CHANGES IN VISUAL ATTENTION
WITH NORMAL AGING

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ABSTRACT

There are unsettled debates in the literature regarding the strength of top-down and bottom-up processing in visual attention. Control of top-down visual attention was assessed in both younger and older adults using a visual search task. In the task, participants were first given the name of the target stimulus's color, then shown a series of eight circles arranged concentrically, each containing either a horizontal or vertical line. Two of the eight circles were color singletons; one was the target singleton and the other a distractor singleton. The rest of the circles were gray. The current study implemented the Stroop effect to manipulate the task difficulty by changing the font color of the cue word. Assessing the strength of top-down attentional control was achieved by determining whether response time (RT) was dependent on the cue type and congruency of the target and distractor line orientations.

It was hypothesized that older adults would demonstrate a weaker top-down control of visual attention than younger adults in the visual search task. However, a mixed-effect model analysis revealed that the younger adults showed the expected Stroop effect when comparing cue types, whereas older adults showed only a partial effect. Moreover, the congruency effect manifested only in younger adults. Given the unexpected results, future research should look at neurological differences between older and younger adults while performing tasks that manipulate top-down control of visual attention to better understand the effect of aging on attentional control.

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CHAPTER 1

INTRODUCTION

Attention is an intangible concept that is difficult to define discretely, yet many have attempted to define it in various ways throughout the history of modern psychology (Brown, 1930), though it can loosely be defined as a conscious perceptual focus (Carrasco, 2011; Corbetta & Shulman, 2002). This task can be broken down into two distinct stages: first, the brain sifts through and prioritizes basic components of perceptual information, then it draws sensory focus towards stimuli based on the available information (Gazzaniga, Ivry, & Mangun, 2009). These stages are often referred to as the pre-attentive and attention stages (Logan, 1992; Wolfe, 2007). Attention has a limited capacity of information it can process because there simply are not enough resources in the brain to process and retain every bit of sensory input, thus requiring a filtering mechanism (Carrasco, 2011; Wolfe, 1994). Attention is crucial to normal behavior and cognition, yet aspects of its inner workings still remain debated upon in the scientific community (Lamy & Zoaris, 2009).

It is important to determine how attention changes as a function of age. Considering the average lifespan in the United States has shown a great incline, jumping from 70 to 79 years since 1960 (The World Bank, 2015), and that the baby-boomer generation has finally reached its golden years, gerontology has become more relevant than ever (Draper & Anderson, 2010). Aging is associated with various types of cognitive declines and changes, including those in visual attention and perception (Fabiani, 2012). Therefore, it is imperative to assess the effects of aging in order to increase the quality of geriatric healthcare. Although such gerontological research is certainly important in aiding older adults, understanding aging effects on attentional control could potentially clarify the understanding of attention as a whole.

Visual Search and Attention

According to visual attention research, there are two primary modes of attention: top-down control and bottom-up control (Bacon & Egeth, 1994; Theeuwes, 1991; Wolfe, 1994). Top-down control guides attention based on prior knowledge such as expectancies or goal-directed behavior (Bacon & Egeth, 1994). For example, if a person is told to turn around and look at the lightning flashing in the sky and does so, the person has directed attention in a goal-directed fashion using the previously given knowledge of the stimulus. In contrast, bottom-up control guides attention based on the perceptual strength of a stimulus, known as salience (Bacon & Egeth, 1994; Theeuwes, 1991). For example, if that person saw a lightning strike flash, the person will likely orient to the source of the flash, meaning that attention was captured. Attentional capture is fundamentally distinct from attentional selection by top-down control because it is an automatic process, whereas attentional selection requires conscious effort. To meet the criteria of automaticity, capture must occur unintentionally and independently of the amount of attentional resources already in use. These criteria are known as the unintentionality criterion and load-insensitivity criterion, respectively (Jonides & Yantis, 1988; Theeuwes, 1991).

In what is arguably the most influential visual attention theory, Treisman and Gelade (1980) laid out many of the fundamental components of attention in their feature integration theory, including the distinction of serial and parallel search, as well as the distinction of pre-attentive processing and attention. Pre-attentive processing automatically handles low-level features (e.g., orientation, shape, color) in parallel at various locations of the visual field simultaneously, guiding visual search so that reaction times (RTs) are independent of the set size (the number of stimuli in the search set) (Bravo & Blake, 1990; Theeuwes, 1991; Treisman & Gelade, 1980; Wolfe, 2007). However, some visual search tasks are dependent on set size, meaning that RT as a function of set size produces a non-zero slope (Gazzaniga et al., 2009). When RT directly increases with set size in a visual search task, visual search is occurring serially, such that the limited attentional resources must be allocated to each stimulus separately. Once the visual search mode shifts from parallel to serial, the search loses the qualities of automaticity and reaches a bottleneck point where pre-attentive processing alone is no longer sufficient to complete the search, requiring deployment of attention (Wolfe, 2007).

Pop-out visual search is a commonly used method in assessing the role of bottom-up and top-down control of attentional selection in visual search paradigms by using a singleton stimulus that "pops out" due to its salience, which is often a result of great featural homogeneity of neighboring stimuli and featural uniqueness of the singleton (Lagroix, Lollo, & Spalek, 2015; Lamy & Zoaris, 2009; McDonald, Green, Jannati, & Lollo, 2013; Töllner, Zehetleitner, Gramann, & Müller, 2010). These differences are usually based on features such as color and shape and can easily be manipulated to change the salience of a stimulus, though different features vary in how greatly they affect salience (Jonides & Yantis, 1988). Search tasks with pop-out singleton targets generally result in highly efficient searches because the singleton can be processed in the early pre-attentive stage, without having to deploy attentional resources to select the target (Treisman & Gelade, 1980).

If a pop-out search task was modified such that the target started to share a common feature with some of the distractor stimuli, then the observer is forced to process two features to find the target. As shown by classic visual search studies (e.g., Treisman & Gelade, 1980), if multiple features need to be processed in order to find the target, there is a greater chance of serial search since the pre-attentive stage alone cannot handle processing multiple features simultaneously (Gazzaniga et al., 2009). Thus, the target no longer "pops out" and becomes more difficult to find. At this point, the amount of pre-attentive processing has reached the bottleneck threshold, where only information deemed with the highest priority can be allowed into conscious attention (Gazzaniga et al., 2009).

Contingent-Capture versus Stimulus-Driven Capture

Although there is consensus that pre-attentive processing relies on bottom-up processing, there is still debate on the degree to which top-down and bottom-up processes control visual attention (Lamy & Zoaris, 2009; Theeuwes, 2010; Töllner et al., 2010). On one end of the spectrum, some researchers have argued that attention is biased towards stimulus salience, supporting a primary role of bottom-up processing (Lamy & Zoaris, 2009; Sawaki & Luck, 2010; Theeuwes, 1991, 1992; Yantis & Jonides, 1984). On the other end, researchers have argued that attention processing is modulated through top-down control, only allowing relevant salient stimuli to capture attention (Bacon & Egeth, 1994; Folk, Remington, & Johnston, 1992; Treisman & Gelade, 1980; Wolfe, 1994). These theories are generally referred to as stimulus-driven capture and contingent-capture, respectively (Bacon & Egeth, 1994; Folk & Remington, 2006).

One explanation for this disparity is that different search paradigms encourage participants to use different search modes. In the literature, two search modes have been identified in visual search: feature-search mode and singleton-detection mode (Bacon & Egeth, 1994; Lamy & Egeth, 2003). Feature-search mode involves searching for the target based on a known feature, such as color or shape. In contrast, singleton-detection mode involves searching specifically for singletons, which is mediated by bottom-up attentional capture of salient stimuli (Bacon & Egeth, 1994). Although search modes are inherently top-down in nature, singleton-detection mode relies on the bottom-up activation induced by salient stimuli. Considering that research from both sides of the debate have produced evidence for the ability of top-down and bottom-up attentional controls to override each other in different circumstances, it seems important to find the degree of control held by both top-down and bottom-up processing and what factors might influence these changes.

