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Attentional Uncertainty in the Stroop Priming Task

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ATTENTIONAL UNCERTAINTY IN THE STROOP PRIMING TASK

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There is extensive evidence that structures in the anterior attentional system (i.e. dorsolateral prefrontal cortex and anterior cingulate) are susceptible to normal aging processes, whereas structural changes in the posterior attentional system are minimal. Using the Stroop priming task, we investigated whether reducing the involvement of the anterior attentional system by pre-cuing the location of the target stimulus would eliminate age differences in interference. Older adults continued to be susceptible to interference when the location cue was ambiguous or invalid, but were less susceptible when the target location of a stimulus was presented with a valid cue.

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Much of the research on cognition and aging indicates that older adults show deficits in inhibitory processes that are related to a decline in attentional functioning. Cognitive neuroscience has identified this attentional network, which has been split into two systems: the anterior attentional system and the posterior attentional system. Evidence from aging experiments shows that tasks that engage the anterior attentional system yield age differences, whereas there are few deficits associated with the posterior attentional system. The purpose of the current study was to explore whether eliminating the involvement of the anterior attentional system with the use of cues would eliminate age differences in the Stroop Priming task.

Selective attention involves the processes of filtering and inhibiting responses to irrelevant stimuli. *f*MRI evidence suggests that the parietal lobe, midbrain, pulvinar nucleus of the thalamus, dorsolateral prefrontal cortex (DLPFC) and the anterior cingulate are all involved in attentional processes (Posner & Peterson, 1990; Posner, 1994; West & Bell, 1997; Banich, Milham, Atchley, Cohen, Webb, Wszalek, Kramer, Liang, Wright, Shenker, Magin, 2000; MacLeod & McDonald, 2000; Miller & Cohen, 2001; Fan, McCandliss, Sommer, Raz, & Posner, 2002; Milham et al., 2002). The anatomical network of the posterior attentional system consists of the parietal lobe, midbrain, and the pulvinar nucleus of the thalamus. The parietal lobe is involved in disengaging, the midbrain is involved in attentional shifts, and the pulvinar nucleus aids in the processing of information gathered from a stimulus. The detecting and alerting system known as the anterior attentional systems includes the DLPFC and the anterior cingulate gyrus. The DLPFC is activated on tasks that require control. The anterior cingulate is important for target selection and conflict resolution.

The basic Stroop task engages the anterior attentional system (Hartley, 1993; West & Bell, 1997; Banich et al., 2000; MacLeod & McDonald, 2000; Milham et al., 2002; Mutter, Naylor, & Patterson, 2005). The task has two dimensions: the color word and the ink color. Stroop found that it took participants longer to name the ink color of a word, when the word name conflicted with the printed ink color. The observed effect suggested that color naming and word reading were competing processes and therefore produced interference. However, practice naming the ink color on trials where the word name conflicted with the printed ink color reduced interference for the ink color naming process. The task demands conflict resolution and the inhibition of inappropriate responses, which are functions of the anterior attentional system. Numerous studies have demonstrated the involvement of the DLPFC and the anterior cingulate when mediating perceptual conflict and response interference in the Stroop task (MacLeod & MacDonald, 2000). For instance, Botvinick, Nystrom, Fissell, Carter, and Cohen (1999) found that neural processing is different for congruent and incongruent trials. The involvement of the anterior cingulate is reduced when the level of conflict is low (congruent trials), which suggests selecting the appropriate target is easier when the color and the word yield the same response. Directing attention to the target may also ease the demands of the task.

Many variations of the Stroop exist and several studies have demonstrated that these variations can influence the magnitude of interference effects (MacLeod, 1991). One such variation is the Stroop Priming Task. In this task, the competing color and word dimensions are separated. Specifically, two words are presented on either side of a fixation point; the target word is presented in colored ink and the prime word in presented in black ink. For example, instead of presenting the word *yellow* printed in *blue* ink, a neutral target word would be presented in *blue* ink next to the prime word *yellow* printed in *black* ink. Participants name the color of the non-black target word presented on the computer screen and the amount of time (in milliseconds) to do so is measured. The location of the colored target word varies from trial to trial. Separating the competing color and word dimensions eases task demands because it presumably reduces the involvement of the anterior attentional system (Hartley, 1993; West & Bell, 1997; Mutter et al., 2005)

Another variation involves cueing the location of the target stimulus. Some experiments have found that pre-cuing the location of a target stimulus, pre-cuing a one letter of a target stimulus, or changing the color of a single letter in a word significantly reduces interference (Hartley, 1993; Besner, Stolz, & Boutilier, 1997; Besner and Stoltz, 1999). Researchers have shown that cues narrow attentional focus, which often results in quick and accurate responses on the Stroop task. Spatial cues engage the posterior attentional system (Hartley, 1993; Brink & McDowd, 1999). They are helpful because they eliminate uncertainty about the location of the upcoming target; therefore, processing time is reduced and performance is enhanced.

