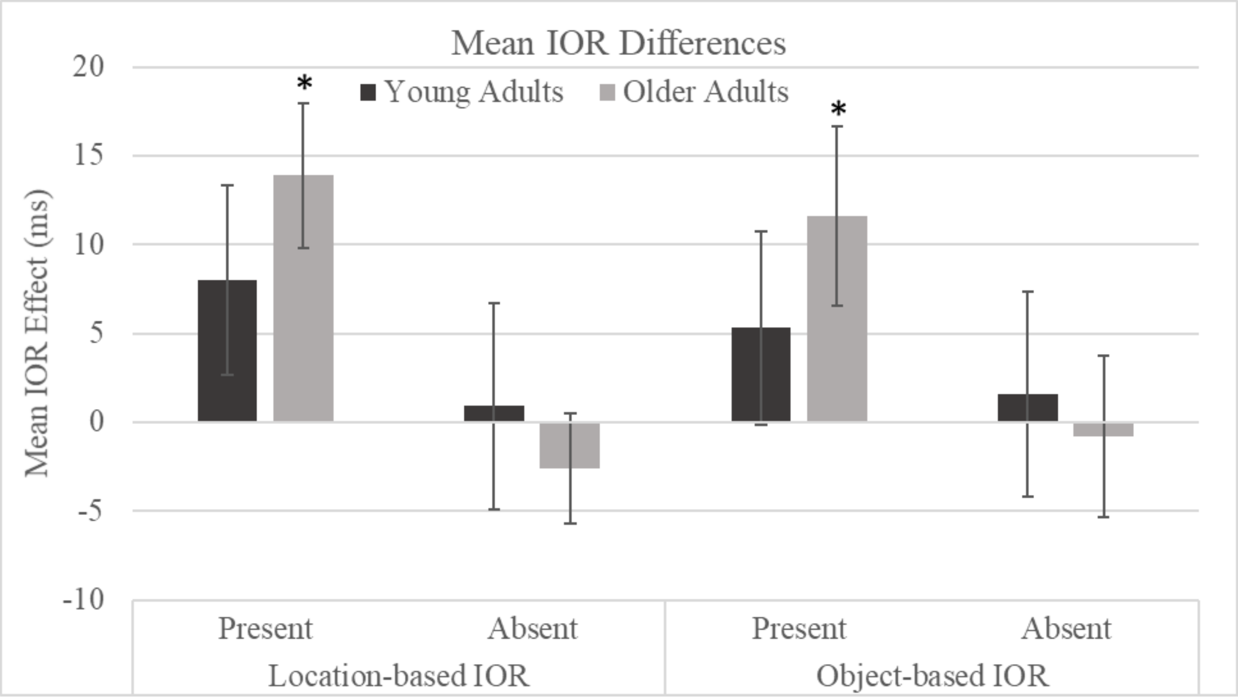
IOR Difference Scores

Inhibition of return is measured as a slower response to a cued location or object than to an uncued location or object. Location-based IOR was measured by subtracting the average of cued-object and uncued-equal condition RTs from cued-location RTs (for methodology, see List & Robertson, 2007). Object-based IOR was measured by subtracting the uncued-equal condition RTs from the cued-object condition RTs. Because the analyses of mean RTs did not reveal significant age interactions (age × cue condition, age × cue condition × object presence), IOR difference scores were analyzed collapsed across age groups (see Figure 4 for breakdown of difference scores across all conditions). Separate *t*-tests were performed with location- and object-based IOR as the dependent variables and object presence (present and absent) as the independent variable. For location-based IOR difference scores for object-present conditions (11 ms) were significantly greater than difference scores for object-absent conditions (-1 ms), *t*(51) = -2.51, *p* = .01. The 11 ms difference score for location-based IOR on object-present trials was significantly greater than zero, *t*(51) = 3.27, *p* = .002. For object-based IOR, difference scores in object-present (8 ms) and object-absent conditions (0 ms) were not significantly different from each other, *t*(51) = -1.55, *p* = .12. The 8 ms difference score for object-based IOR on object-present trials was significantly greater than zero, *t*(51) = 2.28, *p* = .03.

My prediction had been that both young and older adults, independently, would produce location- and object-based IOR. Therefore, I performed *t*-tests on difference scores for each age group on object-present trials. Only the difference scores for older adults were significantly greater than zero: location-based IOR for older adults, *t*(25) = 3.43, *p* = .002, and object-based IOR, *t*(25)= 2.29, *p* = .03.

Figure 4

Mean inhibition of return (IOR) difference scores for young and older adults in Experiment 1



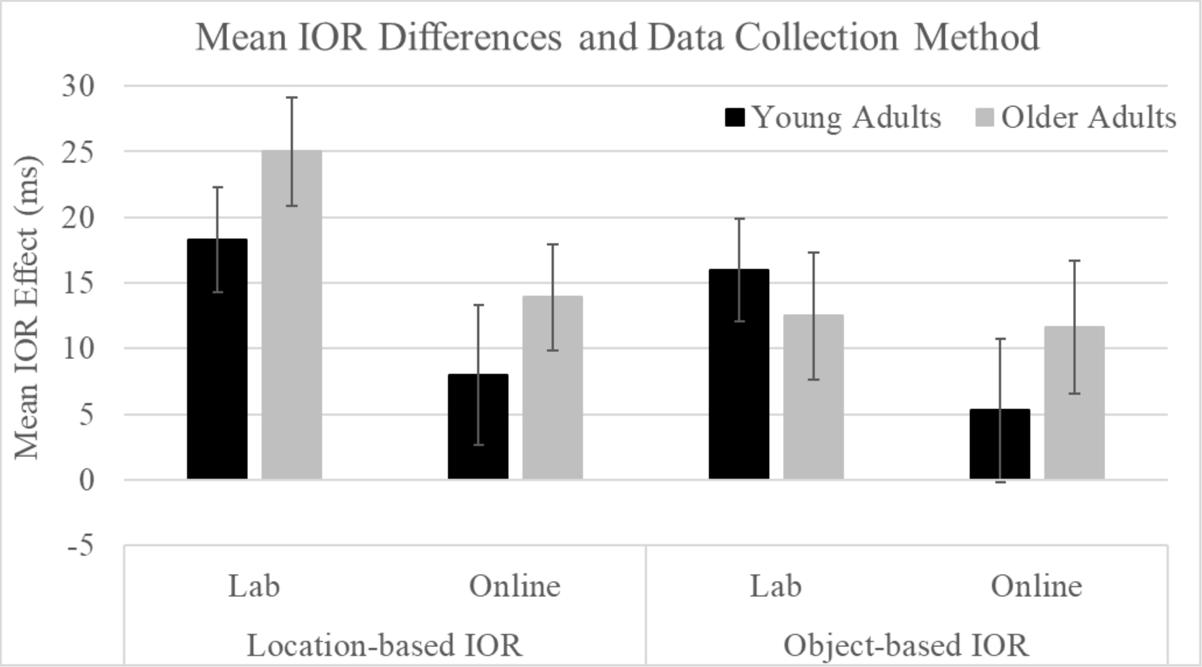
Note. Location-based IOR was calculated by subtracting the average of cued-object and uncued-equal condition RTs from cued-location RTs. Object-based IOR was calculated by subtracting the uncued-equal condition RTs from the cued-object condition RTs. Error bars represent one standard error (±1 SE). The asterisk identifies difference scores which are significantly different than zero.

Online and In-Person Data Comparison

To compare data collection platforms, aging patterns were examined for location- and object-based IOR when data was collected in person compared to a laboratory setting (Figure 5; Huether & Langley, manuscript in revision). Each IOR component was determined using the aforementioned calculations (for methodology, see List & Robertson, 2007). For each type of IOR (object-present trials only), difference scores were submitted to a 2 (method: online and laboratory) × 2 (age group: young and older adults) mixed ANOVA. For location-based IOR, a main effect was found for method, *F*(1, 69) = 4.97, *p* = .03, with larger difference scores for data collected in the lab (*M* = 22) compared to online (*M* = 11). A main effect was not found for age group, *F*(1, 69) = 2.11, *p* = .15 nor was there a significant method × age group interaction, *F*(1, 69) = .01, *p* = .93. For object-based IOR, a main effect was not found for method, *F*(1, 69) = 2.47, *p* =.13, or age group, *F*(1, 69) = .08, *p* =.78. There was also not a significant method × age group interaction, *F*(1, 69) = 1.78, *p* = .19.

Figure 5

Mean inhibition of return (IOR) difference scores on object-present trials for young and older adults for different methods of data collection



Note. IOR difference scores for object-present trials for data collected online and in a laboratory setting were compared. Difference scores were significantly larger than zero for all conditions except young adult data (location- and object-based IOR) collected in the lab. Errors bars reflect one standard error (±1 SE).

Discussion

The purpose of the current study was to replicate findings of object-based and location-based IOR by young and older adults and to evaluate online platforms as a method of collecting data on age differences in attention. For purposes of comparison, I collected online data using a computerized task previously used in the laboratory (Huether & Langley, manuscript in revision). The lab-based study found significant location- and object-based IOR effects for young and older adults. These findings, in conjunction with evidence to support online data collection as a valid method for studying attention (Crump et al., 2013; Kochari, 2019; Miller et al., 2018), contributed to my predictions for significant location- and object-based IOR for young and older adults.

My first prediction was that young and older adults would show significant location-based IOR, an effect which is robust for both age groups across various spatial cueing paradigms in laboratory settings (Castel et al., 2003; Lupiáñez et al., 2006; McAuliffe et al., 2006; McCrae & Abrams, 2001). My findings partially supported this prediction. Location-based IOR was observed for object-present trials and did not vary significantly by age. However, location-based IOR was not observed for object-absent trials, which was unexpected (for similar object manipulation, see Leek et al., 2003; McAuliffe et al., 2001). A recent study used eye tracking to evaluate the effect of placeholders on IOR effects (Hilchey et al., 2018). While the placeholder objects were relatively large rectangles in the current task (Experiment 1), placeholders are typically small squares which are relatively equivalent in size to the cue or target. Hilchey et al. found that on object-absent tasks, the magnitude of IOR was influenced by the participants' eye movements. When participants were required to make an eye movement prior to a responding manually to the appearance of the target, larger IOR effects were observed, which was consistent with studies requiring eye movement responses only (Abrams & Dobkin, 1994; Jayaraman et al., 2016). However, when participants were prevented from moving their eyes, IOR effects were smaller or non-existent. The task instructions for the online and laboratory version of Experiment 1 instructed participants to maintain their focus at the central fixation point for the duration of the trial; however, eye movements were not monitored. It is possible that eye movements, or the lack thereof, influenced the lack of location-based IOR for object-absent trials in Experiment 1.

My second prediction was that young and older adults would show significant object-based IOR. Object-based IOR is an effect that has been more reliably observed with young adults

(List & Robertson, 2007; Tipper et al., 1991) and relatively difficult to capture with older adults (McAuliffe et al., 2006; McCrae & Abrams, 2001) except in the study after which the current experiment was modeled (Huether & Langley, manuscript in revision). The current findings supported this prediction, as difference scores yielded significant object-based IOR for object-present trials; these effects did not differ by age. The lack of object-based IOR on object-absent trials was expected and borne out by no difference between cued-object and uncued-equal conditions in the absence of rectangles.

My third prediction was that there would not be significant differences in the magnitude of IOR effects between online and in-person data collection. The analysis comparing in-person and online data collection yielded unique patterns. Significant differences as a factor of methodology were found with location-based IOR, with larger effects for data collected in a laboratory setting compared to online. This did not support my prediction that the magnitude of IOR difference scores would be equivalent across different methods of data collection. Data collection method did not yield significant differences for object-based IOR.

The IOR patterns observed in this study deviated significantly from previous literature, especially for young adults (List & Robertson, 2007; Lupiáñez et al., 2006; Tipper et al., 1991). The only deliberate change to task parameters between the virtual task and that which was used in the lab was the reduction in number of test trials. This change was made to reduce anticipated participant fatigue and distraction and to mitigate the impact of longer online surveys on participant stipend expenses. Even with the reduction of test trials on the online task, each cue condition (e.g., cued-location) had 64 repetitions for the total task, accounting for manipulations of object presence, rectangle orientations, and placement on the display (e.g., cue could randomly appear at top, bottom, left, or right location). Of course, fewer trials may increase attentiveness but reduce the stability of the RT estimate. Future studies will need to evaluate the sample size and number of test trials (e.g., increase sample size and reduce test trials) appropriate for data collection online. However, I do not consider the unique findings of the current study to be a result of the change in test trial count only.

Sample size is an important consideration with online data collection and could have influenced the results in the current experiment. We used the same approximate sample size in the current study as was used in the original lab-based study. However, as discussed by Chetverikov and Upravitelev (2016), the increased noise caused by diverse web browsers, devices, and CPUs can result in different mean RTs and shape of the distribution, which are important for evaluating difference scores. The authors note that an increased sample size may be necessary, but do not offer additional guidance on how to determine the appropriate size. Recently, Brysbaert (2019) recommended sample sizes of at least 100 participants regardless of data collection method. With more complex analyses, such as interactions including a between-groups variable, sample sizes of 200 were recommended. The author acknowledges the challenges of obtaining funding for such large sample sizes and the advantage of online data collection methods to test larger samples.

Sample size has also been discussed in terms of accessibility to a desired demographic. Stothart et al. (2015) used MTurk to collect data and was unable to recruit a sufficient number of older adults to conduct some of the proposed analyses. Stothart et al. reported they opened one section for recruitment and did not restrict based on demographic information. Therefore, individuals belonging to either age group could participate and after the study was closed, the number of young and older adults were tallied. This problem was not experienced with the crowdsourcing platform Prolific, as the study had a predetermined number of slots open for recruitment for separate young adult and older adult sections. Per an estimate on Prolific, an additional 300 older adult users met eligibility criteria (e.g., health history, age) for the current study. Therefore, had the current study opened recruitment for larger sample sizes, there were enough older adult users registered on Prolific to fill the testing slots.

With data collection in a lab setting, the stimulus size is programmed based on the desired visual angle specific to the monitor size and participant distance from the computer. For the data collected in this study, I found extensive variability in the device specifications used by participants. Using a background function within Qualtrics, I obtained display resolution information for each participant. Screen resolution, which varied greatly with participants, provides a width x height dimension for a display in pixels, ranging in parameters of 480 x 800 (e.g., smart phone) to 1920 x 1200 (e.g., large computer monitor; ViewSonic, 2019). Monitors often have multiple screen resolutions which can be selected, and the display image will adjust its screen borders accordingly. If the participant minimized the screen after the task display had appeared on a maximized screen, or vice versa, the proportion of stimuli could be altered. These two factors could result in the presentation of stimuli varying in size (e.g., cue may no longer have the same width as the border of the rectangle) or in distance from the central fixation point. For example, the cue and target could appear further in the periphery if the stimuli appeared on a larger display. It is possible that significant alterations to the intended display of stimuli could violate the parameters needed to see the behavioral patterns in response to spatial cueing and the orienting of attention.