Support for Contingent-Capture

Many visual attention theories have argued in favor of a stronger role of top-down control in attentional selection, supporting the contingent-capture hypothesis. One such theory is the contingent involuntary orienting hypothesis, originally presented by Folk et al. (1992). This hypothesis asserts that that bottom-up attentional control is limited to stimuli with task-relevant features. The authors suggested that some of the research claiming a stronger role for bottom-up selection (Jonides & Yantis, 1988) was flawed because it assumed that the attentional deployment caused by luminance changes was due to bottom-up control, even though it is possible that attentional deployment was caused by developing an attentional set to attend to the luminance changes.

Another visual search theory that supports a stronger role for top-down control is the guided search theory (Wolfe, 1994, 2007; Wolfe, Cave, & Franzel, 1989; Wolfe & Gancarz, 1997). Guided search theory is predicated on the idea of parsimoniously dividing attention due to the fact that the brain can only take in so much information, suggesting that bottom-up attentional capture is often ignored in favor of top-down capture (Wolfe, 1994). Like Folk et al. (1992), Wolfe (1994) argued that when attending to a distractor stimulus that shares a feature with the task-relevant stimulus, the estimated bottom-up activation should be reduced because attention is guided by the goal-related information that manifests through top-down filtering. The use of an attentional set would imply that top-down attentional mechanisms were being used instead of bottom-up.

Bacon and Egeth (1994) empirically demonstrated the validity of these claims by modifying a visual search paradigm used by Theeuwes (1992), which originally made the claim that attentional capture of irrelevant singletons can override goal-oriented attentional selection. As a counter-explanation, Bacon and Egeth argued that observers were using a singleton detection mode in the original study, implying that capture was being modulated by top-down processing. After replicating the original paradigm, modified versions of the paradigm were implemented which discouraged the use of a singleton-detection mode in favor of a feature-search mode. Bacon and Egeth claimed that the switch occurred because singleton-detection mode required less cognitive demand than feature-search mode, so observers only switched once they needed to use the more effortful method to complete the task.

Efficient searches of salient stimuli are usually considered the result of bottom-up control, which is based on low-level visual information that is processed pre-attentively in parallel (Gazzaniga et al., 2009). However, Yantis and Egeth (1999) counter this argument with a set of experiments showing that the efficiency of the salient trials decreases when salient targets randomly appear only on a small portion of trials. Their results show that the efficiency associated with attending to salient stimuli could be associated with the singleton-detection mode, implying a top-down mechanism to filter salient stimuli. Yantis and Egeth used these experiments to outline the distinction of singleton-detection mode and attentional captures, arguing that the results of the former are often presented as evidence of the latter. This study highlights the importance of making clear interpretations of visual search data in order to truly understand how the mechanisms of attention function.

Support for Stimulus-Driven Capture

Theeuwes (1991) conducted a series of experiments to show how efficient top-down selection was not possible with stimuli that were salient on irrelevant featural dimensions, suggesting that contingent-capture is inherently incorrect because irrelevant stimuli have the ability to capture attention. The lack of efficiency was shown by the RT costs on trials with distractors in three different dimensions: contrast, color, and shape. This study also showed how stimulus-driven attentional capture met the required criteria for automaticity due to the ability of irrelevant singletons to capture attention without intention and at the expense of top-down control (Theeuwes, 1991). The findings from this study were extended and reproduced in Theeuwes (1992). In this extension of the original study, the lack of top-down control persisted even with practice, suggesting that the participants were not able to produce an attentional set to effectively inhibit the stimulus-driven capture.

Visual search paradigms that have repeating target colors can cause intertrial priming, which reduces RT. This could be attributed to a bottom-up process, which becomes more sensitive to stimuli that share features of other stimuli in working visual memory. In contrast, it could be a top-down process, whereby the participant expects the same target color. Maljkovic and Nakayama (1994) demonstrated that by manipulating the probability of switching between two target colors between trials during pop-out visual search, RTs continued to climb even when the probability was 1, meaning that the target color was guaranteed to alternate between each trial. In this situation, it was expected that observers might develop an attentional set to the consistent pattern, which would be indicated by a decrease of RT. These results indicate that instead of being modulated by top-down expectancy, the search efficiency seen in pop-out visual search with repeating target colors was due to stimulus-based priming (Maljkovic & Nakayama, 1994).

Instead of behaviorally operationalizing attention, some studies have used event-related potentials (ERPs) to record neurological activity that can indicate attentional deployment. For example, the N2pc component is an ERP component with a negative amplitude that has been shown to activate during attentional selection specifically in the hemisphere contralateral to the attended visual field approximately 175-300 ms after stimulus presentation (Hickey, McDonald, & Theeuwes, 2006; McDonald et al., 2013).

Hickey et al. (2006) showed that both the irrelevant singleton and the target stimulus in the participants' visual fields corresponded to N2pc activity. Based off the N2pc signals, the study also demonstrated that the irrelevant singleton was able to prevent attentional selection of the target and that participants could experience stimulus-driven capture from the irrelevant singleton (Hickey et al., 2006). However, it is important to note that McDonald et al. (2013) point out that the results of this study are dubious due to low signal-to-noise ratio, as indicated by the fact that the largest pre-stimulus baseline signals had greater amplitudes than the early N2pc signals that were supposedly produced by the distractor stimuli.

Lamy and Zoaris (2009) replicated and subsequently modified the experiment conducted by Yantis and Egeth (1999). Although the results from Yantis and Egeth indicate that top-down modulation of attentional capture is certainly possible, Lamy and Zoaris clearly demonstrate that the top-down modulation was contingent on intertrial priming caused by repeating the distractor singleton's color on each trial (Lamy & Zoaris, 2009). In this scenario, intertrial priming allowed the participant to easily build an attentional set to avoid attending to the irrelevant stimulus, meaning that the participants would know exactly which color to avoid (Lamy & Zoaris, 2009). Thus, by randomizing the color of the distractor and including trials with no distractor, the participants were no longer able to produce an effective top-down attentional set. Without knowing if a trial would include a distractor singleton, the participants could not build a reliable attentional set to ignore the irrelevant singleton because the reward for doing so was inconsistent.

Resolving the Debate

Because both the stimulus-driven capture and contingent-capture hypotheses have shown compelling evidence, it seems logical that there is a middle-ground explanation to account for the roles of both top-down and bottom-up control of attention. Proponents of contingent-capture have shown that top-down modulation of salient stimuli is possible (e.g., Bacon & Egeth, 1994; Folk et al., 1992; Wolfe, 1994; Yantis & Egeth, 1999), but proponents of pure stimulus-driven capture have also demonstrated that it is possible to remove the ability to perform top-down sets, allowing for a stimulus-driven attentional capture (e.g., Hickey et al., 2006; Lamy & Zoaris, 2009; Theeuwes, 1991, 1992, 2010; Theeuwes & van der Burg, 2011). The discrepancy of studies that point strictly to one side or another may be due to different approaches in paradigms, which in turn allow for different situational factors that may induce a top-down control of salient stimuli capture or a purely stimulus-driven capture.

For example, it is important to consider what kind of search mode the participants are using when performing the task. Previous research has indicated that when participants specifically search for singletons, attending to the irrelevant stimuli is more probable, whereas when participants search for a particular feature, the probability of attending to the irrelevant singletons becomes more unlikely (Lamy, Leber, & Egeth, 2004). These examples have been used to discredit stimulus-driven capture because they give rise to a situation explaining how irrelevant singletons can be captured through top-down attentional sets that specifically guide search for singletons, and how irrelevant singletons can be successfully filtered in another search mode. However, as Lamy and Zoaris (2009) demonstrated, it is possible to produce attentional capture of an irrelevant singleton even after the singleton-detection mode was removed by only including singleton distractors on random trials.

Lamy et al. (2004) presented evidence that pointed to top-down modulation of attentional capture, but also speculate that the inhibitory effects found with the top-down filtering of irrelevant singletons could have been due to an initial brief period of stimulus-driven capture that was then inhibited by top-down control afterwards. Additionally, the authors point out that some of their data provides evidence of stimulus-driven capture because response to distractor stimuli sharing the color of the target was quicker for singletons than for distractors that were grouped with other stimuli of the same color (Lamy et al., 2004). This is another example of a situation that strict contingent-capture proponents may choose to interpret as evidence that irrelevant distractors are only captured when they share a feature with the target. However, Lamy et al. elaborated on how this interpretation lacks the consideration of comparing distractors that simply share a feature with the target versus one that is also a singleton, as well as the time frame during which attentional capture takes place.