The current study uses the Stroop Priming Task in combination with a cueing procedure to examine age-related inhibitory deficits. We presented younger and older participants with congruent, incongruent, and neutral trials in which the target location was highlighted with a valid, invalid, or ambiguous cue. We predicted age differences in interference would be eliminated on trials presented with a valid cue because participants would be able to shift their attention toward the location of the upcoming target, which would enable them to filter out the competing prime word. This cue condition engages the posterior attentional system by enabling participants to spatially locate the target and restrict their attentional focus. We further predicted that differences in interference would persist in the ambiguous cue conditions because older participants would be required to maintain a broad attention focus, which would allow the prime word to interfere with the target word. The anterior attentional system, a system that is vulnerable to age related decline, monitors conflicts and inhibits irrelevant responses. Finally, we thought that age difference in interference would be highest in the invalid cue condition because they would find it especially difficult to disengage and shift attentional focus toward the location of the target. These predictions were confirmed. Our results yielded an age-related interference effect for the ambiguous cue condition, which supports past evidence showing an increase in interference with age. However, age differences in interference were eliminated on trials with a valid cue. These findings support the hypothesis that although the anterior attentional system is susceptible to age related deficits, the posterior attentional system is immune to the effects of aging. The results of the current study contribute to the body of literature examining the sensitivity of attentional regions of the brain to the effects of aging.

CHAPTER 1

Attention is a fundamental aspect of cognition and has been defined as the activation of an accessible association that facilitates decision-making processes to produce a task relevant response (Kahneman & Henik, 1981). Although many cognitive scientists accept this definition, it neglects to address the concept of filtering irrelevant stimuli (Kahneman & Henik, 1981; MacLeod & MacDonald, 2000). There is more to selective attention than processing a stimulus through its relevance to another association previously stored in memory. It is the ability to focus on a particular stimulus in the surrounding environment involving location, color, and objects. Consequently, the inability to avoid interference constitutes a failure in selective attention (Kahneman & Henik, 1981; Lowe & Mitterer, 1982).

The main functions of attention are orienting (which involves attentional shifts), target detection, and maintaining alertness (Posner & Peterson, 1990; Posner, 1994; Fan et al., 2002). Orienting is attending to the location of a stimulus and often involves shifts in eye movement to guide attention to the appropriate target location (Posner & Peterson, 1990; Posner, 1994). This activity, observed through neuroimaging and lesion studies, is associated with the posterior region of the brain. This region is heavily involved in target detection processes; for instance, the parietal lobe disengages attention from a stimulus, the midbrain shifts attention to the new target, and the pulvinar nucleus of the thalamus processes information from the detected stimulus (Posner & Peterson, 1990; Posner, 1994; West & Bell, 1997; Banich et al., 2000; MacLeod & McDonald, 2000; Miller & Cohen, 2001; Fan et al., 2002; Milham et al., 2002). The dorsolateral prefrontal cortex (DLPFC) is engaged during tasks that require executive control and is responsible for coordinating attentional responses by activating compatible responses and inhibiting incompatible responses (Miller & Cohen, 2001). The anterior cingulate gyrus increases alertness during a task and is extremely important for inhibitory processing in order to maintain vigilance to a target. It also enables rapid target selection and conflict resolution (Posner & Peterson, 1990; Posner, 1994; West & Bell, 1997; Banich et al., 2000; MacLeod & McDonald, 2000; Miller & Cohen, 2001; Fan et al., 2002; Milham et al., 2002).

The Stroop Effect

The Stroop task is one of the most important ways of examining selective attention processes. In his important study, J. R. Stroop (1935) found that it took participants longer to name the ink color of color words when the printed ink conflicted with the color word itself. Stroop's original study was comprised of three experiments. In the first experiment, the participant had two tasks: a) read the color names with incongruent ink color and b) read the color names printed in black ink. He found no significant difference between groups for response times in either condition, which suggests incongruent ink colors produced little interference when only reading the word. In the second experiment, participants were asked to a) name the color of a solid square (control) and b) name the ink color of the color word which was printed in incongruent ink (experimental condition). In the experimental condition, the response latency increased substantially which suggests that the word reading (automatic) and color naming processes were competing and therefore produced interference. In the third experiment, Stroop allowed participants to practice naming ink colors on incongruent items by administering the same tests used in the two previous experiments. He found that the effect of practice reduced interference for the color naming process.