In addition to the technological confounds, inattentive participants are a common complaint associated with online data collection (Buhrmester et al., 2016). Many studies include attention checks to surveys (e.g., “Please select ‘B’ for your response to this question”) to ensure that participants are carefully reading the questions. My task had a short survey component (on Qualtrics portion) and the remainder of the session was the computer task. While participants had few errors, there is the potential that participants were sporadically attending to the task or observing the computer task out of their peripheral vision, while focusing on other activities (e.g., television, phone, and other web browsers). It would not have been difficult to see the target (black square) appear in the periphery and press the space bar in response, without actively focusing on the central fixation point. One potential cause of the lack of calculable location-based IOR one object-absent trials is the level of engagement with the task. Although IOR effects that were observed with object-present trials suggest that participants were not completely distracted, increased distraction could increase trial-to-trial variability in IOR patterns. To increase attentiveness, future studies could require a discrimination response (i.e., press the K key if the target appears and the L if there is no target), instead of a detection response (e.g., press space bar upon detection).

In an attempt to reduce variability across participant devices and performance, I included strict eligibility criteria in Prolific, provided important and concise instructions (e.g., “use laptop or desktop computers”, “use Google Chrome or Firefox”) for the task description in Prolific, and included a video of task instructions and recommendations (e.g., close all other web browsers and turn off distracting devices). However, with online data collection, there are aspects of testing that the researcher cannot control. In addition to the aforementioned elements, Prolific profiles contain self-report information from the participant; therefore, it is possible that some participant responses may be incorrect or outdated. For example, if an older adult participant recently had a heart attack and has resumed their participation on Prolific, they likely did not go through their profile to update their response to questions about health history.

The purpose of the current study was to replicate findings from data collected in a laboratory setting. For this reason, the screening criteria and task parameters were designed to be as identical to the original study as possible. However, in the study of behavioral research using online data collection, many researchers have adopted different methods which reduce cost and reduce the likelihood of participant inattentiveness related to task duration. To achieve both of these outcomes, some researchers have eliminated screening questions used to obtain demographic information or to conduct screening batteries (e.g., assessments for depressive symptoms or cognitive impairment). Therefore, there are several studies which do not report ages for the sample, or information was obtained for the sample but was not used to match the number of participants per age group (Chetverikov & Upravitelev, 2016; Crump et al., 2013). Another method to reduce the amount of time needed to complete the task is to decrease the number of trials and increase the number of participants tested. Crump et al. (2013) tested participants online on numerous reaction time paradigms and reduced test time to approximately 5 minutes, compared to the average 45 minutes for the current study. This practice was used in other online studies (Kochari, 2019; Stothart et al., 2015), with attentiveness cited as a concern with longer studies. Although, depending on the aims of the study, it may be necessary or deemed worthwhile to perform certain assessments on the participants.

CHAPTER 3: EXPERIMENT 2, AGING AND TOP-DOWN INHIBITION TO OBJECTS

The goal of Experiment 2 was to examine age patterns in inhibitory tagging during multiple object tracking (MOT). Inhibition is a valuable selective attention tool, as it reduces interference from irrelevant information. During MOT tasks, top-down inhibition would act based on the selection template and working memory representations to attend to revealed targets in midst of the identical distractors (Meyerhoff et al., 2017). With healthy aging, older adults experience declines in some inhibitory mechanisms (Campbell, Lustig, & Hasher, 2020; Hasher & Zacks, 1988; Hasher et al., 1999; Kramer et al., 1994; Rey-Mermet & Gade, 2018). The failure to prevent irrelevant distractors from accessing working memory may contribute to the age differences observed in tracking accuracy of moving objects (Hasher et al., 1999).

Pylyshyn (2006) examined the role of inhibition during tracking amongst young adults by incorporating a dot-probe task. During half of the MOT trials, a probe appeared briefly on half the trials at an empty location, on a target, or on a distractor. Once the objects stopped moving and the participants identified the targets, participants were asked if they had seen a probe during the trial. Participants (college students) detected a probe at an empty location with the highest accuracy, followed by on the target, and with the poorest accuracy for a probe presented on a distractor. The finding suggested that inhibition associated with distractor suppression reduced the ability to accurately detect a briefly presented probe when it was presented on a distractor. Pylyshyn reasoned that the highest probe detection might occur at an empty space because it is irrelevant to the tracking task and is more visible at an unoccupied location. Probe detection at a target may be less accurate than at an empty space because the target may partially mask the probe.

In a follow-up study (Pylyshyn et al., 2008), some of the distractors remained in place while the other distractors and the target objects moved around the display. A probe appearing on a static distractor was detected with high accuracy, similar to a probe at an empty location, suggesting that static distractors were not suppressed because they were parceled out as irrelevant objects based on the lack of motion. Inhibition could be reserved for moving distractor objects that competed with the targets due to their motion patterns. A similar pattern of inhibition allocation was observed with guided visual search (Madden et al., 1999; Plude & Doussard-Roosevelt, 1989).

Using the Pylyshyn et al. (2006, 2008) MOT and probe detection task, I manipulated tracking condition in the current study. In the control condition, participants passively viewed static or moving items and responded if a probe appeared during the trial. In the tracking condition, participants tracked moving targets among moving and static distractors. Similar to the Pylyshyn et al. (2008) study, on probe-present trials, a probe appeared at one of four locations (empty space, static distractor, moving distractor, or moving target). The non-tracking condition served as a baseline to illustrate that only when participants were required to track targets would they detect probes on moving targets more efficiently than those on moving distractors. Participants responded using a probe-one response rather than a mark-all targets approach, which could place greater response demands on older adults. With a probe-one response, a single object in the display was marked (e.g., the entire item turned green) and participants were asked if the probed object was a target in the current trial.

One difference between the task parameters of the current study and those of Pylyshyn et al. (2008) was the way in which participants responded to the dot-probe task. Pylyshyn et al. assessed participants at the end of the trial with a prompt, “Did you see a dot during the trial?”

and participants responded with a mouse click “Yes” or “No”. This discrimination task was in addition to the probe-one method to assess tracking accuracy. In the current study, the dot-probe task required an immediate detection response. This change was to reduce the demand on working memory; instead of delaying the two-choice probe response until the end of the trial, participants responded to a probe as soon as it was detected. I also chose this method because it shortened the trial duration, which made the best use of compensation resources and reduced potential participant inattentiveness. I assessed both reaction times and accuracy for probe detection.

Theoretical Considerations with Multiple Object Tracking

I will discuss a few frameworks which aim to describe cognitive limitations on tracking capacity and accuracy during the tracking of multiple objects. Both young and older adults experience limitations in tracking capacity and accuracy in challenging conditions. The frameworks I review are most relevant to the design of the current experiment or to relevant cognitive aging models.

Visual Index Theory (FINST)

The MOT paradigm was initially designed to test predictions of the FINST (FINgers of INSTantiation) theory, also known as the visual index model, which focuses on a fixed number of indices to which the perceived objects could be assigned. The FINST theory argues that pre-conceptual visual indices exist to track a fixed number of objects in parallel (Pylyshyn, 2001; Pylyshyn & Storm, 1988). Tracking multiple objects in parallel is attributed to a visual index being represented on the retina, which leads to an automatic response to the object index as it moves. Despite the use of individual indices to track targets, Pylyshyn (2004) identified that the indices do not hold spatial or identity information. Participants were unable to successfully produce identity information to individual targets, with performance worsening as a target neared or crossed paths with another target. The FINST theory has been considered with MOT research on aging, as age-related impairments in tracking capacity may result from fewer indices (Trick et al., 2009). These considerations would support evidence of age-related declines in tracking capacity (Sekular et al., 2008; Trick et al., 2005).

FLEX Model

A theoretical consideration which may also support age patterns of performance on MOT tasks is the FLEX (FLEXibly allocated index) model. Alvarez and Franconeri (2007) suggest that attentional allocation is flexible when multiple objects are tracked. Limited attentional resources result in poor tracking with a large number of targets and better, more precise tracking, when there are only a few targets. As a result of the flexibility of the indices, an individual should be able to track more targets than normal if other task demands are eased (e.g., very slow movement). Additionally, demand for more precise selection (e.g., target near a distractor) may modulate the attentional resources allocated to a particular target. One of the considerations for explaining age-related cognitive and attentional declines is that the capacity of attentional resources has been compromised or that the resources are not used effectively (Hoyer & Plude, 1982; Madden, 1990). Limited attentional capacity has been implicated in age-related deficits in dual-tasking and selective attention, with significant costs being observed when all resources are used in the primary or relevant task (Kramer & Madden, 2008; Maylor & Lavie, 1998; Verhaeghen et al., 2003). With limited attentional resources, older adults would show costs in performance earlier during the period of movement or show declines in performance with fewer targets compared to young adults.

Perceptual Grouping Model

A competing theory of MOT and relevant for the two experiment in this dissertation is the perceptual grouping model (Yantis, 1992). Consistent with object-based theories of attentional allocation, this model proposes that performance during tracking is enhanced when target objects are perceptually grouped into a polygon. For example, four target objects would be perceived and tracked as a rhombus. Yantis found that perceptual grouping enhanced tracking performance when the perceived polygon was preserved during tracking compared to trials in which objects moved independently and the polygon collapsed. These patterns have been supported by tracking studies examining behavioral performance and eye tracking, as perceptual grouping of targets encourages attention to the center of the perceptual object rather than focusing on individual targets (Meyerhoff et al., 2017).

Experiment 2 Overview

In the current experiment, I considered perceptual grouping in terms of the ignored distractors rather than of the attended targets. I used both static and dynamic distractors. I reasoned that participants would use perceptual grouping to identify irrelevant (static) distractors, not by boundary but by similarity. Perceptual grouping of the static distractors should reduce the total number of objects from which targets must be distinguished and ultimately improve tracking performance.

Predictions for age patterns in the modified MOT task were considered in context of other inhibitory patterns. Search-related inhibition has been observed in inhibitory tagging and visual marking tasks. Inhibitory tagging is argued to develop at the site of a searched item that has been deemed irrelevant in order to prevent re-inspection (Klein, 1988). In contrast, visual marking is proposed to use top-down inhibition to ignore a perceptual group of distractors presented before the target (Watson & Humphreys, 1997). An earlier review of these paradigms suggested greater age-related deficits exist in the inhibition of object identity and features compared to object location (McAuliffe et al., 2006; McCrae & Abrams, 2001; Watson & Maylor, 2002). Additionally, age-related impairments exist for top-down inhibition when task parameters become more challenging (e.g., dynamic stimuli; Watson & Humphreys, 1997).

Per the biased competition model, different magnitudes of inhibition should be placed on static distractors versus moving distractors, as the static distractors should be perceptually grouped and processed as objects that are irrelevant to the tracking task. The aging literature on object-based IOR (McAuliffe et al., 2006; McCrae & Abrams, 2001) and visual marking of dynamic stimuli (Watson & Maylor, 2002) suggest that older adults will be impaired in the selective suppression toward dynamic distractors during multiple object tracking. The inhibitory deficit hypothesis (Hasher & Zacks, 1988; Hasher et al., 1999) suggests that older adults inappropriately attend to irrelevant information (e.g., static distractors) and therefore overload working memory as a result of the inhibitory attentional system failing to suppress distractors. Additionally, the incorporation of the dot probe with a challenging primary task (target tracking) will contribute to increased demands on older adults.

I predicted that a form of top-down inhibition would suppress stimuli which had the potential to be a target (e.g., moving distractors). As a result, probe detection would be slowest (and with poorest accuracy) when the probe was presented on a moving distractor, as it should be the site of the strongest suppression due to the moving distractor's similarity to the target in appearance and movement. I predicted that RTs to detect a probe would be fastest (and with greatest accuracy) when the probe was presented at an empty location, followed by on a static distractor, as these conditions would function as unrelated events which were perceptually distinguishable from targets. Evidence for the pattern supporting this prediction would be from a probe location × tracking interaction. When participants passively observed objects in movement, probe detection for the target and moving distractor conditions should be identical to each other. However, when behavioral goals required that the participant track targets, then irrelevant distractor objects must be suppressed.

Aging models identify the inhibitory system and top-down control as areas sensitive to decline (Braver & Barch, 2002; Hasher & Zacks, 1988). As a result of impaired and/or misplaced inhibition of stimuli, I predicted that age differences would emerge in the pattern of probe detection across the different distractor conditions (moving and static). Consistent with previous research (Pylyshyn et al., 2008), I predicted that young adults would show significantly faster and more accurate probe detection of static distractors compared to targets and moving distractors, and faster and more accurate probe detection of targets compared to moving distractors. If inhibitory selection processes are impaired with age, I predicted that older adults would show smaller differences in probe detection RTs and accuracy between the three conditions. This pattern would suggest that top-down inhibition would be diminished or misplaced. Evidence to support this pattern would take the form of a three-way interaction between age, probe location, and tracking condition. Older adults would show less differentiation in RTs and accuracy to static and dynamic distractors in the tracking condition compared to young adults.

Method

Participants

Twenty-four young adults in the age range of 18-33 years and twenty-four older adults in the age range of 60-71 years participated in the experiment. I used the same recruiting and screening techniques as described in Experiment 1. An additional 14 young adults and five older adults were tested but excluded for high GDS scores of 12 or greater, and one young adult was excluded for a Mini-Cog score of 2 or less. As noted in the Results section, an additional seven participants were excluded for target tracking performance at chance or below (young adults: 3, older adults: 4) and seven participants were excluded for probe detection accuracy below 50% (young adults: 4, older adults: 3). All excluded participants were replaced with individuals who met the screening criteria. Participant 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)	23.8 (4.4)	64.2 (3.3)*
% Female	38%	54%
Education (years)	15.1 (2.2)	15.5 (2.2)
Mini-Cog	4.5 (0.59)	4.6 (0.7)
GDS	4.8 (3.7)	4.2 (3.2)

Note. Abbreviations: SD = standard deviation; Mini-Cog = Mini-Cognitive Assessment. A maximum score of 5 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

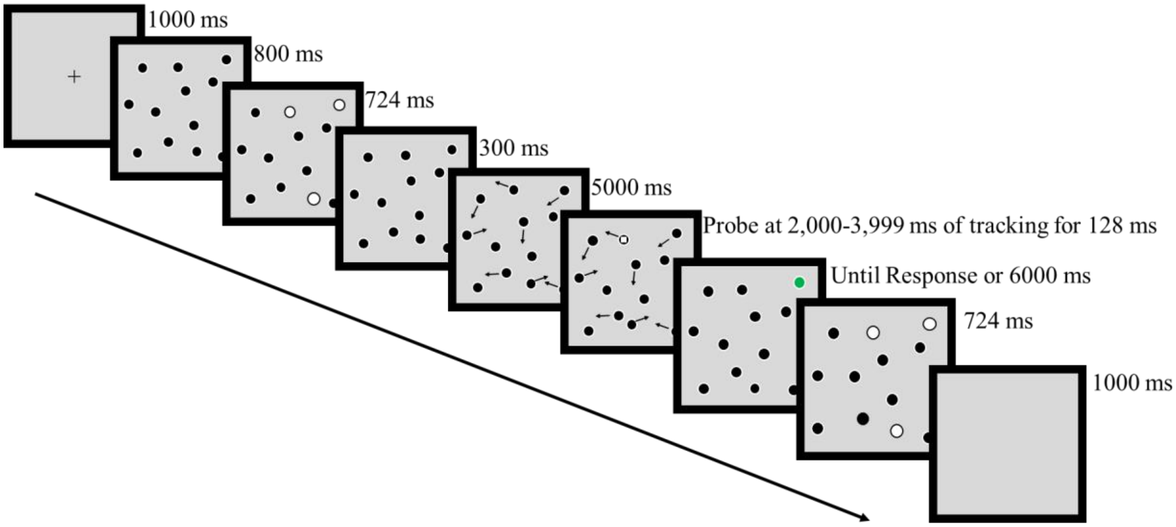
I used the same online programs described in Experiment 1: Prolific for recruiting, Qualtrics for screening and task instructions, and PsychoJS (on Pavlovia platform) for MOT task programming. Participants were instructed to complete the experiment on a desktop or laptop. Some participants attempted to complete the task on a smart phone and resulted in errors during the computer task, which resulted in no data file. The following visual angle dimensions and temporal parameters reflect the programmed specifications for testing in the laboratory, with a 32 cm x 32 cm monitor size and a distance of 34 cm from the computer screen. The following dimensions may have varied across the different monitor sizes and device operating software used by participants. The basic stimulus display consisted of twelve black circles with a white border (circle diameter: 2.7° of visual angle; white border thickness: 0.12°) presented against a gray background. The stimuli were constrained within a borderless 14 cm x 19 cm area. The probe was a white square (0.35° x 0.35°). The circles were prevented from occluding each other during movement by incorporating a repulsion between circles and the borders of the screen. Target set size was constant at three circles. All text in the experiment (e.g., task instructions) was presented in black and at size 20 font. Participants made responses on a keyboard. I prepared an instructional video lasting 5 minutes to explain the task to participants and demonstrate the required key presses (e.g., picture showing left pointer finger to press A key).