Considering that stimulus-driven capture may simply occur earlier than top-down modulation in detecting salient stimuli, one way to test this hypothesis is to manipulate the area of the brain where perceptual processing of vision begins. Emmanouil, Avigan, Persuh, and Ro (2013) took this approach by using transcranial magnetic stimulation (TMS) to alter activity in the primary and secondary visual cortices of participants completing a stimulus discrimination task based on salience. By manipulating the TMS pulse onset, Emmanouil et al. showed that earlier TMS pulses had much greater effects on salient stimulus discrimination, suggesting that bottom-up attention is processed early on. The results of this study are consistent with other neuroimaging studies that have shown similar patterns in temporal spacing of neural activations corresponding to bottom-up and top-down processing (Corbetta & Shulman, 2002). As Lamy et al. (2004) argued, both processes are important in visual attention and can be found in the same search-mode.

Sawaki and Luck (2010) employed a search task while recording ERP of the N2pc component in addition to another ERP component Pd, an ERP signal that is associated with distractor suppression. In contrast to the N2pc component, the Pd component manifests as a positive difference of ipsilateral signals from contralateral signals, with respect to the distractor location (Hickey, Lollo, & McDonald, 2009; Sawaki & Luck, 2010). However, the signals are recorded from the same posterior regions as the N2pc and occur in approximately the same timeframe. The search paradigm included letter targets based on size and identity, target-similar distractors, and irrelevant salient distractors that were separated into two locations, one of which participants were cued to attend to on each trial. The ERP data showed strong signals in the N2pc to target stimuli and target-similar stimuli, consistent with the contingent-capture hypothesis (Sawaki & Luck, 2010). However, this effect was not seen when the target was located in an unattended location. In contrast, irrelevant distractor singletons produced significant Pd signals regardless of distractor location, indicating that the brain was constantly trying to suppress attentional selection of the irrelevant singleton. This result can be interpreted as evidence that while contingent-capture theory has some validity, irrelevant singletons can sometimes capture attention (Sawaki & Luck, 2010).

Vision and Aging

Studying the effect of aging may be useful in understanding the boundaries of the different modes of attentional capture. It is no secret that as humans age, many cognitive changes become apparent, including the ability to focus. As some studies have shown (e.g., Amer & Hasher, 2014; Campbell, Grady, Ng, & Hasher, 2012; Chang, Shibata, Andersen, Sasaki, & Watanabe, 2014; Rowe, Valderrama, Hasher, & Lenartowicz, 2006), aging often has an effect on visual search task performance. Using cross-sectional research designs, it is possible to study how these effects vary across different age groups, allowing researchers to understand the boundaries of attentional capture as a function of age. However, it is crucial to rule out possible confounds in age-related visual studies in order to determine which changes in visual attention are strictly associated with normal aging effects. For example, older adults suffering from age-related diseases could potentially confound a study where the effects of non-pathological aging are in question. This can often be controlled by using a screening test to determine whether the person has normal cognition, such as the Mini Mental State Exam (MMSE) (Folstein, Folstein, & McHugh, 1975).

Visual Attention in Older Adults

In visual search, older adults have shown significantly greater difficulty in ignoring the irrelevant stimuli, compared to younger adults (Chang et al., 2014). This could indicate that aging causes a decline of top-down control of visual selection. This effect can be explained by the fact that older adults have a tendency to absorb irrelevant perceptual information (Amer & Hasher, 2014; Rowe et al., 2006). In a pair of experiments, Amer and Hasher showed that older adults performed significantly better than younger adults on a general knowledge test whose answers were presented as irrelevant word stimuli in a Stroop task and a 1-back task (Amer & Hasher, 2014). The study showed that older adults have a much greater susceptibility to conceptual priming, such that it implicitly facilitated their performance on a knowledge test by priming the older adults with some of the answers to the test.

To better understand the underlying mechanism of this effect in older adults, it is useful to look at neuroimaging data collected while older adults participate in these attention-based tasks. For instance, Campbell et al. (2012) had older adults perform 1-back tasks with pictures that contained task-irrelevant words while in an fMRI scanner and found decreased functional connectivity between the prefrontal cortex (PFC) and parietal regions, a network that is implicated in executive control. Additionally, the behavioral data showed that older adults performed worse on the tasks because they were distracted by the irrelevant stimuli. In conjunction with the neuroimaging results, the evidence seems to indicate that increased distraction to irrelevant stimuli may be due to a weaker focus on top-down control on incoming visual information, making it difficult to properly allocate neural resources to the desired stimulus (Campbell et al., 2012).

In addition to studying neuroimaging data, electrophysiological data is also useful in assessing the effects of aging on visual attention. Amenedo, Lorenzo-López, and Pazo-Álvarez (2012) measured ERPs in younger and older adults performing a visual singleton search task involving a target, which differed only by its orientation relative to the distractors. As expected, RTs in older adults were significantly longer than in younger adults. Based on the ERP data, older adults displayed slower and less controlled attentional selection (Amenedo et al., 2012). Additionally, the data indicated that older adults showed a delayed onset of attentional inhibition compared to the younger adults (Amenedo et al., 2012). Interestingly, older adults showed a greater ERP activity for attentional inhibition, potentially indicating that older adults have to deploy more neural resources to inhibit incorrect responses (Amenedo et al., 2012; van der Lubbe & Verleger, 2002).

Visual Limitations of Aging

When studying vision in older adults, especially when comparing their performance to that of younger adults, it is important to consider visual limitations that come about as a natural result of aging. Perhaps the most common type of visual impairment associated with age is presbyopia, an age-related decline in the ability to focus on nearby objects, which manifests in most people starting at the age of 40 (Hickenbotham, Roorda, Steinmaus, & Glasser, 2012). Although the etiology of presbyopia is not fully understood, the condition causes one to lose the optical ability of accommodation, which allows the lens to change its power in order to focus on stimuli at different viewing distances (Hickenbotham et al., 2012; Papadopoulos & Papadopoulos, 2014). The range of visual focus that a person can achieve is described by an optical property called the amplitude of accommodation. Thus, as symptoms of presbyopia worsen through age, the amplitude of accommodation decreases (Anderson & Stuebing, 2014).

By measuring the amplitude of accommodation across different ages in addition to amplitude data collected in other research studies, one study was able to produce a curvilinear model predicting the accommodative amplitude from age (Anderson, Hentz, Glasser, Stuebing, & Manny, 2008). By using a sigmoidal curve, the authors were able to describe the stability of accommodative amplitude before approximately 20 years of age and after 50 years of age, while also accounting for the rapid decline in amplitude from age 20 to 50. Thus, it is important to consider presbyopia as a factor in cross-sectional visual search tasks comparing age groups on either boundary of the decline. Due to the effects of presbyopia, it is important to consider the viewing distance in visual search studies involving older adults. While younger adults can focus on stimuli at various viewing distances, it is more difficult for older adults. Therefore, it is important to control for presbyopia in visual experiments by requiring use of corrective eyeglasses or contact lenses and ensuring that the viewing distance is not too long.

The Current Study

The purpose of the current study was to assess the roles of top-down and bottom up attentional processing and how it is affected by aging, using a modified version of the pop-out visual search paradigm used by Theeuwes and van der Burg (2011). In this paradigm, the observer is given the color of the target at the beginning of each trial. Then, the observer is given a set of circles arranged in a larger circle, each with a horizontal or vertical line inscribed. Two of the circles are colored singletons, whereas the rest are grey. The task requires that the observer find the circle with the color that was given and report whether the orientation of the line inside was horizontal or vertical.