Due to the pervasiveness of these findings, the Stroop task is widely used as a measure to investigate automatic and controlled processes in selective attention and other effects closely related to inhibitory processing. Interference and facilitation are two distinctive components of the Stroop task that can be isolated by comparing congruent and incongruent trials with neutral stimuli. Interference occurs when response times increase for trials involving incongruent stimuli compared to neutral stimuli, and facilitation occurs when response times decrease for trials involving congruent stimuli relative to neutral stimuli (Stroop, 1935; MacLeod, 1991; Besner, 2001; Mutter, et al., 2005). In fact, interference observed during the administration of the task is now widely known as the Stroop effect.

There are many explanations for the interference and facilitation effects seen in the Stroop task. One explanation is automaticity; specifically, word reading is an automatic process whereas ink color naming requires controlled processing. Skilled readers automatically process word information because the association between a word and its name is strong (Stroop, 1935; MacLeod & Dunbar, 1988; MacLeod, 1991; Dulaney & Rogers, 1994; Lindsay & Jacoby, 1994). The increase in response time may be attributed to the word information interfering with naming the ink color.

Another explanation for the observed interference in the Stroop task is the relative speed of processing or "horse race" model (Dunbar & MacLeod, 1984). The "horse race" model suggests that the competing processes of reading the word and naming the color occur in parallel, and that word reading finishes more quickly. Because word reading is more likely to win the race, it interferes with color naming when generating a response. The parallel-distributed processing model is similar to the “horse race” model (Cohen, et al., 1990). This model suggests that there is a mechanism responsible for the strength of the processed stimulus. The proposed mechanism strengthens processing units through practice (practice effect), determines the strength of two competing processing units (interference or facilitation), and selectively attends to the stronger unit. Cohen, Dunbar, and McClelland’s (1990) model states that the word reading and color naming processing units that can be modulated by attention are associated with different pathways of varied strengths. The presentation of a stimulus activates response units that match the word or the color of that particular stimulus. The activation of the unit is contingent upon the demands of the task, thus the stronger unit is elicited and produces a response. For instance, the word *red* written in yellow ink activates processing pathways for ink color, the word name, and the demands of the task (color naming vs. word reading). Interference occurs when two conflicting pathways are activated concurrently and facilitation occurs when two corresponding pathways are activated concurrently.

Working memory (WM) processes have been implicated in tasks similar to the Stroop that require attentional control. The WM system consists of both a storage component and an attentional component and is capable of maintaining memory traces while simultaneously processing information, facing distractions, and managing shifts in attention (Hasher & Zacks, 1988; Conway, Cowan, Bunting, Therriault, & Minkoff, 2002; Long & Prat, 2002). Therefore, inhibitory mechanisms are essential for competency in WM functioning. In selective attention, these mechanisms assure that the information gathered from a stimulus is relevant to the goals of a task. A decrease in inhibitory functioning will reduce efficiency in attentional shifts and allow competing (task irrelevant) information to influence a response (Hasher & Zacks, 1988; Cohen et al., 1990; Long & Prat, 2002). For instance, the Stroop task involves selectively attending to one element of a stimulus (ink color) and ignoring all other elements (word name). One important role of WM during the Stroop task is to maintain task relevant information while inhibiting conflicting information that is unrelated to the goals of the task (Hasher & Zacks, 1988; Cohen et al., 1990; Conway et al., 2002; Long & Prat, 2002; Kane & Engle, 2003).

Kane and Engle (2003) tested the relationship between the Stroop effect and WM, successful goal maintenance, and inhibition. They proposed that the same inhibitory mechanism that actively maintains goals in a WM task is responsible for the interference and facilitation effects observed in the Stroop task. The purpose of their study was to find if measures of executive functioning would predict Stroop interference. Depending on the context of the task (proportion of congruent and incongruent trials), WM capacity should predict whether the participant would be able to inhibit competing information and maintain the goals of the task.

Prior to administering the Stroop task, Kane and Engle (2003) screened each participant for WM capacity. Afterwards, they increased the demands of WM by manipulating the proportion of congruent (e.g., the word 'yellow' in yellow ink) and incongruent trials (e.g., the word 'yellow' in green ink) presented. Congruent trials require no inhibition and allow for successful responses even if participants disregard the ink and automatically respond to the word. Responses given during incongruent trials are sensitive to interference because participants must inhibit an automatic response. Thus, WM is employed to maintain the goal of naming the ink color and to inhibit task irrelevant information. Participants with low WM spans made more errors on incongruent trials than those with high spans. Individuals with low spans were slower, less accurate and had difficulty switching tasks, which implies a failure in goal maintenance. Participants with high spans performed better and were able to keep track of the goal when they were given a higher percentage of incongruent trials. When given a higher percentage of incongruent trials, those with low spans were also capable of keeping track of the goal, but made more response errors than those with high spans. Participants with low spans were more likely to neglect the goals of the task, like inhibiting conflicting information. As a result, the findings reveal that task context and WM span are directly related to Stroop interference.