Procedure

Following informed consent and screening on Qualtrics, participants viewed the instructional video for an overview of the task and were then transferred to an html site, through the platform Pavlovia, for the computer task. The test trials were divided into two parts: tracking and non-tracking conditions, with non-tracking trials completed first by all participants. Participants completed non-tracking trials first to encourage passive viewing, prior to the explicit instructions to follow targets and ignore distractors during the tracking trials. Figure 6 illustrates the basic trial sequence for tracking trials. A blank screen was presented for 1000 ms, followed by the presentation of twelve circles at random locations for 800 ms. Three circles were identified as targets by alternating their appearance with entirely white circles four times, with each alternation lasting 181 ms. Once the targets were revealed, all circles returned to black and remained static for 300 ms. During the tracking period, all three targets and five distractors moved, while four distractors remained static. Circles were randomly assigned as target, moving distractor, or static distractor identities. The tracking period lasted for 5 s, in which the targets and moving distractors all moved across the display independently. At a random time between 2,000 to 3,999 ms of the tracking movement (third or fourth second), a white probe appeared on eighty percent of the trials for 128 ms. Participants were instructed to press the A key with their left finger as quickly as possible when they detected the white dot. Immediately after the circles stopped moving, a circle was probed (i.e., filled green) for 400 ms. Participants were prompted with written instructions on the screen to determine if the green circle was a target and with their right hand, press the K key if it was a target and the L key if it was not a target. Participants had six seconds to respond. The green circle appeared at a target on half of the tracking trials and on a distractor (moving or static) on the remaining half of the trials. Feedback was provided by having the correct targets flash white while the probe remained green. After a 1,000 ms blank screen, the next trial commenced.

Figure 6

Experiment 2 trial sequence for the tracking condition with a probe

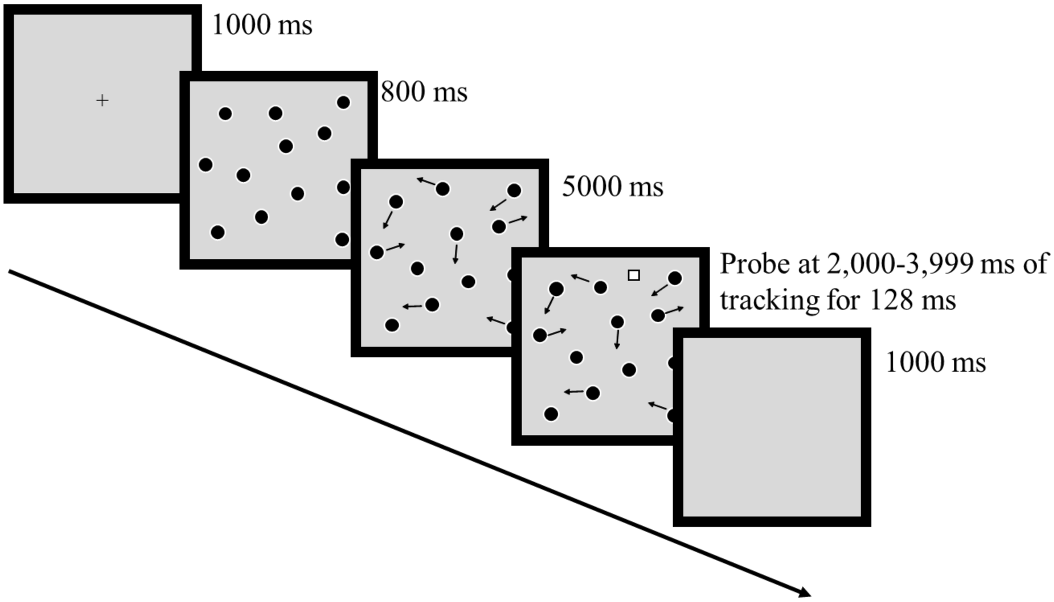


Note. Following a reveal of the targets to be tracked, all objects returned to an identical appearance. Targets were tracked for a five second (s) duration. At a random time between 2,000 to 3,999 ms of the tracking movement (third or fourth second), a white probe appeared on eighty percent of the trials at one of four locations (empty space, target, moving distractor, static distractor) for 128 ms. Participants were instructed to press the A key upon detection of the probe. In this display, the probe appeared on a target. Once all the items stopped moving, one circle turned green and participants were required to respond if the green circle was a target. Feedback was provided following the response.

The trial sequence was the same for non-tracking trials except that none of the objects were identified as targets. Eight circles began moving (consistent with three targets and five distractors in the tracking condition) and four circles remained stationary for a period of 5 s. At a random time between 2,000 to 3,999 ms of the tracking movement (third or fourth second), a white probe appeared on eighty percent of the trials for 128 ms. Participants were instructed to press the A key as quickly as possible upon detecting the white dot. Figure 7 illustrates the basic trial sequence for non-tracking trials.

Figure 7

Experiment 2 trial sequence for the non-tracking condition with a probe



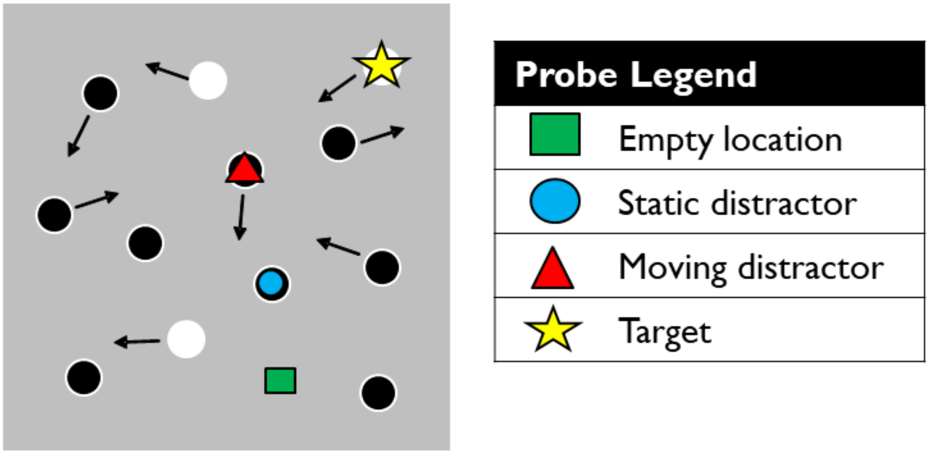
Note. A blank display was presented for 1000 ms, followed by the appearance of the circles for 800 ms. Eight circles moved for a five second (s) duration. At a random time between 2,000 to 3,999 ms of the tracking movement (third or fourth second), a white probe appeared on eighty percent of the trials at one of four locations (empty space, target, moving distractor, static distractor) for 128 ms. Participant were instructed to press the A key upon detecting the probe. In the non-tracking condition, the target and moving distractor conditions were equivalent and were randomly assigned the condition name. The labels target and moving distractors were used in this condition for the purpose of analyses. In this display, the probe is at an empty space.

Participants completed 6 practice trials before each tracking condition (non-tracking, tracking) with two trials containing no probe and one trial per probe location (empty space, target, moving distractor, static distractor). There were 180 total test trials with 60 trials (3 blocks of 20 trials) for the non-tracking condition and 100 trials (5 blocks of 20 trials) for the tracking condition. Each block 16 trials with a probe and 4 without a probe presented in random order. Within each set of 16 probe-present trials, there were 4 trials for each of the 4 probe locations. Figure 8 illustrates the different probe locations. 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.

Participants were also encouraged to close all other programs and browser windows to complete the task without distractions (e.g., television, phones, noisy environments). The Qualtrics screening and computer task lasted about 45 minutes in duration.

Figure 8

Probe locations for Experiment 2



Note. Eighty percent of the trials had a probe present. In the task, the probe was a small white square. The probes are shown here in different colors to differentiate between the conditions. A probe could appear at an empty location or on a static distractor, moving distractor, or moving target.

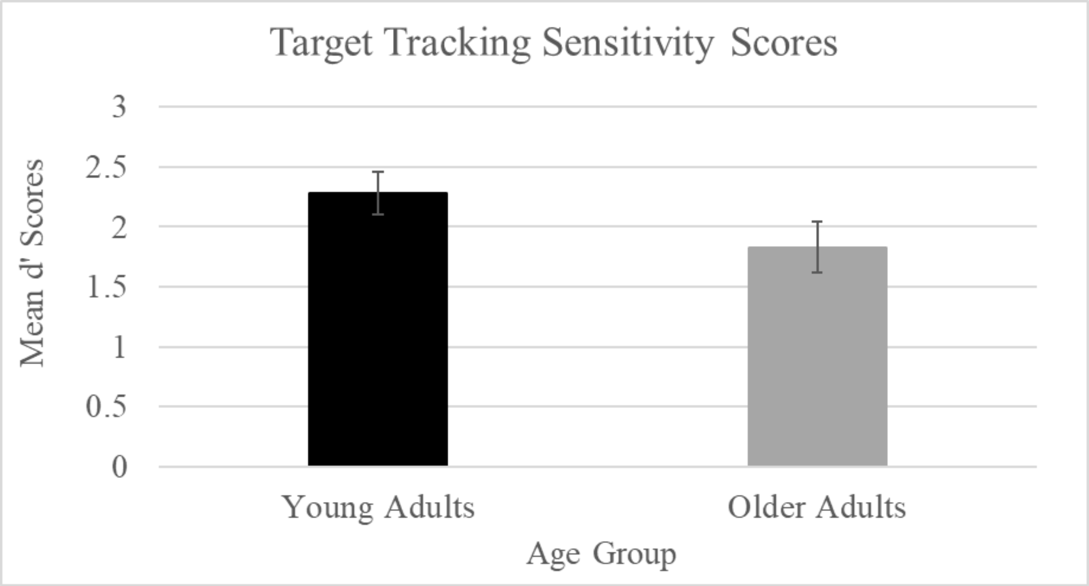
Results

Target Tracking Accuracy

Target tracking performance was analyzed using d prime (d') sensitivity scores. One participant who had a false alarm rate of zero had their score modified by dividing 0.5 by *n* (see Macmillan & Kaplan, 1985). Participants who had a d' of zero or less, consistent with performing at chance level, were excluded from all analyses (young adults: 3, older adults: 4). The primary dependent measure of reaction time to detect probes was to evaluate inhibition placed on stimuli during target tracking; therefore, participants who did not show evidence of tracking (i.e., at chance performance) were excluded. For the final participant sample, young and older adults did not significantly differ in their accuracy rates, $t(46) = -1.64$, $p = .11$, although young adults had slightly better performance (*d'* = 2.3) compared to older adults (*d'* = 1.84). Both age groups had d' scores that were significantly greater than zero (*t*s > 10, *p*s < .0001). Figure 9 illustrates target tracking performance.

Figure 9

Experiment 2 sensitivity scores for tracking performance



Note. Target tracking performance was evaluated using d' scores. Both young and older adults had d' scores that were significantly greater than zero (i.e., chance performance). Performance did not significantly differ for young and older adults. Error bars reflect one standard error.

Estimates on tracking capacity (K) were calculated per the methods recommended by Cowan (2001) and Pashler (1988). One was subtracted from the sum of the proportions for hits and correct rejections. This value was then multiplied by three, the number of targets in the task. Young adults tracked an estimated 2.00 targets, while older adults tracked an estimated 1.75 targets. The difference in the number of targets tracked did not significantly differ between young and older adults, $t(46) = -1.45$, $p = .16$.

Probe Detection Accuracy

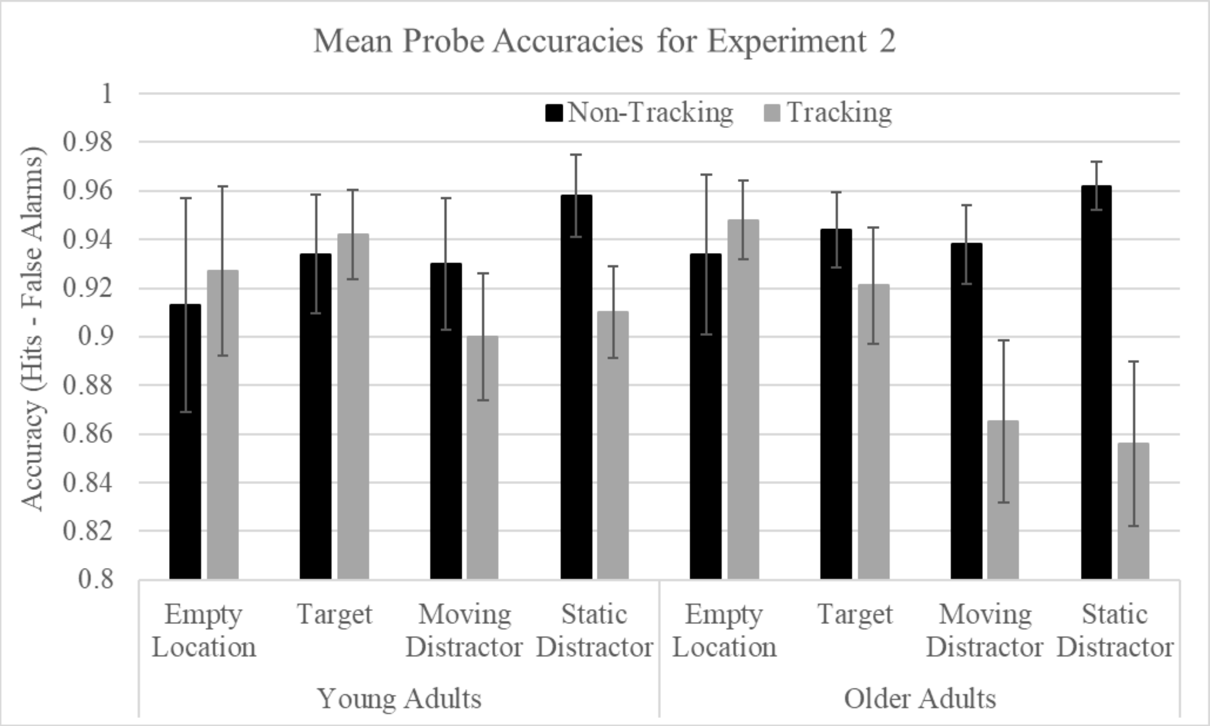
Consistent with Pylyshyn's series of MOT studies (Pylyshyn, 2006; Pylyshyn et al., 2008), I calculated probe detection accuracy as hits (detecting a probe when it was present) minus false alarm rates (indicated a probe was present when it was not). Trials with RT responses less than 100 ms, greater than 2,000 ms, or more than 2.5 *SD* from an individual's probe detection mean were excluded from the analysis. Participants were excluded if probe detection accuracy was below 50% (young adults: 4, older adults: 3), most often resulting from participants who did not complete the probe detection task during Part II (tracking condition) of the task. The participants excluded for poor probe detection accuracy are different from the participants excluded for poor target tracking. These accuracy rates were high for the final sample: 0.93 for older adults and 0.94 for young adults.