The strength of top-down control of visual attention was assessed based on whether the participant successfully attended to the target singleton, without having attention captured by the distractor singleton. This was determined based on the difference between RTs on trials where the singletons contain lines of the same orientation (i.e., both are horizontal or both are vertical) and RTs on trials where the singletons' lines have opposite orientations. If contingent-capture theory is correct, which states that distractor singletons do not capture attention, then RTs should not depend on the line orientation of the distractor singletons because the distractor should be completely suppressed from attentional focus. However, if stimulus-driven capture theory is correct, which states that attention is deployed based on salience, then the RTs will depend on the line orientation inside the distractor. The stimulus-driven capture view suggests that observers will sometimes inadvertently attend to the distractor first before selecting the target. Specifically, the average RT of trials containing lines matching in orientation should be shorter than that of trials containing lines that have different orientations, which Theeuwes and van der Burg (2011) referred to as a congruency effect.

A major addition to the paradigm used in the current study is the application of the Stroop task into the target cue, which simply contains the word of the target's color. Some cue words were displayed in their own color, while others were displayed in the distractor's color. Additionally, some of the cues were displayed in a neutral grey color to act as a control. The cue word's text color acted as an extra irrelevant piece of information that the observer is supposed to suppress. Strength in top-down attentional control was assessed by looking for an effect of congruency type and the cue type that used the Stroop effect.

In the current study, it was hypothesized that the congruency effect would be reproduced, showing a weakness in top-down control. However, due to changes in perceptual and attentional control as a result of aging, it was also hypothesized that this effect would be more pronounced in older adults, indicative of a weaker top-down control of attentional selection (McLaughlin & Murtha, 2010; Theeuwes & van der Burg, 2011).

In concordance with the claim that aging is associated with a weaker top-down control, older adults were expected to show greater RT benefits on matching cue trials (compared to neutral cue trials) and greater RT costs on mismatching cue trials (compared to neutral cue trials) than the younger adults. This pattern was also expected for comparing the cue effect of older adults across the three cue types to that of the younger adults.

CHAPTER 2

METHOD

Participants

Participants were recruited using the SONA system in the psychology department at California State University, Fullerton (CSUF) and the Osher Lifelong Learning Institute (OLLI) at the CSUF campus. Students recruited from SONA were required to be between the ages of 18 and 28 and were categorized as the younger adults group, whereas participants recruited from OLLI were required to be between 65 and 75 years old and were categorized as the older adults group. In order to account for any visual deficiencies, participants were asked to reveal any visual disorders so they could be noted. Additionally, participants were required to have normal or corrected-to-normal visual acuity. Data were collected from a total of 68 participants, but one participant from each age group was dropped. This left a total of 36 younger adults and 30 older adults.

Instruments and Apparatus

Demographics

In order to acquire a demographic profile, participants were asked to report their age, number of years of formal education, gender, handedness, and ethnicity. Besides age, each of these variables was used to determine any significant differences between the two groups.

Mini-Mental State Exam

The MMSE was used to assess normal cognition, ensuring that the participants had normal memory and were lucid (Folstein et al., 1975). The MMSE consists of simple questions and tasks, such as identifying items and stating the current date and location. It was used as a screening test to ensure that participants are cogent enough for their data to be usable and valid. Participants who scored lower than 26 out of 30 points were dropped from the data set to ensure that the results are not confounded by potentially pathological aging effects, as the current study was focused on normal aging. This threshold was chosen as it is commonly used in aging studies (e.g., McLaughlin & Murtha, 2010). The MMSE has been used in various cross-sectional aging and visual studies (e.g., Amenedo et al., 2012; Amer & Hasher, 2014; Campbell et al., 2012; McLaughlin & Murtha, 2010) for this purpose.

Visual Acuity Test

A visual acuity test was given in order to confirm that participants had normal or corrected-to-normal visual acuity. Participants were asked to read sentences from a vision chart at a 40 cm distance. Participants were asked to read the top set of sentences, which corresponds to a Snellen fraction of 20/100. Although this does not correspond to perfect vision, it was sufficient to effectively complete the visual search task in the current study.

Color Vision Tests

The 24-plate edition of Ishihara's Tests for Color Deficiency was used to ensure that participants did not have any red-green color vision deficiency. This task involves looking at a circle of colored dots, from which numbers are perceived based on color distinction. In order to pass this test, participants had to correctly state at least 10 of the

15 numerals. Because Ishihara's Test screens only for red-green color vision deficiencies, an F-2 plate was also used to screen for blue-yellow color vision deficiencies.

Electronic Apparatus and Software

For the visual search task, stimuli were generated with MATLAB using the Psychophysics Toolbox Version 3.0.12 (Brainard, 1997) on a 27" iMac with a nominal refresh rate of 60 Hz. Luminance and CIE chromaticity coordinates were measured for each color used in the search task with a Photo Research PR-650 SpectraScan colorimeter. Gaze coordinates and pupil size were recorded using an EyeTribe eye tracker. However, due to issues with collecting data from participants wearing eyeglasses with multifocal lenses, the eye tracking data were not analyzed in the current study. Lastly, participant responses were recorded using a Gravis GamePad Pro controller.

Search Task and Stimuli

The search paradigm used in this study was adapted from Theeuwes and Van der Burg (2011) with some modifications. Like the original paradigm, the current version contained four consecutive screens on each trial. The first screen displayed a gray fixation cross (width & height: 1.36°, CIE: [.333, .334], 23.9 cd/m^2) in the center of the screen, which the participants were asked to fixate on until the search screen came up. This screen lasted 900 milliseconds (ms), after which a cue word appeared on the screen. The four cue words in the paradigm were "red" (width: 3.66°, height: 2.03°), "yellow" (width: 7.68°, height: 2.59°), "green" (width: 6.88°, height: 2.05°), and "blue" (width: 5.01°, height: 2.03°). Each word was displayed in 126 point Arial font. The cue words were displayed in one of three different font colors, representing different cue types: gray (neutral cue), the color that the word describes (matching cue), or the color of the upcoming distractor singleton (mismatching cue). Participants were explicitly told at the beginning of the session that the font color of the cue was irrelevant and to focus on the meaning of the word to find the target stimulus. On each trial, the cue screen was displayed for 850 ms.

Following the cue screen was a secondary fixation cross screen, identical to the first fixation cross screen, but only for 750 ms. Lastly, the search screen was displayed until the participant responded. On the search screen, there were eight circles (radii: 1.56°) equally spaced around a fixation in a circular formation (radius: 8.85°). Six of the eight circles had gray (CIE: [.333, .334], 23.9 cd/m^2) outlines while the other two circles had colored outlines. The four possible colors were the same as the four cue words, and each color was set up to look as natural as possible to ensure participants would easily identify the colors correctly (red: 23.6 cd/m^2, CIE: [.651, .335]; yellow: 69.2 cd/m^2, CIE: [.423, .522]; green: 23.6 cd/m^2, CIE: [.295, .623]; blue: 6.27 cd/m^2). The two colored circles that appeared on the search screen of each trial consisted of the target singleton (the circle drawn in the cue word color) and the distractor singleton (the circle drawn in one of the three remaining colors). Each circle contained a gray line (length: 1.87°) that was either vertically or horizontally oriented. The orientations of the lines within the non-singleton, gray circles were randomly generated, whereas the orientations of the lines within the target and distractor singletons were congruent (both vertical or both horizontal) in half of the trials and incongruent (different orientations) in the other half of the trials. The congruency effect was examined by comparing the meant RT of congruent and incongruent stimuli. Similarly, the distance between each target and distractor was counterbalanced in order to eliminate effects of target-distractor proximity on RT.

Participants were asked to determine whether the line inside the target was horizontal or vertical on each trial. If the participant responded correctly, the word “Correct!” was displayed, otherwise the word “Incorrect!” was displayed and a beep sound was played. A graphic summary of the paradigm can be found in Figure 1.