Mean accuracy rates were submitted to a 2 (age group: young and older adults) × 2 (tracking: tracking and non-tracking) × 4 (probe location: empty space, target, moving distractor, and static distractor) mixed ANOVA, with age as the between-subjects variable and tracking and probe location as the within-subjects variables. A marginal main effect was found for tracking, *F*(1, 46) = 3.77, *p* = .059, with participants detecting probes relatively more accurately on non-tracking trials (*M* = 0.94) compared to tracking trials (*M* = 0.91). A main effect was not found for age, *F*(1, 46) = 0.06, *p* = .81, or probe location, *F*(3, 46) = 1.31, *p* = .27.

A significant probe location × tracking interaction was found, *F*(3, 46) = 6.76, *p* = .0003. To investigate the interaction, one-way ANOVAs were conducted within each tracking condition. For non-tracking trials, accuracy did not significantly differ across probe location *F*(3, 47) = 1.33, *p* = .27. For tracking trials, a main effect for probe location was found, *F*(3, 47) = 5.49, *p* =.001, reflecting the following order of accuracy rates (moving distractor = 0.88, static distractor = 0.88, moving target = 0.93, empty space = 0.94). Using an SNK post-hoc test, comparisons indicated that a) empty space and moving target conditions were not significantly different from each other, and b) static distractor and moving distractor conditions were not significantly different from each other, and c) empty space and moving target conditions were significantly different from static distractor and moving distractor conditions. No significant interaction was found for age × tracking, *F*(1, 46) = 1.08, *p* = .30, age × probe location, *F*(3, 46) = 0.9, *p* = 0.45, or age × probe location × tracking, *F*(3, 46) = 0.6, *p* = .62. Mean accuracy patterns across all factors are presented in Figure 10.

Figure 10

Probe detection accuracy rates for young and older adults in tracking and non-tracking conditions



Note. Errors bars reflect one standard error (±1 SE).

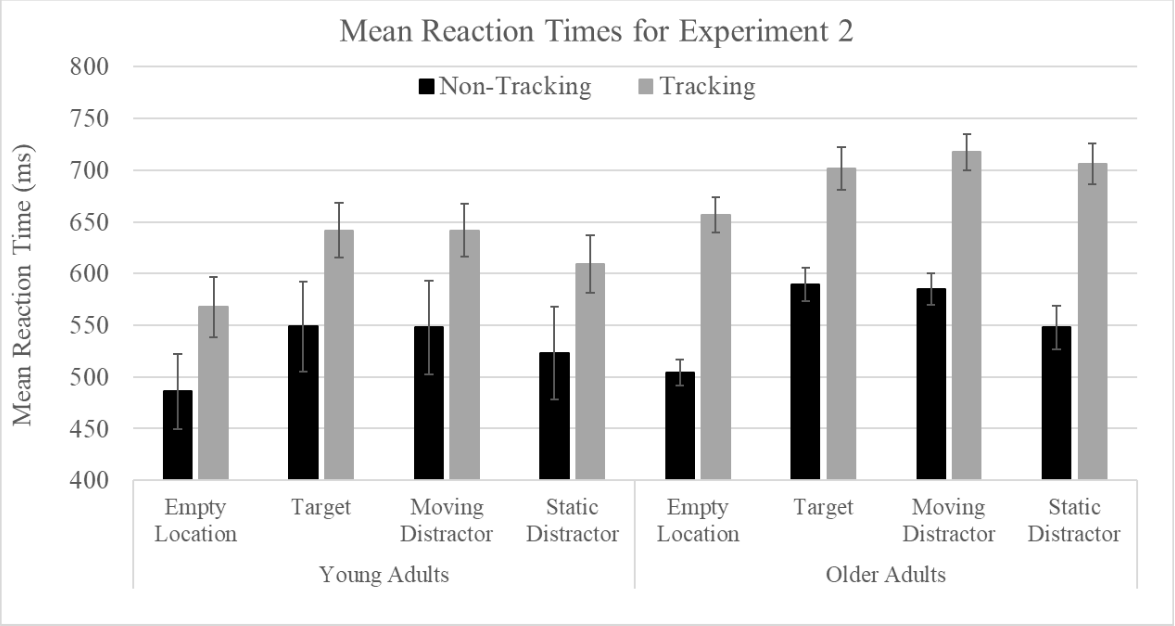
Probe Detection Reaction Times

The mean probe detection RTs were submitted to a 2 (age group: young and older adults) × 2 (tracking: tracking and non-tracking) × 4 (probe location: empty space, target, moving distractor, static distractor) mixed ANOVA, with age as the between-subjects variable and tracking and probe location as the within-subjects variables. A main effect was found for tracking, $F(1, 46) = 62.4$, $p < .0001$, with participants detecting probes faster on non-tracking trials ($M = 542$ ms) compared to tracking trials ($M = 651$ ms). A main effect was also found for probe location, $F(3, 46) = 17.49$, $p < .0001$, reflecting the following ordering of RTs (moving distractor = 623 ms, moving target = 613 ms, static distractor = 596 ms, and empty space = 554 ms). Using an SNK post-hoc test, comparisons indicated that a) RTs for moving distractor and moving target were not significantly different from each other b) RTs for moving target and static distractor were not significantly different from each other, c) moving distractor RTs were significantly different from static distractor RTs, and d) empty space RTs were significantly different from all other condition RTs. A significant main effect was not found for age, $F(1, 46) = 3.04$, $p = .088$, although the trend indicated young adults detected probes relatively faster ($M = 567$ ms) than older adults ($M = 626$ ms).

A significant age group × tracking interaction was found, $F(3, 46) = 4.32$, $p = .043$. To investigate the interaction, I used t-tests to examine age effects within each tracking condition. For non-tracking trials, probe detection RTs did not significantly differ for young ($M = 526$ ms) and older adults ($M = 557$ ms), $t(23) = 0.73$, $p = .47$. For tracking trials, a significant age difference was found, $t(23) = 2.81$, $p = .007$, with young adults detecting probes more quickly ($M = 607$ ms) than older adults ($M = 696$ ms). A probe location × tracking interaction was not significant, $F(3, 46) = 1.97$, $p = .12$, nor was an age × probe location interaction, $F(3,46) = 0.13$, *p* = .94, or age × probe location × tracking interaction, *F*(3, 46) = 0.56, *p* = .64. Mean accuracy patterns across all factors are presented in Figure 11.

Figure 11

Probe detection reaction times for young and older adults in tracking and non-tracking conditions



Note. Errors bars reflect one standard error (±1 SE).

Discussion

The purpose of Experiment 2 was to evaluate age patterns of top-down inhibition on distractor objects during a challenging object tracking task. To evaluate suppression of irrelevant objects during selective attention, a dot-probe task was added to the traditional MOT paradigm (modeled after Pylyshyn et al., 2008). Accuracy and RTs to a probe presented during the tracking were measured, with lower accuracy or slower RTs reflecting greater suppression of the stimulus object. Age-related impairments in inhibitory processing (Hasher & Zacks, 1988; Hasher et al., 1999) and divided attention tasks (Hartley, 1992; Ponds et al., 1988) led to the hypothesis that older adults would show poorer suppression of distractors during the MOT task.

My first prediction was that detection of probes on moving distractors would be the least accurate and slowest because moving distractors would compete for attention with the moving targets and thus need to be inhibited. If suppression was tied to selective attention, then poor detection of probed on moving distractors would be specific to trials in which participants were tracking objects. On non-tracking trials there would be similar accuracy and RTs for detecting probes on targets and moving distractors. Consistent with that prediction, the pattern of detection accuracy for probes at different locations varied by tracking condition. However, probes on static and moving distractors were detected less accurately compared to the probes on targets and empty spaces. This pattern was not consistent with Pylyshyn et al., (2008), who found probes on static distractors were detected with high accuracy, similar to the empty locations. In contrast to the accuracy findings, RTs to probe locations did not vary significantly as a function of tracking condition. It is worth noting that moving target and moving distractor conditions had a 3 ms difference during non-tracking trials and 23 ms difference during tracking trials, suggesting the possibility that in a sample with less noise and improved tracking performance (suggesting active engagement in the task and effective suppression of distractors), a significant interaction may have emerged for RTs consistent with greater inhibition of moving distractors than static distractors. Given the significant interaction observed with accuracy as an outcome measure, and the trend for differentiable RT patterns for moving targets and distractors in the tracking condition, I would conclude that my first prediction was supported: probes were detected less efficiently when presented on moving distractors, suggesting this type of distractor was inhibited during tracking. Poorer detection of probes on moving distractors compared to an empty space suggested that the suppression was not due to enhanced attention to targets, but a result of inhibition to distractors objects. However, the accuracy data indicates that active suppression is placed on all distractor objects (moving or static) during target tracking, not only on task-relevant moving distractors.

My second prediction was that age differences would emerge in the probe detection patterns (in both response time and accuracy) reflecting inhibition. Consistent with models of impaired and misplaced inhibition of stimuli (Hasher & Zacks, 1988; Hasher et al., 1999), I predicted that an age × probe location × tracking condition interaction would emerge, to reflect different age patterns of suppression. More specifically, I predicted that young adults would show significant differences in accuracy rates and RTs between probe conditions during tracking, with the poorest detection of probes at moving distractors, followed by moving targets, and the best detection of probes occurring at static distractors and empty spaces. In contrast, I predicted that older adults would show smaller (or non-significant) differences between the moving distractor, target, and static distractor conditions, but maintain high probe detection at the empty space. If inhibitory processes used during selective attention are impaired with age, then weaker or misplaced inhibition would be expected.

My second prediction was not supported, as the age × probe location × tracking condition interaction was not significant in predicting accuracy rates or RTs. The only significant finding was that age differences in probe detection RTs were found in the tracking condition and not in the non-tracking condition. This pattern was not observed with measures of accuracy. Therefore, the overall slower RTs of older adults for tracking trials only may reflect a more cautious approach to the challenging tracking (Starns & Ratcliff, 2010) and probe detection tasks. This explanation would also be consistent with research on aging and divided attention, in which greater costs were observed with the secondary task (probe detection), when the primary task (object tracking) is very challenging (Hartley, 1992; Ponds et al., 1988). Based on the findings of

Experiment 2, I would conclude that both young and older adults demonstrate inhibition of distractor objects when tracking multiple objects, but do not show differentiable suppression between moving and static distractors.

The current study was not designed to test the theoretical models proposed to explain MOT patterns, and without having conducted the first experiment that was originally proposed for this dissertation (Appendix), it is difficult to make a conclusion about which model of MOT best supports the current findings. I had initially predicted that static distractors would be considered irrelevant and removed from the task demands as a set of units forming a perceptual object. This was not the pattern observed, as the dot-probe accuracy data showed suppression of static and moving distractors. Therefore, my application of the perceptual grouping model (Yantis, 1992) to distractors, rather than targets, was not supported. Rather, the FINST theory (Pylyshyn, 1988) and FLEX model (Alvarez & Franconeri, 2007) may be better candidates for explaining behavioral patterns in the current study.

The main difference between the FINST and FLEX models is whether attentional allocation is rigid or flexible. An estimate on target tracking capacity (Cowan, 2001; Pashler, 1988) found that both young and older adults were likely tracking about two of the three targets. The tracking capacity of two targets is substantially less compared to previous research for young adults, who have been found to regularly track four targets (Alvarez & Franconeri, 2007). It is possible that some young adults were performing the online task while engaged in other activities, therefore reducing the amount of resources allocated to the task. Older adults have been shown to track two or three targets, although performance tends to decline for more than two targets (Sekular et al., 2008; Trick et al., 2005). The decline in tracking capacity for young adults may suggest that it is a flexible system which contributed to the behavioral patterns. It is also possible that if less than three targets were being tracked, then one of the targets could have been tagged as a distractor and erroneously inhibited.

During MOT, divided attention allows for more than one object to be monitored simultaneously. In turn, attention to multiple objects while completing the dot-probe task increases the demand placed on executive control processes. A review of studies on divided attention revealed age differences across a range of primary and secondary tasks, including visual search, memory, motor skill, and visual detection tasks (Craik et al., 2010; Georgiou-Karistianis et al., 2006; Hartley, 1992). Older adults are reported to show relatively equivalent costs compared to young adults when the tasks are less challenging (Somberg & Salthouse, 1982), and greater costs when the tasks are more demanding (Georgiou-Karistianis et al., 2006; Ponds et al., 1988; Salthouse et al., 1984) or when the primary task involves memory or motor tasks (Hartley, 1992). While deficits in divided attention have been attributed to limited cognitive processing resources (Craik et al., 2010), it has also been noted that age differences on a divided task should be carefully interpreted when there are significant age differences on the primary task (Somberg & Salthouse, 1982). In Experiment 2, no age differences were found for d’ scores on target tracking, probe detection accuracy, or probe detection reaction times. A significant age group × tracking interaction for RT data reflected significantly slower RTs by older adults on tracking trials, although the overall findings suggest that this slower detection did not result in poorer accuracy.

An interesting outcome of this study was that different patterns were observed when dot-probe accuracy and RTs served as the dependent variable. Studies which have compared accuracy and RT measures across different paradigms argue that some mechanisms may be more appropriately measured using one outcome measure over the other (Prinzmetal et al., 2005; Urry et al., 2015). The dot-probe MOT design (modeled after Pylyshyn et al., 2008) used accuracy as the primary outcome measure. Therefore, I completed analyses on accuracy. However, because I incorporated the dot-probe as a detection task, rather than a discrimination task (prompt at the end of the trial), participants' responses times were also of interest. While a comparison of RTs yielded main effects for probe location, it did not yield the same patterns as measures of accuracy. Online data collection could have contributed to noisy data for probe detection response times, as different devices, operating software, and browsers, among other factors, could affect the collection of accurate RTs. It is also possible that inhibition during target tracking is characterized by temporal patterns which were missed by assessing probe detection during the trial, rather than at the end.

The findings of the current study suggest that both young and older adults employ top-down suppression during target tracking. Inhibition is presumed to be characterized by different domains (Nigg, 2000), and these different types of inhibition do not show uniform age patterns (Kramer et al., 1994). While research shows that older adults have impairments in the manifestation of effortful inhibition or inhibition with demanding tasks (Watson & Maylor, 2002), the current experiment did not support evidence of age differences in top-down suppression of the distractors.

CHAPTER 4: GENERAL DISCUSSION

Selective attention acts through competing bottom-up and top-down biases (Desimone & Duncan, 1995). If salient information is available, such as distinct objects, or perceived objects through perceptual grouping, it will influence attentional selection (Duncan, 1984). Without salient information, or if the task is goal-directed, top-down processes will guide attention by suppressing non-target features (Deco & Rolls, 2004). Normative aging affects the components of selective attention differentially, with relative preservations in the use of bottom-up biases (Lindenberger & Mayr, 2014; Plude & Doussard-Roosevelt, 1989), impairments of top-down control (Braver & Barch, 2002), and declines in inhibitory processing (Hasher & Zacks, 1988; Hasher et al., 1999). A review of the behavioral patterns for object-based inhibition tend to support evidence of different types of inhibition (Connelly & Hasher, 1993; Kramer et al., 1994; Nigg, 2000), with object-based inhibitory effects yielding complex and often conflicting findings (Huether & Langley, manuscript in revision; Kramer & Atchley, 2000; Kramer et al., 1994; McAuliffe et al., 2006; McCrae & Abrams, 2001). In the two experiments of this dissertation, I examined age differences in the inhibitory mechanisms of object-based attention. Experiment 1 examined age patterns of location- and object-based inhibition of return (IOR) and served to replicate findings from a study conducted in a laboratory setting (Huether & Langley, manuscript in revision) using online data collection methods. Experiment 2 served to evaluate age patterns of top-down inhibition directed at distractor objects during an MOT task, also employing online data collection methods.

Object-Based Inhibition

For Experiment 1, I predicted that measurable location- and object-based IOR would be found for young and older adults. Object-based IOR was observed for object-present trials only, consistent with my prediction. If there was a significant effect on object-absent trials, it would suggest the cue effect was due to spatial proximity of the cues rather than attention crossing or not crossing an object boundary. Unexpectedly, for location-based IOR, difference scores were significant for object-present trials only. Evidence for location-based IOR was consistent with my prediction, although the lack of location-based IOR for object-absent trials was not consistent with previous research (Leek et al., 2003; McAuliffe et al., 2001; Tipper et al., 1991). Response times for object-absent trials did not show the ordering of cue conditions which would reflect inhibition, suggesting that the results are not due to noise alone. The unexpected pattern with object-absent trials may be better explained by some of the challenges experienced with online data collection, discussed in the next section.

Whereas IOR measures automatic inhibitory processes, Experiment 2 served to measure age differences in top-down inhibition during selective attention. Using a dot-probe task during multiple object tracking (MOT), I examined patterns of suppression towards distractor objects. I predicted that detection performance would be worst for probes presented on moving distractors compared to probes on targets and empty locations, reflecting inhibition. I also predicted that age differences would emerge, with older adults showing attenuated inhibition resulting from impaired (diminished suppression of probes on moving distractors) or misplaced inhibition (suppression of probes on static distractors). The findings of Experiment 2 would suggest that suppression of moving distractors was employed during target tracking, although the critical interaction between probe location and tracking condition was significant for accuracy measures, but not RTs. The interaction for accuracy reflected significant differences in dot-probe detection when probes were presented on distractors (static and moving) compared to target and empty space. The pattern was not consistent with Pylyshyn et al. (2008), who found that static distractors were not suppressed. The authors concluded that the lack of suppression towards static distractors was due to selective inhibition towards relevant distractors (moving), instead of inhibition being placed uniformly across all objects other than the targets. Per this rationale, the current study would suggest that participants were actively suppressing any non-target object (but not locations, as measured by probes at empty spaces). If this is the case, it would indicate that both age groups had difficulty selectively dispatching top-down inhibition or that they found stationary distractors potentially distracting, too. Contrary to my second prediction, age differences did not emerge in probe detection as a function of probe location.

Per the biased competition account (Desimone & Duncan, 1995), objects boundaries and representations should serve to guide attention using bottom-up processes to segregate stimuli from the background (Vecera & Behrmann, 2001). The findings in Experiment 1 supported evidence of object boundaries (rectangles) facilitating the orienting of attention in the development of location-based and object-based IOR. In Experiment 2, I predicted that the static distractors would serve as a perceptual grouping of objects, which could be segregated from the task-relevant moving objects to reduce cognitive load. Although Pylyshyn et al. (2008) found that young adults selectively suppressed moving distractors and not static distractors, I did not observe the same pattern. The lack of selective suppression in Experiment 2 may suggest that object representations comprised of perceptual groupings (similarity of static distractors) may be less effective in capturing attention, or may require a secondary perceptual characteristic (e.g., proximity, similarity by color or luminance). The proposed experiment that was not conducted in this dissertation (Appendix), would test the effectiveness of static distractors on target tracking performance across different cognitive demands (number of items in the display). Top-down biases guide attention when competition cannot be resolved by bottom-up cues or if there are task-related goals, such as tracking targets which look identical to moving distractors (Desimone & Duncan, 1995). The filtering of distractors occurs through suppression of the unwanted, or distracting stimuli. In Experiment 2, the inhibition of distractor objects compared to targets and empty locations, suggests that top-down processes biased attention by suppressing competing distractor objects.

I used paradigms that tested different types of inhibition, with IOR measuring automatic inhibition and MOT probe detection reflecting top-down inhibition. Experiment 1 yielded significant location- and object-based IOR. In Experiment 2, participants showed inhibition to distractors objects, that was not specific to moving distractors but included static distractors, too. Age differences were predicted by models of impairments in inhibitory processing (Hasher & Zacks, 1988) and cognitive control (Braver & Barch, 2002), where more effortful inhibition would yield the greatest declines in older adult performance. Age differences were not revealed in the existence of magnitude of inhibitory effects. For Experiment 1, significant location- and object-based IOR was observed within object boundaries. For Experiment 2, age differences were observed as slower RTs by older adults during tracking trials, but there were no age differences in inhibition as measured by slowed detection of probes on moving or static distractors. The evidence of preserved inhibitory functioning observed by older adults in this study suggest that both automatic and effortful inhibitory processes can be resistant to age-related decline, and changes in temporal patterns may be captured by behavioral data under the appropriate task parameters.

A recent review of inhibitory functioning in older adults suggests that the variability in findings of may be moderated by other factors such as experience with the task (Campbell et al., 2020). The larger location-based IOR effects observed with laboratory-based data collection, compared to data collected online, may have been influenced by the participant samples. With data collected in the laboratory, older adult participants are often recruited from a pool of previous participants and therefore, individuals who have completed similar computer tasks. The participants who come to the lab tend to be healthier, more educated, and more independent than the general older adult population. Older adults with prior experience and practice with computer tasks have been shown to perform better on some measures of attention than older adults who have not had experience with similar computer tasks (Wilkinson & Yang, 2020). Studies listed on Prolific can include attention tasks but are primarily surveys, therefore it is unknown the extent to which older adults on Prolific have had experience with computer attention tasks. However, older adult participants recruited through Prolific were younger than the participants tested in the lab and may also have represented a higher functioning and computer-proficient group of older adults. It is possible the older adult Prolific sample reflected a more homogenous and high functioning group of individuals, compared to older adults recruited from the community in laboratory-based studies. In either case, it is important to note that these volunteer convenience samples are self-selected and screened to be a high functioning group of older adults. The differences in mean age between older adult samples tested online, in the laboratory, and in the research cited in this dissertation, may also reflect cohort differences. Data collected in the laboratory (original study from Experiment 1 and literature cited in this dissertation) have often included more older adults from the Silent Generation (born between 1928-1945), whereas the data collected online includes more older adult participants from the Baby Boomer Generation (1946-1964). Therefore, it is possible that evidence of inhibitory functioning in older adults observed in this dissertation may have represented behavior that differed from the general population and across different cohorts.

Online Data Collection

Previous research has shown that findings from complex attention tasks can be replicated using a virtual platform (Crump et al., 2013; Kochari, 2019; Stothart et al., 2015). For Experiment 1, I predicted that the magnitude of location- and object-based IOR from data collected online would be similar to the effects observed in laboratory data (Huether & Langley, manuscript in revision). However, IOR effects from RT data collected online compared to a laboratory setting was significantly smaller for location-based IOR, with larger difference scores for data collected in a laboratory setting compared to online. These differences could arise from differences in task presentation across devices, from differences in the timing of responses across devices, from greater variability in performance due to greater distractions in the testing environment outside the lab, or from differences in the characteristics of participants recruited for online versus laboratory studies.

With online data collection, a unique pattern emerged in the amount of variability in the outcome measures, particularly for young adults. Traditional age patterns show greater variability in RTs for older adults compared to young adults (Hultsch et al., 2002). However, in the current studies, standard deviations were greater for young adults in every test condition compared to older adults. This variability could be attributed to differences in stimulus presentation and recording of accurate response times as a result of different devices or operating software. However, due to the increased variability by young adults rather than older adults, this pattern could have resulted from a lack of participant engagement and attentiveness. If participants are not consistently following task instructions or failing to attend to the appropriate stimuli, they may respond prematurely or delayed, resulting in greater variability. Another consideration is the diverse demographics of participants who completed the online task.

Compared to a relatively homogenous group of young adults who participate in the laboratory-based studies (college students from the Midwest), the participants on the online tasks reflect greater diversity in age, ethnicity, and education. More diverse demographics were represented with the young adult Prolific sample and likely also included more diverse abilities (low and high functioning).

A challenge that emerged with the use of online data collection was an unexpected issue with the Pavlovia platform. On the MOT task only, I received numerous messages from participants regarding a glitch which would occur and freeze or reset the task during Part II of the task (tracking trials). When this error occurred, no data was recorded for the trials completed. After trying numerous approaches to identify the problem, we were able to use the developer window on the web browser to identify the error message when the glitch occurred. The error resulted when there was less graphics memory for the browser, most often occurring with older or smaller (e.g., tablet, phone) devices. The background Qualtrics function obtained device information for participants and many participants who experienced the glitch were using the appropriate devices as requested in our study requirements. Unfortunately, this error resulted in numerous payments to participants for their time spent on the task when the glitch occurred (roughly 35 minutes into session). Future studies should consider adopting the popular methodological approach with online data collection in which the number of test trials is drastically reduced and the sample size is increased to achieve enough statistical power (Crump et al., 2013). By reducing the study duration, participant attentiveness would likely increase and the likelihood of glitches, observed only in Part II of the MOT study, should decrease or be eliminated.

Another consideration was the high number of exclusions related to a high score on the Geriatric Depression Scale (GDS; Yesavage et al., 1983; validated in young adult sample, Ferraro & Chelminski, 1996). The cutoff we used is consistent with symptoms of moderate to severe depression (Wancata et al., 2006), which could result in slowing of reaction times and cognitive functions. Across Experiment 1 and Experiment 2, the exclusion rate for high GDS was 31% for young adults and 18% for older adults. In 2017, the average prevalence of major depressive episode was 13.1% for young adults (18-25) and 4.7% for older adult (50+; NIMH, 2019). The high rate of abnormal GDS scores in the current study may mean that the population of participants who are active on Prolific tend to have greater incidence of depression compared to the general population, a pattern which has been found with MTurk samples (Arditte et al., 2015; Ophir et al., 2020). This may be related to the type of individuals who regularly participate on crowdsourcing sites; however, it may also be inflated by the current circumstances in society. Data was collected during a period in which many people were in quarantine, as a result of the 2020 novel coronavirus pandemic. The pandemic also resulted in many people having reduced work hours, losing their jobs, being without childcare services, having difficulty paying bills, and being homebound in quarantine. Participants may have responded to certain items of the GDS in a way that was consistent with the restrictions of the pandemic and not necessarily representative of their mindset. For example, the question, “Do you prefer to stay at home, rather than going out and doing new things?” may have resulted in more participants responding “yes” because they were not permitted to leave the house and engage in activities.

Despite the challenges I experienced using online data collection, the evidence of IOR effects by older adults and probe effects during MOT would suggest that the behavioral tasks to measure these attentional effects can be assessed in a virtual setting. Although I clearly specified device requirements and notified that payment would not be made for violations of the device specifications (e.g., task is performed on a smart phone), a researcher could also set task parameters to shorten the online task. These changes should reduce the incidence of computer-related errors during the task and participant inattentiveness.

Conclusion

In conclusion, the behavioral data obtained in the current study provides support that both age groups showed evidence of automatic inhibitory processing towards objects. While top-down inhibition was observed with distractor objects, there was a lack of selective inhibition differentiating relevant objects (moving distractors) from irrelevant objects (static distractors). This finding would suggest that there are different domains of inhibition which may be differentially impacted by age (Kramer et al., 1994) and that more effortful inhibition may be more sensitive to decline with age and task demands (Braver & Barch, 2002; Hasher & Zacks, 1988). However, the lack of age interactions make it difficult to make firm conclusions about age differences in object-based effects with automatic inhibition. The lack of age differences in top-down suppression during MOT suggests that both young and older adults employed selective attention towards objects that were not targets. However, the lack of age differences for dot-probe detection accuracies or response times, target tracking d’ scores, or tracking capacities deviates from previous literature (Sekular et al., 2008; Störmer et al., 2013; Trick et al., 2005). Therefore, replication of Experiment 1 and 2 should be conducted online with the recommended changes to the task parameters, such as a shortened duration and increased sample size. Experiment 2 should also be replicated in a laboratory setting, to examine age patterns of top-down suppression using a dot-probe MOT task in a controlled environment. Further research is necessary to differentiate between outcomes resulting from behavioral measures and testing environment.