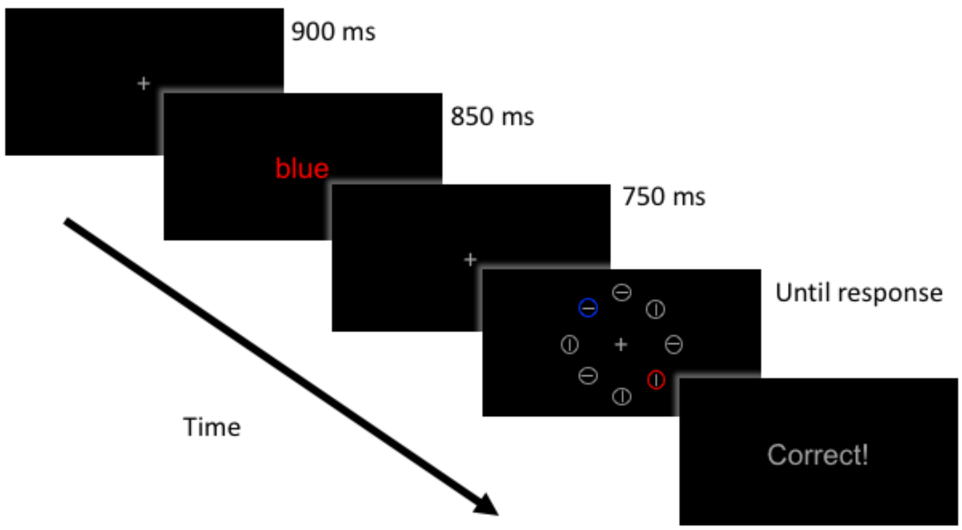

Figure 1. An example trial where there is a mismatching cue type with the word "blue" (displayed in red font color), the blue target singleton, and a red distractor singleton. In this example, the participant should respond by pressing the "L1" button on the GamePad to report that the line orientation inside the blue circle is horizontal.

Procedure

At the beginning of each session, participants were given a consent statement. Instead of collecting signatures, consent was given by the participant’s willingness to continue, obviating the need for collecting extra personal information. After reading the consent statement, participants were asked basic demographic questions. Next, they were given the MMSE to check mental status, a visual acuity test to ensure their visual acuity was sufficient, and lastly the color vision tests (Ishihara's test an F-2 plate) to make sure participants did not have any color vision deficiencies that would prevent them from being able to respond to the color stimuli in the experiment.

Once the screening tests were complete, participants were asked to sit in front of the computer monitor with a viewing distance of 60 cm using a chin rest with the lights turned off. Then, they were given instructions on how to use the GamePad Pro controller and were shown a step-by-step example of a trial. Participants were instructed to gaze at the fixation cross, look at the cue word, search for the target singleton, and then report the orientation of the line inside that singleton by pressing either "L1" for horizontal or "R1" for vertical on the GamePad Pro. RT and response accuracy were recorded on each trial. In order to remove any potential cognitive load associated with remembering the buttons, a reminder message was displayed on the screen in between each trial. Each session lasted approximately 60-90 minutes in total.

Design

Each session consisted of a practice block followed by two experimental blocks. The practice block consisted of 36 trials, allowing the participants to get acquainted with the task. Subsequently, the four experimental blocks each contained 144 trials, totaling to 576 experimental trials. This number was chosen because it is a multiple of the number of unique trials upon counterbalancing cue type (three levels), congruency type (two levels), cue color (four levels), distractor color (three levels, since it cannot be the same as the target), and the distance between the target and distractor (four levels). Additionally, the target color and distractor color never repeated between consecutive trials in order to avoid inter-trial priming. At the end of every block, the screen displayed the participant's average RT and response accuracy for that block to motivate participants to pay attention and engage in the task. Participants were given 60 seconds between each block. However, they also had the option to press the yellow button on the GamePad to continue. In order to keep the participant informed, a timer was displayed on the screen during the break to inform them when the experiment would continue.

CHAPTER 3

RESULTS

Statistical analysis was conducted in R (R Core Team, 2015) using RStudio (RStudio Team, 2015) as an interface. The data were imported from a dataset containing all of the visual search data and a dataset containing screening and demographic information for each participant. One older participant was dropped due to having an MMSE score just below the cutoff, but no participants were dropped based off of any other screening tests. In addition, one younger participant was removed from the dataset due to low accuracy (81.42%) for the visual search response, well below 2.58 standard deviations of the average accuracy (*M* = 97.06%, *SD* = 2.84). Because RT tends to be positively skewed, outliers were determined for each participant by computing each participant's mean RT and checking to see if any responses were greater than 2.58 standard deviations above that participant's mean RT. Additionally, RTs faster than 200 ms were determined as outliers because such responses are impossible due to neural response latency (Whelan, 2008). There were a total of 408 outliers, consisting of 1.07% of the observations. The outliers were removed from the dataset to eliminate biased results from the model.

Group Differences

Several tests were conducted to assess for differences between the younger and older adult groups on MMSE scores, Ishihara's test scores, and years of formal education between the two age groups. The distributions of the MMSE and Ishihara's test scores exhibited ceiling effects due to the fact that the participants had normal cognition and normal color vision, respectively. Due to these ceiling effects, both distributions when broken down by age group had extremely negative skews. In contrast, the distribution for years of formal education was somewhat normally distributed in older adults, but showed an extreme floor effect in the younger adults. This was expected due to the fact that many younger participants were college freshmen, whereas the older adults have had more time to produce variability in their levels of education. As a result of these violations of normality, Mann-Whitney *U*-tests were used in lieu of *t*-tests. Unlike *t*-tests, *U*-tests are non-parametric and thus do not require the data to be normally distributed.

The *U*-test for the MMSE scores showed no significant difference between younger adults ($M = 29.56$, $SD = 0.77$) and older adults ($M = 29.40$, $SD = 0.77$), $U = 472.00$, $p = .327$. Likewise, there was no significant difference found in Ishihara's test scores between younger adults ($M = 14.25$, $SD = 0.97$) and older adults ($M = 14.13$, $SD = 0.90$), $U = 487.00$, $p = .472$. However, the older adults ($M = 16.70$, $SD = 2.15$) had significantly more years of formal education than the younger adults ($M = 13.11$, $SD = 1.67$), $U = 972.50$, $p < .001$. This was expected due to the fact that the younger adults were all undergraduate students and thus have not yet had the opportunity to complete any higher educational degrees.

Furthermore, χ^2 tests were used to assess differences between the two groups in terms of gender, ethnicity, and handedness. The test for gender differences showed that the distribution of males and females was not significantly different between the groups, $\chi^2(1, n = 66) = 0.17$, $p = .679$. This was also the case with handedness, $\chi^2(1, n = 66) =$

0.43, p = .510. However, there was a significant difference in the distribution of ethnicity between the two groups, $\chi^2(3, n = 66) = 37.14, p < .001$. A summary of the group differences can be found in Table 1.

Table 1

A Comparison between the Younger and Older Adult Groups

	Younger Adults	Older Adults	p
Sample size	$n = 36$	$n = 30$	
Mean Age (SD)	19.31 (2.08)	68.77 (2.81)	
Gender			.679[a]
Male	15	21	
Female	11	19	
Ethnicity			$<$ .001[a]
Asian	7	2	
Caucasian	7	28	
Hispanic	21	0	
Middle Eastern	1	0	
Handedness			.510[a]
Right	32	24	
Left	4	6	
MMSE (SD)	29.56 (0.77)	29.4 (0.77)	.327[b]
Ishihara's Test (SD)	14.25 (0.97)	14.13 (0.9)	.472[b]
Years of Education (SD)	13.11 (1.67)	16.7 (2.15)	$<$ .001[b]

[a] From a χ^2 test. [b] From a Mann-Whitney U test.

Model Analysis

In order to account for dependent variance due to repeated measures, a linear mixed-effects model was used to assess the effect of age group, cue type, and stimulus congruency on RT. The mixed model was specified with each combination of the independent variables and their interactions as fixed effects to replicate a 2x3x2 ANOVA. The random effects portion was specified with an intercept, a random slope for cue type, and a random slope for congruency, grouped by participant ID. This was done to account for dependence of repeated measures within participants. Additionally, the covariance structure of the random effects was left unstructured such that the random effects were allowed to covary within subjects, but not between them. After computing the model parameters for the model, an ANOVA using type III sums of squares was conducted on the model in order to directly assess the effects of each variable and their interactions. The Satterthwaite approximation was used in order to calculate the denominator degrees of freedom for each effect in the ANOVA since the standard formula would not apply for a mixed model, allowing there to be multiple denominator degrees of freedom. The model was designed using the *lme4* package (Bates, Mächler, Bolker, & Walker, 2015) and inferential statistics were computed using an auxiliary package for *lme4* called *lmerTest* (Kuznetsova, Bruun Brockhoff, & Haubo Bojesen Christensen, 2015).

As is the case with most linear models, a linear mixed effect model requires that the response variable be normally distributed. Unfortunately, RT tends to have a non-Gaussian distribution. In this case, the data were positively skewed. Logarithmic and inverse transformations were considered for the data because they both can successfully normalize the distribution. However, the inverse transformation was chosen due to the fact that it is robust to loss of power in linear models with RT as the response variable (Ratcliff, 1993).

<u>Main Effects</u>

The ANOVA results indicated that the older adults (M = 1.05, 95% CI [0.98, 1.12]) had significantly longer RTs compared to the younger adults (M = 1.37, 95% CI [1.30, 1.43]), $F(1, 64.00) = 43.09$, $p < .001$. Back-transformation of the means into milliseconds units showed that the older adults' mean RT was 949.67 ms and that the younger adults' mean RT was 732.55 ms. Additionally, the results showed a significant main effect of cue type, $F(2, 64.00) = 36.72$, $p < .001$. Lastly, the results showed a significant difference between trials with congruent stimuli ($M = 1.22$, 95% CI [1.17, 1.27]) and trials with incongruent stimuli ($M = 1.20$, 95% CI [1.15, 1.25]), $F(1, 64.00) = 18.33$, $p < .001$. These means correspond to 820.55 ms and 833.75 ms, respectively.

Interaction Effects

There was a significant interaction effect of age group and cue type, $F(2, 64.00) = 12.75$, $p < .001$, indicating that the effect of cue type differed between the younger and older adults. Similarly, the congruency by age group interaction was also significant, $F(1, 64.00) = 6.71$, $p = .012$. This interaction suggests that the congruency effect significantly also varied between the two age groups. However, the interaction effect between congruency and cue type was not significant, $F(2, 37743.06) = 0.45$, $p = .637$. Nonetheless, the three-way interaction effect between age group, cue type, and congruency was significant, $F(2, 37743.06) = 3.05$, $p = .047$. A summary of the ANOVA can be found in Table 2.

Table 2

ANOVA Table for the Mixed-Effects Model

Effect	SS	Num. *df*	Den. *df*	MS	*F*	*p*
Age Group	4.34	1	64.00	4.34	43.09	$< .001^{***}$
Cue Type	7.39	2	64.00	3.70	36.72	$< .001^{***}$
Congruency	1.84	1	64.00	1.84	18.33	$< .001^{***}$
Age Group x Cue Type	2.57	2	64.00	1.28	12.75	$< .001^{***}$
Age Group x Congruency	0.68	1	64.00	0.68	6.71	$.012^{**}$
Cue Type x Congruency	0.09	2	37743.06	0.05	0.45	.637
Age Group x Cue Type x Congruency	0.61	2	37743.06	0.31	3.05	$.047^{*}$

* $p < .05$; ** $p < .01$; *** $p < .001$.

Simple Effects. Simple effects tests were conducted on the three-way age group x cue type x congruency interaction effect to further investigate the effects of cue type and congruency in each age group. To achieve this, the simple effects tests were sliced by age group. The cue type x congruency interaction was not significant for the younger adults, $F(2, 37743.06) = 2.56$, $p = .077$, nor for the older adults, $F(2, 37743.06) = 1.08$, $p = .341$. However, the tests confirmed that both younger adults, $F(2, 64.00) = 40.74$, $p < .001$, and older adults, $F(2, 64.00) = 5.45$, $p = .007$, displayed significant effects of cue type. A plot of this interaction effect can be found in Figure 2. The simple effects tests also revealed a significant effect of congruency for younger adults, such that congruent trials were significantly shorter than incongruent trials, $F(1, 64.00) = 24.71$, $p < .001$. In contrast, the older adults did not show this effect, which explains why the overall effect of congruency was not significant, $F(1, 64.00) = 1.56$, $p = .216$. Figure 3 depicts a plot of this interaction, showing the steeper change in RT in the younger adults.

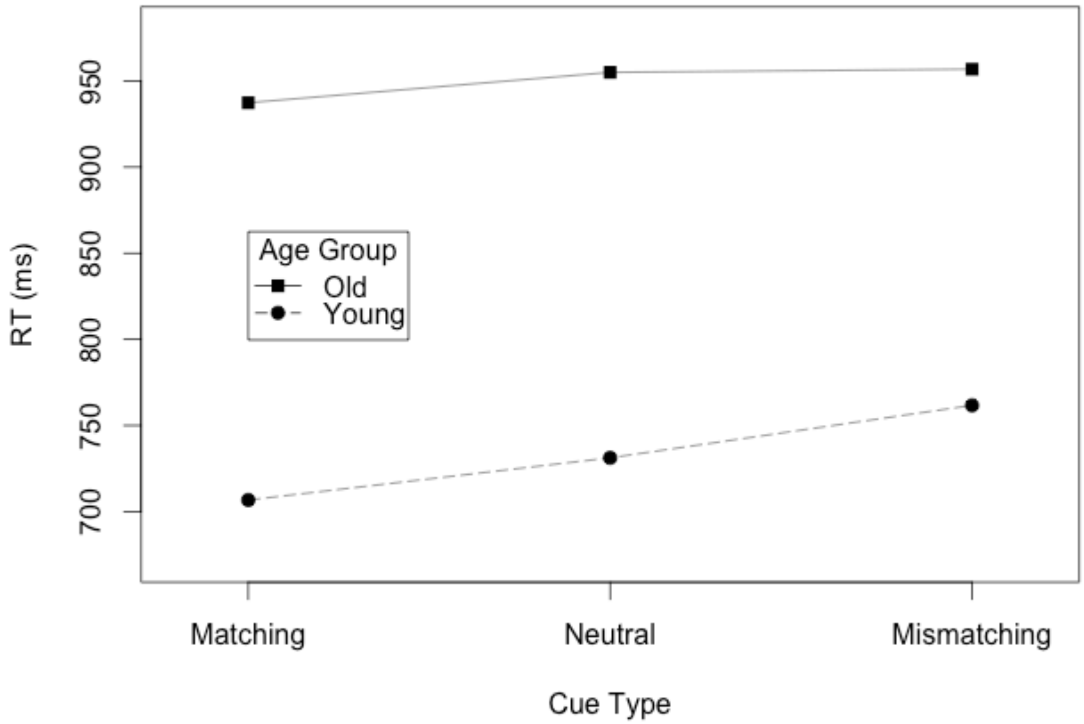

Figure 2. An interaction plot of the age group by cue type interaction. Mean estimates were computed using least squares from the mixed effect model and were back-transformed into milliseconds units. Error bars were omitted due to the fact that confidence intervals cannot be back-transformed when using a non-linear transformation.

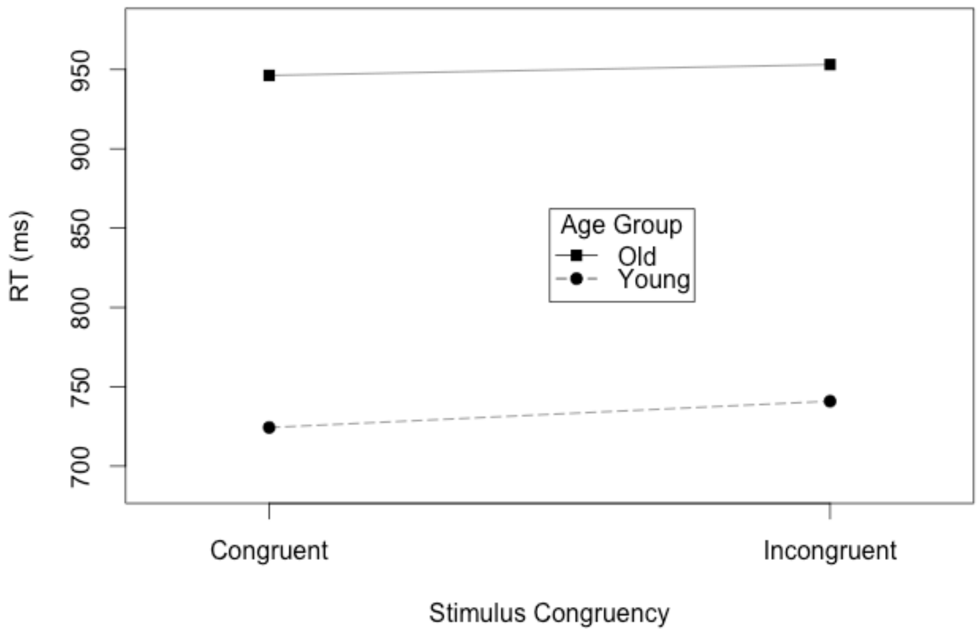

Figure 3. An interaction plot of the age group by stimulus congruency interaction. Mean estimates were computed using least squares from the mixed effect model and were back-transformed into milliseconds units. Error bars were omitted due to the fact that confidence intervals cannot be back-transformed when using a non-linear transformation.