REFERENCES

Abrams, R. A., & Dobkin, R. S. (1994a). Inhibition of return: effects of attentional cuing on eye movement latencies. Journal of Experimental Psychology: Human Perception and Performance, 20(3), 467-477. doi: 10.1037//0096-1523.20.3.467

Alvarez, G. A., & Franconeri, S. L. (2007). How many objects can you track?: Evidence for a resource-limited attentive tracking mechanism. *Journal of Vision*, *7*(13), 14. doi: 10.1167/7.13.14

Arditte, K. A., Çek, D., Shaw, A. M., & Timpano, K. R. (2016). The importance of assessing clinical phenomena in Mechanical Turk research. *Psychological Assessment*, *28*(6), 684-691. doi: 10.1037/pas0000217

Baylis, G. C., & Driver, J. (1992). Visual parsing and response competition: The effect of grouping factors. *Perception & Psychophysics*, *51*(2), 145-162. doi:10.3758/BF03212239

Borson, S., Scanlan, J., Brush, M., Vitaliano, P., & Dokmak, A. (2000). The Mini-Cog: A cognitive 'vital signs' measure for dementia screening in multi-lingual elderly. *International Journal of Geriatric Psychiatry*, *15*(11), 1021-1027. doi:10.1002/1099-1166(200011)15:11>1021::AID-GPS234>3.0.CO;2-6

Braver, T. S., & Barch, D. M. (2002). A theory of cognitive control, aging cognition, and neuromodulation. *Neuroscience & Biobehavioral Reviews*, *26*(7), 809-817. doi:10.1016/S0149-7634(02)00067-2

Bridges, D., Pitiot, A., MacAskill, M. R., & Peirce, J. W. (2020). The timing mega-study: comparing a range of experiment generators, both lab-based and online. *PeerJ*, 8, e9414. doi: 10.7717/peerj.9414

Brysbaert, M. (2019). How many participants do we have to include in properly powered experiments? A tutorial of power analysis with reference tables. *Journal of Cognition, 2*(1), 1-38. doi: 10.5334/joc.72

Buhrmester, M., Kwang, T., & Gosling, S. D. (2016). Amazon's Mechanical Turk: A new source of inexpensive, yet high-quality data?. *Perspectives on Psychological Science*, *6,* 3-5. doi:10.1177/1745691610393980

Campbell, K. L., Lustig, C., & Hasher, L. (2020). Aging and inhibition: Introduction to the special issue. *Psychology and Aging*, *35*(5), 605. doi: 10.1037/pag0000564

Castel, A. D., Chasteen, A. L., Scialfa, C. T., & Pratt, J. (2003). Adult age differences in the time course of inhibition of return. *Journal of Gerontology Series B: Psychological Sciences & Social Sciences, 58*(5), 256-259. doi: 10.1093/geronb/58.5.P256

Chen, Z. (2012). Object-based attention: A tutorial review. *Attention, Perception, & Psychophysics*, *74*(5), 784-802. doi:10.3758/s13414-012-0322-z

Chetverikov, A., & Upravitelev, P. (2016). Online versus offline: The Web as a medium for response time data collection. *Behavior Research Methods*, *48*(3), 1086-1099. doi:10.3758/s13428-015-0632-x

Christensen, K. J., Moye, J., Armson, R. R., & Kern, T. M. (1992). Health screening and random recruitment for cognitive aging research. *Psychology and Aging*, *7*(2), 204-208. doi: 10.1037/0882-7974.7.2.204

Chung, S. Y., & Nahm, E. S. (2015). Testing reliability and validity of the eHealth Literacy Scale (eHEALS) for older adults recruited online. *Computers, Informatics, Nursing: CIN*, *33*(4), 150-156. doi:10.1097/CIN.0000000000000146

Connelly, S. L., & Hasher, L. (1993). Aging and the inhibition of spatial location. *Journal of Experimental Psychology: Human Perception and Performance*, *19*(6), 1238-1250. doi:10.1037/0096-1523.19.6.1238

Corbett, A., Owen, A., Hampshire, A., Grahn, J., Stenton, R., Dajani, S., Burns, A., Howard, R., Williams, N., Williams, G., & Ballard, C. (2015). The effect of an online cognitive training package in healthy older adults: An online randomized controlled trial. *Journal of the American Medical Directors Association*, *16*(11), 990-997. doi:10.1016/j.jamda.2016.06.014

Cowan, N. (2001). The magical number 4 in short-term memory: A reconsideration of mental storage capacity. *Behavioral and Brain Sciences*, *24*, 87–114. doi: 10.1017/S0140 525X01003922

Cowan, N., Naveh-Benjamin, M., Kilb, A., & Saults, J. S. (2006). Life-span development of visual working memory: When is feature binding difficult?. *Developmental Psychology*, *42*(6), 1089-1102. doi:10.1037/0012-1649.42.6.1089

Craik, F. I., Luo, L., & Sakuta, Y. (2010). Effects of aging and divided attention on memory for items and their contexts. *Psychology and Aging*, *25*(4), 968-979. doi:10.1037/a0020276

Crump, M. J., McDonnell, J. V., & Gureckis, T. M. (2013). Evaluating Amazon's Mechanical Turk as a tool for experimental behavioral research. *PloS One*, *8*(3). doi:10.1371/journal.pone.0057410

Deco, G. & Rolls, E. T. (2004). *Computational neuroscience of vision*. New York, New York, USA: Oxford University Press.

Desimone, R., & Duncan, J. (1995). Neural mechanisms of selective visual attention. *Annual Review of Neuroscience*, *18*(1), 193-222. doi:10.1146/annurev.ne.18.030195.001205

Drummond, L., & Shomstein, S. (2013). The timecourse of space-and object-based attentional prioritization with varying degrees of certainty. *Frontiers in Integrative Neuroscience*, *7*, 1-10. doi:10.3389/fnint.2013.00088

Duncan, J. (1984). Selective attention and the organization of visual information. *Journal of Experimental Psychology: General*, *113*(4), 501-517. doi: 10.1037/0096-3445.113.4.501

Egly, R., Driver, J., & Rafal, R. D. (1994). Shifting visual attention between objects and locations: Evidence from normal and parietal lesion subjects. *Journal of Experimental Psychology: General*, *123*(2), 161-177.

Eriksen, C. W., & Yeh, Y. Y. (1985). Allocation of attention in the visual field. *Journal of Experimental Psychology: Human Perception and Performance*, *11*(5), 583-597. doi:10.1037/0096-1523.11.5.583

Ferraro, F. R., & Chelminski, I. (1996). Preliminary normative data on the Geriatric Depression Scale-Short Form (GDS-SF) in a young adult sample. *Journal of Clinical Psychology*, *52*(4), 443-447. doi: 10.1002/(SICI)1097-4679(199607)52:4<443::AID-JCLP9>3.0.CO;2-Q

Folstein, M. F., Folstein, S. E., & McHugh, P. R. (1975). “Mini-mental state”: A practical method for grading the cognitive state of patients for the clinician. *Journal Psychiatric Research*, *12*, 189-198. doi: 10.1016/0022-3956(75)90026-6

Gazzaley, A., Sheridan, M. A., Cooney, J. W., & D'Esposito, M. (2007). Age-related deficits in component processes of working memory. *Neuropsychology*, *21*(5), 532-539. doi:10.1037/0894-4105.21.5.532

Georgiou-Karistianis, N., Tang, J., Mehmedbegovic, F., Farrow, M., Bradshaw, J., & Sheppard, D. (2006). Age-related differences in cognitive function using a global local hierarchical paradigm. *Brain Research*, *1124*(1), 86-95. doi: 10.1016/j.brainres.2006.09.070

Germine, L., Nakayama, K., Duchaine, B. C., Chabris, C. F., Chatterjee, G., & Wilmer, J. B. (2012). Is the Web as good as the lab? Comparable performance from Web and lab in cognitive/perceptual experiments. *Psychonomic Bulletin & Review*, *19*(5), 847-857. doi:10.3758/s13423-012-0296-9

Goodale, M. A., & Milner, A. D. (1992). Separate visual pathways for perception and action. *Trends in Neurosciences*, *15*(1), 20-25. doi:10.1016/0166-2236(92)90344-8

Gottlob, L. R. (2006). Age-related deficits in guided search using cues. *Psychology and Aging*, *21*(3), 526-534. doi:10.1037/0882-7974.21.3.536

Graham, E. R., & Burke, D. M. (2011). Aging increases inattentional blindness to the gorilla in our midst. *Psychology and Aging*, *26*(1), 162-166. doi:10.1037/a0020647

Granello, D. H., & Wheaton, J. E. (2004). Online data collection: Strategies for research. *Journal of Counseling & Development*, *82*(4), 387-393. doi:10.1002/j.1556-6678.2004.tb00325.x

Guerin, J. M., Copersino, M. L., & Schretlen, D. J. (2018). Clinical utility of the 15-item geriatric depression scale (GDS-15) for use with young and middle-aged adults. *Journal of Affective Disorders*, *241*, 59-62.

Hartley, A. A. (1992). Attention. In Craik, F. I. M., & Salthouse, T. A. (Eds.). *The handbook of aging and cognition.* (pp. 3-49). Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.

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

Hasher, L., Zacks, R. T., & May, C. P. (1999). Inhibitory Control, Circadian Arousal, and Age. In D. Gopher & A. Koriat (Eds.), *Attention and performance, XVII,* (pp. 653-675). Cambridge, MA: MIT Press.

Hilchey, M. D., Pratt, J., & Christie, J. (2018). Placeholders dissociate two forms of inhibition of return. *Quarterly Journal of Experimental Psychology*, *71*(2), 360-371. doi: 10.1080/17470218.2016.1247898

Hoyer, W. J., & Plude, D. J. (1982). Aging and the allocation of attentional resources in visual information processing. In R. Sekular, D. Kline, & K. Dismukes (Eds.), *Aging and human visual function* (pp. 245-263). New York: Liss.

Huether, A. X. A. (2018). *Aging and object-based inhibition of return* (Master's thesis). Retrieved from ProQuest Dissertations and Theses. (Accession Order No. 10827728)

Huether, A. X. A., & Langley, L. K. L. *Aging and inhibition of return to locations and objects*. Manuscript submitted for publication.

Hultsch, D. F., MacDonald, S. W., & Dixon, R. A. (2002). Variability in reaction time performance of younger and older adults. *The Journals of Gerontology Series B: Psychological Sciences and Social Sciences*, *57*(2), P101-P115. doi: 10.1093/geronb/57.2.P101

Hunsaker, A., & Hargittai, E. (2018). A review of Internet use among older adults. *New Media & Society*, *20*(10), 3937-3954. doi: 10.1177/1461444818787348

Jayaraman, S., Klein, R. M., Hilchey, M. D., Patil, G. S., & Mishra, R. K. (2016). Spatial gradients of oculomotor inhibition of return in deaf and normal adults. *Experimental Brain Research*, 234, 323-330. doi: 10.1007/s00221-015-4439-x

Kahneman, D., Treisman, A., & Gibbs, B. J. (1992). The reviewing of object files: Object-specific integration of information. *Cognitive Psychology*, *24*(2), 175-219. doi:10.1016/0010-0285(92)90007-O

Kimchi, R., Yeshurun, Y., & Cohen-Savransky, A. (2007). Automatic, stimulus-driven attentional capture by objecthood. *Psychonomic Bulletin & Review*, *14*(1), 166-172. doi:10.3758/BF03194045

Klein, R. (1988). Inhibitory tagging system facilitates visual search. *Nature*, *334*(6181), 430-431. doi: 10.1038/334430a0

Kochari, A. R. (2019). Conducting web-based experiments for numerical cognition research. *Journal of Cognition, 2*(1), 39-21. doi:10.5334/joc.85

Koo, B. M., & Vizer, L. M. (2019). Mobile technology for cognitive assessment of older adults: A scoping review. *Innovation in Aging, 3*(1), 1-14. doi: 10.1093/geroni/igy038

Kramer, A. F., & Atchley, P. (2000). Age-related effects in the marking of old objects in visual search. *Psychology and Aging*, *15*(2), 286-296. doi: 10.1037/0882-7974.15.2.286

Kramer, A. F. Humphrey, D. G., Larish, J. F., Logan, G. D., & Strayer, D. L. (1994). Aging and inhibition: Beyond a unitary view of inhibitory processing in attention. *Psychology and Aging*, *9*(4), 491-512. doi:10.1037/0882-7974.9.4.491

Kramer, A. F. & Madden, D. J. (2008). Attention. In Craik, F. I. M., & Salthouse, T. A. (Eds.). (2008). *The handbook of aging and cognition* (3rd ed.). New York: Psychology Press.

Lamy, D., & Egeth, H. (2002). Object-based selection: The role of attentional shifts. *Perception & Psychophysics*, *64*(1), 52-66. doi:10.3758/BF03194557

Leek, E., Reppa, I., & Tipper, S. P. (2003). Inhibition of return for objects and locations in static displays. *Perception and Psychophysics, 65*(3), 388-395. doi:10.3758/BF03194570

Lindenberger, U., & Mayr, U. (2014). Cognitive aging: Is there a dark side to environmental support?. *Trends in Cognitive Sciences*, *18*(1), 7-15. doi: 10.1016/j.tics.2013.10.006

List, A. & Robertson, L. C. (2007). Inhibition of return and object-based attentional selection. *Journal of Experimental Psychology: Human Perception and Performance, 33*(6), 1322-1334. doi:10.1037/0096-1523.33.6.1322

Lupiáñez, J., Klein, R. M., & Bartolomeo, P. (2006). Inhibition of return: Twenty years after. *Cognitive Neuropsychology, 23*(7), 1003-1014. doi: 10.1080/02643290600588095

Lupiáñez, J., Milán, E. G., Tornay, F. J., Madrid, E., & Tudela, P. (1997). Does IOR occur in discrimination tasks? Yes, it does, but later. *Perception & Psychophysics*, *59*(8), 1241-1254. doi:10.3758/BF03214211

Macmillan, N. A., & Kaplan, H. L. (1985). Detection theory analysis of group data: Estimating sensitivity from average hit and false-alarm rates. *Psychological Bulletin*, *98*(1), 185-199. doi: 10.1037/0033-2909.98.1.185

Madden, D. J. (1990). Adult age differences in attentional selectivity and capacity. *European Journal of Cognitive Psychology*, *2*(3), 229-252. doi: 10.1080/09541449008406206

Madden, D. J., Gottlob, L. R., & Allen, P. A. (1999). Adult age differences in visual search accuracy: Attentional guidance and target detectability. *Psychology and Aging*, *14*(4), 683-694. doi:10.1037/0882-7974.14.4.683

Major Depression. (2019, February). National Institute of Mental Health. Retrieved August 18, 2020, from https://www.nimh.nih.gov/health/statistics/major-depression.shtml#part_155720

Maylor, E. A., & Lavie, N. (1998). The influence of perceptual load on age differences in selective attention. *Psychology and Aging*, *13*(4), 563-573. doi: 10.1037/0882-7974.13.4.563

McAuliffe, J., Chasteen, A. L., & Pratt, J. (2006). Object- and location-based inhibition of return in younger and older adults. *Psychology and Aging, 21*(2), 406-410. doi:10.1037/0882-7974.21.2.406

McAuliffe, J., Pratt, J., & O'Donnell, C. (2001). Examining location-based and object-based components of inhibition of return in static displays. *Perception & Psychophysics, 63*(6), 1072-1082. doi: 10.3758/BF03194525

McCrae, C. S. & Abrams, R. A. (2001). Age-related differences in object- and location-based inhibition of return of attention. *Psychology and Aging*, *16*(3), 437-449. doi:10.1037/0882-7974.16.3.437

McMains, S., & Kastner, S. (2011). Interactions of top-down and bottom-up mechanisms in human visual cortex. *Journal of Neuroscience*, *31*(2), 587-597. doi:10.1523/JNEUROSCI.3766-10.2011

Meyerhoff, H. S., Papenmeier, F., & Huff, M. (2017). Studying visual attention using the multiple object tracking paradigm: A tutorial review. *Attention, Perception, & Psychophysics*, *79*(5), 1255-1274. doi:10.3758/s13414-017-1338-1

Miller, R., Schmidt, K., Kirschbaum, C., & Enge, S. (2018). Comparability, stability, and reliability of internet-based mental chronometry in domestic and laboratory settings. *Behavior Research Methods, 50*(4), 1345-1358. doi:10.3758/s13428-018-1036-5

Mozer, M. C., & Vecera, S. P. (2005). Object- and space-based attention. In L. Itti, G. Rees, & J. Tsotsos (Eds.), *The encyclopedia of the neurobiology of attention* (pp. 130-134). New York, NY: Elsevier Press.