Least Squares Mean Differences. The classic ANOVA model is a specific example of the general linear model, which contains only fixed effects. As such, the intercept produced in a classic ANOVA model is the unweighted grand mean of each group in the highest order term, and the rest of the coefficients are groups differences from the mean for each level of the factor predictors. However, when ANOVA is used on a mixed effect model, the fixed effect coefficients are no longer the same due to the fact that a mixed model also has random effects incorporated. Thus, the least squares means are used instead of sample means to produce ANOVA statistics from the mixed effects model. Least squares means are simply the expected responses predicted by the model; in a classic ANOVA setting, the least squares means are equivalent to the sample group means. However, in the current model's context, least squares means provide a more accurate estimation of the true population means because the fixed effects in a mixed effects model are estimated while taking into account the random effects.

Least squares means difference tests were conducted to assess the pattern of cue type's effect in younger and older adults. The results revealed that younger adults exhibited significantly longer RTs on mismatching trials (*M* = 1.31, 95% CI [1.25, 1.38]) than neutral trials (*M* = 1.37, 95% CI [1.30, 1.43]), $t(64) = -6.18$, $p < .001$. In milliseconds, these means correspond to 761.67 ms and 731.21 ms, respectively. Furthermore, younger adults showed significantly longer RTs on neutral trials than matching trials (*M* = 1.42, 95% CI [1.35, 1.48]), $t(64) = 7.73$, $p < .001$. The mismatching mean RT in milliseconds was 706.71 ms. However, older adults showed a slightly different pattern. For older adults, RTs on neutral trials (*M* = 1.05, 95% CI [0.98, 1.12]) did not significantly differ from RTs on mismatching trials (*M* = 1.05, 95% CI [0.98, 1.11]), $t(64) = -0.21$, $p = .833$. These means corresponded to 955.02 ms and 956.85 ms, respectively. However, the older adults had significantly longer RTs on neutral trials compared to matching trials (*M* = 1.07, 95% CI [1.00, 1.14]), $t(64) = 2.93$, $p = .005$. The mismatching mean in milliseconds was 937.38 ms. A bar plot of the back-transformed mean estimates and significance results of the difference tests can be found in Figure 4.

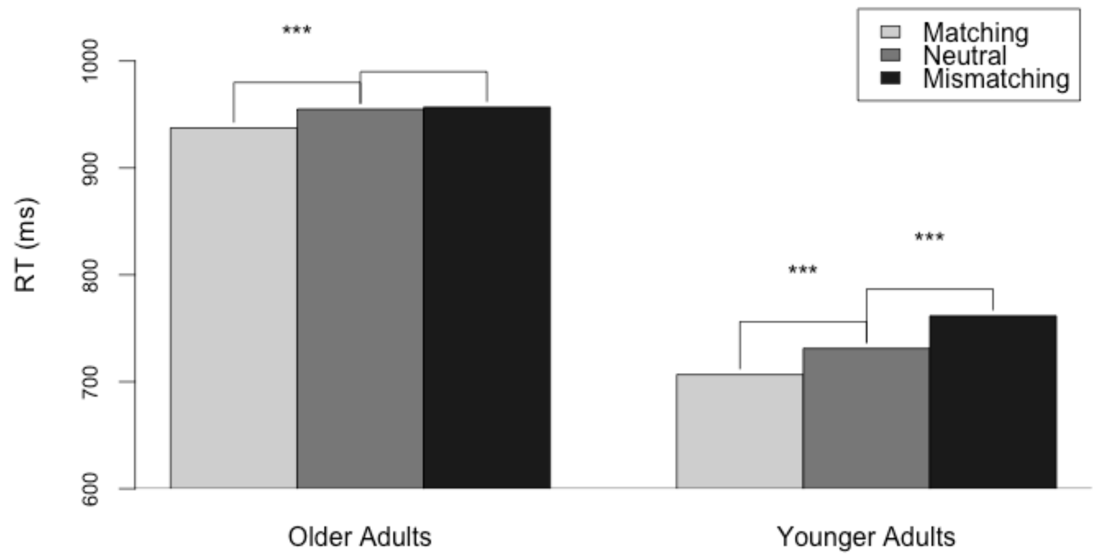

Figure 4. A bar plot of the least squares means of cue type, split by age group. Mean estimates were back-transformed into milliseconds units. Error bars were omitted due to the fact that confidence intervals cannot be back-transformed when using a non-linear transformation. Significance markers are based on t-tests conducted with the transformed mean estimates.
* $p < .05$; ** $p < .01$; *** $p < .001$.

CHAPTER 4

DISCUSSION

The main goal of the current study was to assess the strength of top-down control of visual attention and how it changes with age. The strength of top-down control was tested using the cue type and stimulus orientation congruency conditions. Cue type was used to manipulate the difficulty of top-down control via the Stroop effect, such that matching cue trials provided irrelevant but perceptually valid information (the font color) that aided top-down control, whereas mismatching cue trials gave invalid information that weakened top-down control. The stimulus congruency was used as a means to determine whether participants were able to completely guide their attention in a goal-oriented task, a sign of strong top-down attentional control. The congruency effect, demonstrated by shorter RT for congruent stimuli compared to RT for incongruent stimuli, indicates weaker top-down attentional control. Lastly, the effect of both cue type and stimulus congruency was analyzed between age groups to see how aging affected top-down attentional control.

The results demonstrated that RT was significantly different between trials with different cue types. Overall, participants showed the expected trend in RT, such that RTs from matching cue trials were significantly shorter than RTs from neutral cue trials, and that RTs from neutral cue trials were significantly shorter than RTs from mismatching cue trials. This was due to the fact that on matching trials, the irrelevant information (i.e., the font color of the cue word) matched the cue word itself, making the irrelevant information valid to the task. On the other hand, the mismatching cue's font color was always displayed in the color of the upcoming distractor, which likely increased cognitive load due to invalid perceptual information that needs to be filtered out in order to efficiently complete the task.

When comparing the pattern of cue type differences for each age group, it was discovered that the overall trend of cue effect was consistent in the younger adults, but not in the older adults. Although the older adults showed a significant increase in RT from matching cue to neutral cue trials, they did not show a significant difference between neutral and mismatching cues. This finding was not consistent with the initial hypotheses; it was expected that older adults would in fact show a larger delay in RT on mismatching trials based on aging effects demonstrated in other studies (e.g., Amer & Hasher, 2014; Rowe et al., 2006) that suggested older adults have a diminished capacity for filtering out irrelevant information. Instead, it was the younger adults that showed significant effects of the cue types. Visual inspection of Figure 3 shows that the slopes (which indicate magnitude of difference in RT between cue types) are steeper for the younger adults than the older adults.

The results also confirmed that there was an overall significant effect of stimulus congruency. This is in line with the findings of Theeuwes and van der Burg (2011), the study on which the current study's visual search paradigm was based, and also lends some evidence to the stimulus-driven capture theory. However, further analysis showed that this congruency effect was only present in younger adults, not older adults. This latter finding was exactly the opposite of what was originally proposed; it was believed that older adults would show a larger congruency effect because the congruency effect found by Theeuwes and van der Burg (2011) was understood as an effect of involuntary attentional capture, a sign of weaker top-down control of attention. Thus, it seems that older adults may be less prone to stimulus-driven capture, suggesting that there is merit to contingent capture as well and that age may play a role in determining how attention is captured. As studies have implicated a weaker top-down attentional control in older adults (e.g., Amer & Hasher, 2014; Rowe et al., 2006), it seemed reasonable to predict a stronger congruency effect in older adults.

One potential explanation for this result is that younger adults may have completed the task more hastily than the older adults, leaving their attention to be guided more by bottom-up processes. This could be a potentially plausible explanation due to the fact that younger adults had significantly shorter RTs than older adults in all conditions, which may be the result of completing the task with less attentive focus. All participants were informed that the current study was about aging effects. Knowing the goal of the study, older adults may have been more motivated to focus on the task than the younger adults, at the cost of having significantly longer RTs overall. In fact, research on motivation have shown that older adults tend to be more motivated in completing cognitive tasks (Hess, Emery, & Neupert, 2012). Moreover, the older adults were participating on their own volition, whereas the younger adults were participating for class credit and thus may have not been as intrinsically motivated as the older adults. Another potential explanation for this effect is the education level of the two groups. The group differences analysis showed that older adults had significantly more years of education compared to the younger adults. This was expected due to the fact that the younger adults were undergraduate students, whereas the older adults were from OLLI, a group of well-educated retired adults who are still furthering their education. Thus, it is also possible that the sample of older adults was not truly representative of the population of adults between the ages of 65 and 75, such that the OLLI members may have had stronger control of attentional resources than the average adult in the same age range.

However, it is also possible that this finding was not the result of some confounding factor like sampling error or motivational differences, but rather a neurological effect of aging. For example, although Hong, Sun, Bengson, Mangun, and Tong (2015) found that older adults did not exhibit a diminished capacity for visuospatial attention compared to younger adults, it was demonstrated that the neural mechanisms used to pool attentional resources was different. In particular, the younger adults showed α-wave activity contralateral to the cued target location, as demonstrated in other studies (e.g., Spaak, Fonken, Jensen, & de Lange, 2015; Worden, Foxe, Wang, & Simpson, 2000). However, older adults did not show this same EEG activity, and the current study used semantic cues instead of spatial cues. Regardless, Hong et al. provide an example on how the neurological mechanisms underlying allocation of attentional resources in older adults vary from those of younger adults.

Madden et al. (2007) showed that older adults exhibited a different pattern of cortical activation compared to younger adults while performing a top-down visual search task. Their findings indicated that older adults showed greater fronto-parietal activation, whereas cortical activation from the younger adults was focused more in occipital areas. In addition, older adults showed an overall greater amount of cortical activation than the younger adults, suggesting that older adults have to allocate more neurological resources than younger adults in top-down controlled attention. If true, it is possible that the older adults in the current study could have exhibited similar cortical activation patterns, causing them to overcompensate. This could explain why older adults managed to show a greater top-down control than the younger adults in the current study.

As in the current study, Lien, Gemperle, and Ruthruff (2011) hypothesized that older adults would show a decline in top-down attentional control, but found otherwise. Their results indicated that older adults demonstrated the same ability to maintain attentional control, although their RTs were much longer than the younger adults, just like in the current study. However, the results of the current study suggested that older adults actually showed greater top-down control than the younger adults. Although there are very few examples of cognition improving with age, it has been demonstrated that older adults can be more efficient with word recognition and processing than younger adults, possibly due to having more reading experience (Lien et al., 2006). Thus, it is possible that using a verbal cue may have confounded the aging effect in the current study. If so, then a using a featural (e.g., simply displaying the color instead of the word) or auditory cue may have yielded different results. However, with these other options, it would not be possible to manipulate the cue type as in the current study.

Staub, Doignon-Camus, Bacon, and Bonnefond (2014) also provide an example of when older adults perform better than younger adults on a visual attention task. Specifically, older adults showed a greater ability to sustain attention, whereas younger adults showed a decline in attention over time. Staub et al. noted that the older adults showed greater activation of ERP components associated with attentional resource allocation than younger adults, which could contribute to greater attentional performance.

Overall, Staub et al. found that this resource allocation was distributed around the frontal regions. Li, Gratton, Fabiani, and Knight (2013) also found that older adults showed greater activation in frontal areas, but while performing specifically top-down and bottom-up attention tasks. In contrast to the conclusions drawn by Staub et al., Li et al. found that older adults performed worse than younger adults and concluded that the extra frontal activation found in older adults is the result of decreased inhibition of sensory information. Although the methods used by Li et al. are more relevant to the current study, there is an important distinction to make. The visual search paradigm used in the current study contained both top-down elements (the cue as an instruction) and bottom-up elements (the salience of the singleton stimuli), whereas Li et al. used top-down and bottom-up as separate conditions.

As discussed, older adults show greater frontal activation than younger adults during attention tasks (Li et al., 2013; Madden et al., 2007; Staub et al., 2014). This difference in neural activation may be attributed to a need to compensate for decreased attentional resources associated with age (Madden et al., 2007). In a series of experiments assessing the cocktail party effect in younger and older adults, Naveh-Benjamin et al. showed that older adults were much less likely to notice their names being said compared to younger adults while focusing on an unrelated task. As the authors pointed out, younger adults with lower working memory (WM) spans were more likely to notice their names compared to younger adults with higher WM spans and the overall WM spans of older adults resembled the spans of the younger adults in the lower WM span group, yet older adults responded like the higher WM span group. Naveh-Benjamin et al. concluded that this paradoxical result can be explained by a decrease in available attentional resources in older adults. Perhaps these behavioral results can be explained by the overcompensation of the frontal regions seen in older adults during attention tasks. In line with that conclusion an attentional resource limitation associated with age could explain why the older adults showed a greater top-down control. If the older adults were focusing with limited resources on the goal of the task, then they would have a more difficult time allocating resources to process the cue word color and the pop-out effect produced by the singleton stimuli. This could also explain the pattern of the cue type effect in older adults. Older adults showed a significant decrease in RT on matching cue trials compared to neutral cue trials, but no difference between neutral cue trials and mismatching cue trials. This could be due to the fact that on matching trials, the cue color word was displayed in its own color, making it relevant to the current task and acting as a reinforcement to focusing on the target color. On the other hand, neutral cues (which were displayed in gray) and mismatching cues were displayed in irrelevant colors, thus not meeting the criteria to have attentional resources allocated to them.

Limitations and Future Research

It is important to note that although eligible participants for the younger adults group could be between the ages of 18 and 28, the age distribution was extremely skewed. Because the younger adults were recruited from the psychology department research pool, they tended to be much closer to 18 years of age. This contrasts with the older adults group, which had a more dispersed age distribution. This difference in age variability could potentially have confounded aging effects found in this study. Furthermore, the greater variability of age in the older adults group could also be linked to a greater variability in aging effects. However, the comparison of older and younger adults on MMSE score showed no significant difference and similar variability, though this was the case after dropping one participant from the older adults group. The group comparison analysis revealed that the ethnic distributions were significantly different between the younger and older adults. As mentioned earlier, another limitation to consider is the fact that the older adults were recruited from OLLI, which may not be very representative of the general population of their age group. Thus, the effects of aging found in the study may not be generalizable to the population of adults between the ages of 65 and 75.

When looking at effects of aging, it is important to consider cohort effects as a potential confound. The current study was conducted on a computer using a video game controller to respond to the task. This may have created a cohort effect because the older adults may have not been as familiar and comfortable with these devices as the younger adults. Thus, a cohort effect could account for some of the aging effects found in the study. In addition, the older adults were aware that the current study was looking at the effect of aging. Being aware of this fact, the older adults may have been more cautious when responding to the task, focusing more on accuracy than speed. This would cause them to go more slowly, giving them more time to process the task which would increase strength of top-down attentional control. It would account not only for the large increase in RT for older adults compared to younger adults, but it would also explain why older adults showed no congruency effect and weaker differences between cue types.

It has become more commonplace to record physiological responses (e.g., ERPs) in conjunction with behavioral responses in visual attention studies. The current study could have benefited from the use of EEG recordings as a method of confirming location of directed attention, though this would have required an extra control of target and distractor placement. Fewer visual search studies have used more powerful techniques such as functional MRI. Such a resource could help explain the behavioral differences between younger and older adults in attentional control. Future studies should consider looking at the difference in physiological response in older and younger adults in a visual search paradigm that manipulates top-down control abilities in order to profile the changes in neural activity that arise from aging.

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