Nigg, J. T. (2000). On inhibition/disinhibition in developmental psychopathology: Views from cognitive and personality psychology and a working inhibition taxonomy. *Psychological Bulletin, 126*(2), 200–246. doi:10.1037/0033-2909.126.2.220

Ophir, Y., Sisso, I., Asterhan, C., Tikochinski, R., & Reichart, R. (2020). The Turker blues: Hidden factors behind increased depression rates in Amazon's Mechanical Turk. *Clinical Psychological Science*. *8*(1), 65-83. doi: 10.1177/2167702619865973

Pashler, H. (1988). Familiarity and visual change detection. *Perception & Psychophysics, 44*, 369‑378. doi: 10.3758/BF03210419

Perry, C. J., & Fallah, M. (2014). Feature integration and object representations along the dorsal stream visual hierarchy. *Frontiers in Computational Neuroscience*, *8*(84). doi:10.3389/fncom.2014.00084

Plude, D. J., & Doussard-Roosevelt, J. A. (1989). Aging, selective attention, and feature integration. *Psychology and Aging*, *4*(1), 98-105. doi:10.1037/0882-7974.4.1.98

Ponds, R. W., Brouwer, W. H., & Van Wolffelaar, P. C. (1988). Age differences in divided attention in a simulated driving task. *Journal of Gerontology, 43*(6), P151-P156. doi: 10.1093/geronj/43.6.P151

Posner, M. I. (1980). Orienting of attention. Quarterly Journal of Experimental Psychology, 32(1), 3-25. doi: 10.1080/00335558008248231

Posner, M. I., & Cohen, Y. (1984). Components of visual orienting. In Bouma H. & Bouwhuis D. (Eds.), *Attention and Performance X: Control of Language Processes*, (pp. 531-556). London: Erlbaum.

Pratt, J., Spalek, T. M., & Bradshaw, F. (1999). The time to detect targets at inhibited and noninhibited locations: Preliminary evidence for attentional momentum. *Journal of Experimental Psychology: Human Perception and Performance*, *25*(3), 730-746. doi: 10.1037/0096-1523.25.3.730

Prinzmetal, W., McCool, C., & Park, S. (2005). Attention: Reaction time and accuracy reveal different mechanisms. *Journal of Experimental Psychology: General*, *134*(1), 73-92. doi: 10.1037/0096-3445.134.1.73

Pylyshyn, Z. W. (2001). Visual indexes, preconceptual objects, and situated vision. *Cognition*, *80*(1-2), 127-158. doi: 10.1016/S0010-0277(00)00156-6

Pylyshyn, Z. (2004). Some puzzling findings in multiple object tracking: I. Tracking without keeping track of object identities. *Visual Cognition*, *11*(7), 801-822. doi: 10.1080/13506280344000518

Pylyshyn, Z. W. (2006). Some puzzling findings in multiple object tracking (MOT): II. Inhibition of moving nontargets. *Visual Cognition*, *14*(2), 175-198. doi:10.1080/13506280544000200

Pylyshyn, Z. W., Haladjian, H. H., King, C. E., & Reilly, J. E. (2008). Selective nontarget inhibition in multiple object tracking. *Visual Cognition*, *16*(8), 1011-1021. doi:10.1080/13506280802247486

Pylyshyn, Z. W., & Storm, R. W. (1988). Tracking multiple independent targets: Evidence for a parallel tracking mechanism. *Spatial Vision*, *3*(3), 179-197. doi:10.1163/156856888x00122

Rey-Mermet, A., & Gade, M. (2018). Inhibition in aging: What is preserved? What declines? A meta-analysis. *Psychonomic Bulletin & Review*, *25*(5), 1695-1716. doi: 10.3758/s13423-017-1384-7

Salthouse, T. A., Rogan, J. D., & Prill, K. A. (1984). Division of attention: Age differences on a visually presented memory task. *Memory & Cognition*, *12*(6), 613-620. doi: 10.3758/BF03213350

Saxton, J., Morrow, L., Eschman, A., Archer, G., Luther, J., & Zuccolotto, A. (2009). Computer assessment of mild cognitive impairment. *Postgraduate Medicine*, *121*(2), 177-185. doi: 10.3810/pgm.2009.03.1990

Sekuler, R., McLaughlin, C., & Yotsumoto, Y. (2008). Age-related changes in attentional tracking of multiple moving objects. *Perception*, *37*(6), 867-876. doi:10.1068/p5923

Shomstein, S., & Behrmann, M. (2008). Object-based attention: Strength of object representation and attentional guidance. *Perception & Psychophysics*, *70*(1), 132-144. doi:10.3758/PP.70.1.132

Somberg, B. L., & Salthouse, T. A. (1982). Divided attention abilities in young and old adults. *Journal of Experimental Psychology: Human Perception and Performance*, *8*(5), 651-663. doi: 10.1037/0096-1523.8.5.651

Starns, J. J., & Ratcliff, R. (2010). The effects of aging on the speed–accuracy compromise: Boundary optimality in the diffusion model. *Psychology and Aging*, *25*(2), 377-390. doi: 10.1037/a0018022

Störmer, V. S., Li, S. C., Heekeren, H. R., & Lindenberger, U. (2011). Feature-based interference from unattended visual field during attentional tracking in younger and older adults. *Journal of Vision*, *11*(2), 1-12. doi:10.1167/11.2.1

Störmer, V. S., Li, S. C., Heekeren, H. R., & Lindenberger, U. (2013). Normal aging delays and compromises early multifocal visual attention during object tracking. *Journal of Cognitive Neuroscience*, *25*(2), 188-202. doi:10.1162/jocn_a_00303

Stothart, C., Boot, W., & Simons, D. (2015). Using Mechanical Turk to assess the effects of age and spatial proximity on inattentional blindness. *Collabra: Psychology*, *1*(1), 1-7. doi:10.1525/collabra.26

Tassinari, G., Aglioti, S., Chelazzi, L., Marzi, C. A., & Berlucchi, G. (1987). Distribution in the visual field of the costs of voluntarily allocated attention and of the inhibitory after-effects of covert orienting. *Neuropsychologia*, *25*(1), 55-71. doi: 10.1016/0028-3932(87)90043-1

Tassinari, G., Aglioti, S., Chelazzi, L., Peru, A., & Berlucchi, G. (1994). Do peripheral non-informative cues induce early facilitation of target detection? *Vision Research, 34*(2), 179-189. doi: 10.1016/0042-6989(94)90330-1

Tipper, S. P., Driver, J., & Weaver, B. (1991). Object-centered inhibition of return of visual attention. *Quarterly Journal of Experimental Psychology, 43A*, 289-298. doi: 10.1080/14640749108400971

Tipper, S. P., Weaver, B., Jerreat, L. M., & Burak, A. L. (1994). Object-based and environment-based inhibition of return of visual attention. *Journal of Experimental Psychology: Human Perception and Performance*, *20*, 478-499.

Tomasino, K. N., Lattie, E. G., Ho, J., Palac, H. L., Kaiser, S. M., & Mohr, D. C. (2017). Harnessing peer support in an online intervention for older adults with depression. *The American Journal of Geriatric Psychiatry*, *25*(10), 1109-1119. doi:10.1016/j.jagp.2017.04.015

Treisman, A. M., & Gelade, G. (1980). A feature-integration theory of attention. *Cognitive Psychology*, *12*(1), 97-136. doi:10.1016/0010-0285(80)90005-5

Trick, L. M., Hollinsworth, H., & Brodeur, D. A. (2009). Multiple-object tracking across the lifespan: Do different factors contribute to diminished performance in different age groups. In D. Dedrick & L.M. Trick (Eds.), *Computation, cognition, and Pylyshyn* (pp. 79-99). Cambridge, MA: MIT Press.

Trick, L. M., Perl, T., Sethi, N. (2005). Age-related differences in multiple-object tracking. *Journals of Gerontology: Series B*, *60*(2), P102–P105. doi: 10.1093/geronb/60.2.P102

Urry, K., Burns, N. R., & Baetu, I. (2015). Accuracy-based measures provide a better measure of sequence learning than reaction time-based measures. *Frontiers in Psychology*, *6,* 1158. 1-14. doi: 10.3389/fpsyg.2015.01158

Vecera, S. P., & Behrmann, M. (2001). Attention and unit formation: A biased competition account of object-based attention. In T.F. Shipley & P. Kellman (Eds.), *From fragments to objects: Segmentation and grouping in vision* (pp. 145-180). New York, NY: Elsevier.

Verhaeghen, P., Steitz, D. W., Sliwinski, M. J., & Cerella, J. (2003). Aging and dual-task performance: A meta-analysis. *Psychology and Aging*, *18*(3), 443-460. doi:10.1037/0882-7974.18.3.443

Wancata, J., Alexandrowicz, R., Marquart, B., Weiss, M., & Friedrich, F. (2006). The criterion validity of the Geriatric Depression Scale: A systematic review. *Acta Psychiatrica Scandinavica*, *114*(6), 398-410. doi: 10.1111/j.1600-0447.2006.00888.x

Watson, D. G., & Humphreys, G. W. (1997). Visual marking: Prioritizing selection for new objects by top-down attentional inhibition of old objects. *Psychological Review*, *104*(1), 90-122. doi: 10.1037/0033-295X.104.1.90

Watson, D. G., & Humphreys, G. W. (1998). Visual marking of moving objects: A role for top-down feature-based inhibition in selection. *Journal of Experimental Psychology: Human Perception and Performance*, *24*(3), 946-962. doi: 10.1037/0096-1523.24.3.946

Watson, S. E., & Kramer, A. F. (1999). Object-based visual selective attention and perceptual organization. *Perception & Psychophysics*, *61*(1), 31-49. doi: 10.3758/BF03211947

Watson, D. G., & Maylor, E. A. (2002). Aging and visual marking: Selective deficits for moving stimuli. *Psychology and Aging*, *17*(2), 321-339. doi: 10.1037/0882-7974.17.2.321

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

Wertheimer, M. (1923). Untersuchungen zur Lehre von der Gestalt: II. *Psychologische Forschung*, 4, 301-350. [Partial translation in W. D. Ellis (Ed.) (1950). *A sourcebook of Gestalt psychology* (pp. 71-81). New York, NY: Humanities Press.]

What is monitor resolution? Resolutions and aspect ratios explained. (2019, July 29). ViewSonic. Retrieved August 5, 2020, from https://www.viewsonic.com/library/tech/monitor-resolution-aspect-ratio/#:~:text=Monitor%20resolution%20describes%20the%20visual,a%20specific%20number%20of%20pixels.&text=This%20means%20that%20the%20screen,screen%20will%20be%201%2C080%20pixels

Wilkinson, A., & Yang, L. (2020). Long-term maintenance of multiple task inhibition practice and transfer effects in older adults: A 3.5-year follow-up. *Psychology and Aging*, *35*(5), 765-772. doi: 10.1037/pag0000430

Xie, B. (2012). Improving older adults' e-health literacy through computer training using NIH online resources. *Library & Information Science Research*, *34*(1), 63-71. doi:10.1016/j.lisr.2011.07.006

Yantis, S. (1992). Multielement visual tracking: Attention and perceptual organization. *Cognitive Psychology*, *24*(3), 295-340. doi: 10.1016/0010-0285(92)90010-Y

Yesavage, J. A., Brink, T. L., Rose, T. L., Lum, O., Huang, V. S., Adey, M., & Leirer, V.O. (1983). Development and validation of a geriatric depression screening scale: A preliminary report. *Journal of Psychiatric Research, 17*, 37-49. doi: 10.1016/0022-3956(82)90033-4

APPENDIX: PROPOSED EXERIMENT 1

The goal of Experiment 1 is to examine age patterns in the use of bottom-up object property information to reduce attentional demand in an object tracking task. A core principle of the biased competition account is the interplay of bottom-up and top-down biases in selective attention. Bottom-up biases serve as the first set of processes which separate an object from its background and potentially from other objects, if it is salient. Desimone and Duncan (1995) argued that if bottom-up biases are not available or sufficient to identify a desired target, that top-down information in the form of a selection template or observer goals guides attention to the relevant object or location. Top-down processes undergo age-related changes, subject to poorer maintenance and updating of selection templates, and more sensitive to intrusion by irrelevant information (Braver & Barch, 2002; Hasher & Zacks, 1988). In contrast, older adults demonstrate relative preservation of bottom-up processes and tend to rely on salient information when it is available (Lindenberger & Mayr, 2014).

In the aging literature reviewed earlier, the guided search task was introduced as a paradigm which demonstrated older adults were able to use bottom-up information in a guided search task to parcel out a group of irrelevant distractors and reduce the number of items required for serial search (Madden et al., 1999; Plude & Doussard-Roosevelt, 1989). Consistent with the biased competition account, a set of irrelevant distractors would serve as salient bottom-up information which could be perceptually grouped as a unit (e.g., grouping of red squares in an array of black squares and circles) and segregated from the remaining items consisting of the target and relevant distractors (sharing an identifying feature with the target).

As reviewed, the multiple object tracking (MOT) findings indicate that older adults are able to successfully select moving targets from amongst distractors, although they track fewer items than young adults. Older adults' performance is more greatly impacted as task demands such as tracking duration and object speed increase (Sekuler et al., 2008; Störmer et al., 2013; Trick et al., 2005). Possible sources of older adults' tracking limitation are selective attention deficiencies that make it difficult to efficiently distinguish targets from distractors or working memory deficits that disrupt object file maintenance and updating needed for moving objects.

Pylyshyn et al. (2008) evaluated whether young adults used bottom-up processes to identify a subset of objects as non-targets. Moving targets were tracked among moving and static distractors. Static distractors could be perceptually grouped and distinguished as irrelevant objects. If this pre-attentive segregation occurred, then inhibition of static distractors would not be necessary to track targets. To evaluate whether young adults used suppression to ignore moving distractors while tracking objects, participants detected a dot-probe within the MOT display. As the design of the task was not to evaluate tracking performance, the number of targets was not manipulated nor was further testing conducted on target tracking.

The moving-static manipulation is ideal for evaluating age patterns on the use of bottom-up information to reduce the cognitive load in a challenging task. Similar to the guided search task, static distractors should be able to be perceptually grouped to reduce their saliency, as irrelevant distractors, from the number of items needing to be tracked. This bottom-up bias would remove the load on the top-down processes which must track the selected targets among moving distractors which look identical to the targets. In this study, I will measure multiple object tracking performance using target selection accuracy rates. Similar to the aforementioned MOT paradigm (Pylyshyn et al., 2008), I will include static distractors among the moving distractors during the tracking task. I will not use a dot-probe component in this task (see

Experiment 2), as I am interested in measuring age differences in the effect bottom-up information has on accuracy across varying levels of difficulty (i.e., number of targets).

Per the biased competition account, I predict that overall tracking performance in a task with moving and static distractors will have higher accuracy rates compared to trials in which all the distractors are moving. Based on evidence that older adults use bottom-up perceptual grouping to enhance performance in a serial search task (Madden et al., 1999; Plude & Doussard-Roosevelt, 1989), and often rely on salient cues in the environment (Lindenberger & Mayr, 2014), I predict that both young and older adults will show improved performance when static distractors are present. However, top-down processes, particularly the maintenance and updating of selection templates and object files, are sensitive to the aging process (Braver & Barch, 2002; Cowan et al., 2006; Gazzaley et al., 2007). In MOT tasks, older adults show significant declines in the number of targets tracked (Sekular et al., 2008; Störmer et al., 2013; Trick et al., 2005). If this age deficit is attributed to working memory, I predict that the age differences will be present in the number of targets tracked, even in the trials with static distractors. Using the Pylyshyn et al. (2008) paradigm, the first experiment will manipulate bottom-up information by comparing tracking accuracy between a standard MOT condition in which targets are tracked among moving distractors and one in which half the distractors remain static. My aim is to identify if an increase in bottom-up information will reduce the costs in tracking accuracy across an increasing number of targets. Per the biased competition account (Desimone & Duncan, 1995), grouping objects based on a salient irrelevancy cue (static items among moving targets and distractors) should serve as a default bias which would reduce the load on top-down attentional processes. Based on older adults' ability to utilize bottom-up information to aid performance (Lindenberger & Mayr, 2014; Plude & Doussard-Roosevelt, 1989), I predict that older adults will be able to perceptually group static distractors and demonstrate improved performance (tracking accuracy) on trials in which half the distractors remain static. Number of targets will be manipulated to examine if the static condition will lead to larger age differences as the task becomes more challenging. I predict that older adults will show a larger increase in tracking accuracy as target number increases, as they have a larger margin from which their performance can improve.

Method

Participants

Twenty-four young adults (age range recruited: 18-30) and twenty-four older adults (age range recruited: 60-90) will participate in the experiment. Similar tasks used a sample size of 18-20 young adults (Pylyshyn, 2006; Pylyshyn, 2008) or 13 participants per page group (Trick, Hollinsworth, & Brodeur, 2009). Young adults will be undergraduate students from North Dakota State University and receive course credit for their participation. I will recruit 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 will be paid $10/hour for their participation.

Participants will complete a self-report health questionnaire (Christensen et al., 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 will be excluded if they have a visual acuity of 20/40 or worse to ensure that all participants can adequately see the stimuli presented on the computer task. I will exclude 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, will be excluded because it may affect their measured reaction times and ability to follow task instructions. Participants will complete the WASI Vocabulary subtest and questions about completed education to determine whether the young and older groups are approximately matched on crystallized intelligence and education level. Exclusions will not be made based on the WASI assessment. Additional exclusions will be based on health history of conditions that may affect cognitive functioning, such as stroke, heart attack, and diagnosis of a neurodegenerative disease.

Apparatus and Stimuli

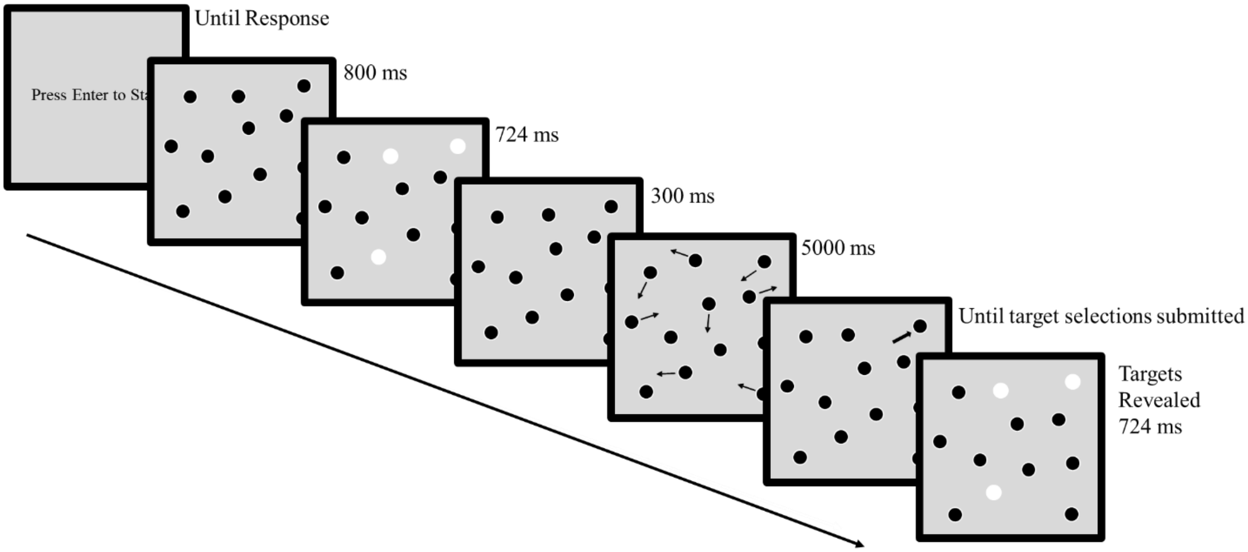
Stimuli will be presented on a 33-cm CRT color monitor connected to a Windows 7 Optiplex 790 computer set to a refresh rate of 85 Hz. Stimuli will be presented and reaction times will be recorded using Presentation software (Version 18.0, Neurobehavioral Systems, Inc., Berkeley, CA). The participants will be seated 34 cm from the computer monitor; the distance will be held constant with the use of a chin rest. All stimuli will be presented on a gray background. The basic stimulus display will consist of twelve black circles with a white border (circle diameter: 2.7° of visual angle; white border thickness: 0.12°). All stimuli will be presented on a gray background. The gray display which will contain the stimuli will be a 14 cm x 19 cm box. The remainder of the computer monitor outside the display will be black. The circles will be prevented from occluding each other by incorporating a repulsion between circles and the borders of the screen.

Procedure

Figure A1 illustrates the basic trial sequence. Participants will press a key to start a trial and twelve circles will be presented at random locations for 800 ms. Two to five targets will be identified by alternating the appearance of the black circles with entirely white circles four times, with each alternation lasting 181 ms. Once the targets have been revealed and all circles are returned to the original black appearance, the circles will remain static for 300 ms. Half of the trials will have all stimuli move (targets and distractors) and half of the trials will have half of the distractors move while half of the distractors remain static. The tracking period will last for 5 seconds (s) in which the targets and moving distractors will all move across the display independently. Following the tracking period, participants will be prompted to use the mouse and select the items that were targets and click “OK” button to submit the responses. Participants will select as many targets as were first indicated and guess if they are not sure. Feedback will be provided to the participant by revealing the actual targets through the alternating pattern in the initial stage (four iterations of 181 ms alternations between black and white circles).

Figure A1

Experiment 1 trial sequence for the condition with half the distractors moving

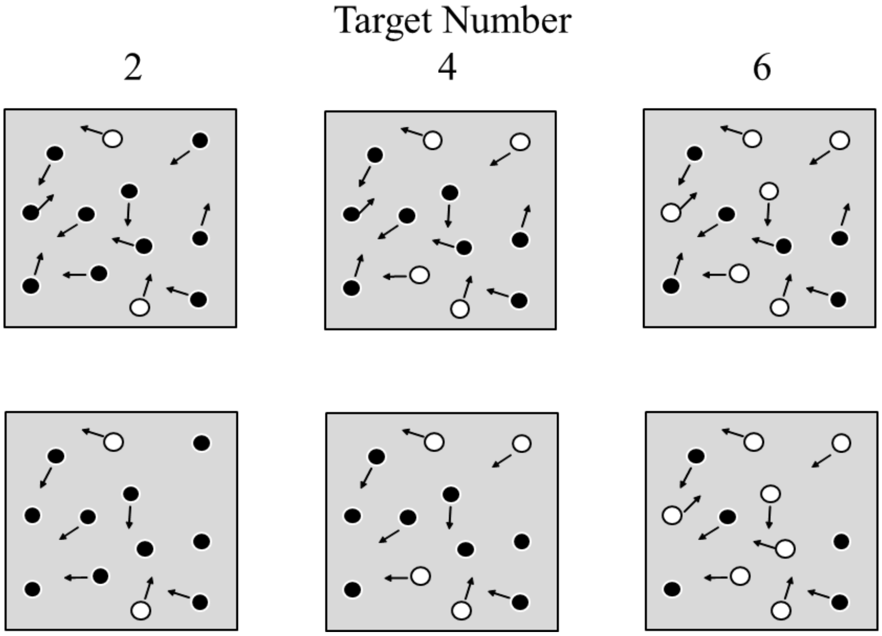


Note. Following a reveal of the targets to be tracked, all objects will return to an identical appearance. Targets will be tracked for a five second duration. Once all the items have stopped moving, participants will be required to select the number of targets that were identified at the beginning of the trial. Once responses are submitted, the original targets will be revealed.

Participants will complete 10 practice trials for each half (all distractors moving, half distractors moving) with two test trials per target number. There will be 200 total test trials with 100 trials per each of the distractor conditions (all or half distractors moving). Within each of the 100 trials, there will be 5 blocks of 20 trials each with 5 trials per target number (2, 4, 6). Figure A2 illustrates the different conditions. 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 A2

Critical conditions for Experiment 1



Note. The experiment will consist of two types of trials. In the dynamic condition (top row of figure), participants will track 2, 4, or 6 dynamic targets among moving distractors. In the static/dynamic condition (bottom row of figure), participants will track 2, 4, or 6 dynamic targets among moving and static distractors.

Design and Predictions

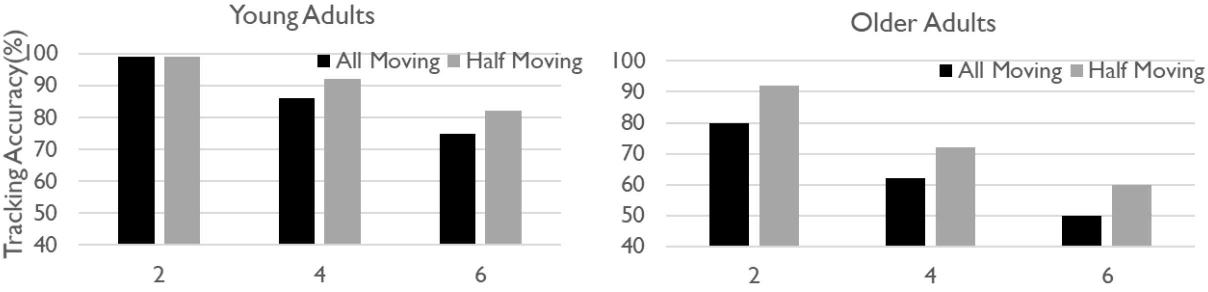
The mean accuracy (percentage of targets correctly identified) will be submitted to a 2 (age group: young and older adults) × 2 (distractor movement: dynamic, dynamic/static) × 3 (target number: 2, 4, 6) mixed ANOVA, with age as the between-subjects variable and distractor conditions and target number as the within-subjects variables. Trials with accuracy rates greater than 2.5 *SD* from an individual's mean accuracy will be excluded from the analysis.

Main effects for age, distractor movement, and target number are expected. Young adults are expected to track objects more accurately than older adults. Participants are expected to perform more accurately when there are dynamic and static distractors compared to trials in which all distractors were moving. Participants are expected to perform more accurately with a target number of 2 and performance is expected to worsen as the target number increases.

Significant age × target number, distractor condition × target number, and age × distractor condition × target number interactions are expected (see Figure A3 for the expected patterns). An age × target number interaction will be driven by older adults showing a steeper decline in accuracy as the number of targets increases compared to a shallower decline in accuracy for young adults. A distractor condition × target number interaction will be driven by steeper declines in accuracy for the moving distractor condition as target number increases. In contrast, when static distractors are available, participants will be expected to show better accuracy overall with shallower declines as target numbers increase. The age × distractor condition × target number interaction will be due to age differences in the magnitude in which accuracy changes across target number and distractor condition. Since older adults are expected to experience much larger declines in accuracy as the target number increases, I predict that older adults will show a larger reduction in errors with more targets when the trials contain both moving and static distractors. In contrast, since young adults will already be performing at a higher accuracy rate, they will show an improvement in performance when static distractors are present, but to a smaller magnitude than older adults. I predict that older adults will benefit from bottom-up perceptual grouping of stationary objects to reduce distraction and will therefore show this benefit as much if not more than young adults.

Figure A3

Expected pattern of tracking accuracies for young and older adults



Note. I predict a critical age × target number × distractor interaction will occur. I predict young adults will have better tracking accuracies overall and that both age groups will see improved performance in the condition which half the distractors remain static. However, the pattern of tracking accuracy across target number will show greater improvements for older adults than younger adults.

Discussion

I predict that both young and older adults will show improved tracking accuracy on trials when the distractors consist of moving and static objects. Per the biased competition account (Desimone & Duncan, 1995), and in accordance with the aging literature (Lindenberger & Mayr, 2014; Madden et al., 1999; Plude & Doussard-Roosevelt, 1989), both young and older adults should be able to use bottom-up information to parcel out irrelevant distractors and reduce attentional load needed to track targets moving among dynamic distractors. If age differences are present (indicated by a significant age × distractor condition interaction), I predict that it would be as a reduced benefit of the static distractors for young adults. Higher accuracy for young adults may obscure effects of static distractors, particularly with a smaller number of targets. This is an admitted limitation of the current design but implemented in order to keep target numbers within a range in which older adults can perform the task.

My second prediction is that older adults will show greater improvements than young adults across increasing target numbers in the dynamic/static distractor condition compared to the dynamic distractor condition. In previous research, older adults show steeper declines in tracking accuracy as the target number increases, compared to young adults (Sekular et al., 2008; Störmer et al., 2013; Trick et al., 2005). Therefore, older adults will be expected to show greater improvements in tracking accuracy when the distractors include static objects. Of course, if the age × distractor condition × target number interaction is not significant, it does not necessarily offer evidence against bottom-up distraction reduction in older adults; it only indicates that the distraction reduction is not greater for older adults than it is for young adults as the number of tracked targets increases. If bottom-up distraction reduction is smaller for older adults than for young adults, particularly as the number of tracked items increases, it may suggest that older adults did not maintain and update the object files for all of the targets and that the additional bottom-up information (static distractors) did not improve performance as expected because the number of targets exceeded what could be held in working memory. While Experiment 1 considers the dynamics of bottom-up biases to reduce top-down load during tracking, Experiment 2 will examine age differences in the suppression of distractors, as elements of inhibitory processing are proposed to undergo significant declines with age (Hasher & Zacks, 1988).