Long and Prat (2002) also examined the relationship between Stroop interference and WM span and found a similar effect. Participants were given a reading span test to measure their WM capacity before the administration of the Stroop task. The authors tested whether individuals with low spans would show more interference on the Stroop task than those with high spans. Using negative priming, they also observed what strategies high spans employ to suppress automatically reading the word in order to deliver a task relevant response. Although individuals with a high span performed well in all conditions, those with low spans performed better when they were given more incongruent trials. Low spans were able to maintain a goal when the task did not require attentional shifts. Overall, those with higher WM capacity developed a strategy that enabled them to inhibit task irrelevant information during a trial. Thus, WM capacity is directly related to processes that engage selective attention. Long and Prat (2002) used a higher proportion of neutral trials in combination with incongruent trials, unlike Kane and Engle (2003) who used a higher proportion of neutral trials in combinations with incongruent trials. Despite this difference, there were few disparities between the findings.

Current neuroscientific evidence suggests that there are two attentional systems involved in the Stroop task: the anterior attentional system and the posterior attentional system. The anterior attentional system is located in the dorsolateral prefrontal cortex (DLPFC) and the anterior cingulate gyrus. Lesion and PET studies reveal that the posterior attentional system is located in the parietal cortex, midbrain, and the pulvinar nucleus of the thalamus (Posner & Peterson, 1990; Posner, 1992; Hartley, 1993; Kramer, Humphrey, Larish, Logan, & Strayer, 1994; West & Bell, 1997; Brink & McDowd, 1999; Banich et al., 2000; MacLeod & McDonald, 2000; Miller & Cohen, 2001; Fan et al., 2002; Milham et al., 2002). Although these systems interact with several parts of the brain, they are distinct from data processing systems and function to carry out processes involved in attention (Posner, 1994). The anterior attentional system provides attentional control and regulates cognitive processes such as conflict monitoring, conflict resolution, working memory, and target detection when faced with task irrelevant information. The posterior system mediates spatial localization.

Since the advent of neuroimaging studies, more is known about these attentional systems and their involvement in the Stroop. Recent studies have investigated the operation of the anterior and posterior attentional systems in the Stroop task through a variety of imaging techniques including EEG, PET, and fMRI (Posner & Peterson, 1990, West & Bell, 1997; Banich et al., 2000; MacLeod & McDonald, 2000; Miller & Cohen, 2001; Milham et al., 2002). The anterior network is more active during incongruent than congruent trials on the Stroop task and is heavily involved in conflict resolution. The association between the color word and its name is strong; therefore, one has to consciously make an effort to inhibit an automatic response of reading. The anterior attentional system recruits activation from the DLPFC and the anterior cingulate to meet the demands of the Stroop task. The DLPFC is recruited for executive functions such as activating task relevant information and inhibiting task irrelevant information. For instance, task irrelevant information (e.g. reading the word instead of naming the ink color) competes for priority in processing due to automaticity. Control is needed from the DLPFC to select the correct information that should be used to guide performance. In addition, the anterior cingulate is active on tasks that present incongruent stimuli in comparison to congruent and control/neutral stimuli. When competing information (word reading vs. ink color) is presented in the Stroop task, the anterior attentional system is activated to provide control and reduce uncertainty (Posner & Peterson, 1990; Posner, 1992; Hartley, 1993, MacLeod & McDonald, 2000; Miller & Cohen, 2001). The anterior attentional system also processes information regarding color and form. The anterior cingulate gyrus is heavily involved in the detection of ink color on the Stroop task as well as focal awareness, target detection, response selection and executive functions such as integrating sensory information from the task and stored information from memory (goal maintenance).

The posterior attentional system is responsible for providing attentional restriction (orienting), spatial localization, and controlling attentional shifts (Posner & Peterson, 1990; Posner, 1992; Posner, 1994; Hartley, 1993; Kramer et al., 1994; West & Bell, 1997; Brink & McDowd, 1999; Banich et al., 2000; MacLeod & McDonald, 2000; Miller & Cohen, 2001; Fan et al., 2002; Milham et al., 2002; Kane & Engle, 2003). The operation of the posterior attentional system is illustrated in an experiment conducted by Banich et al. (2000) in which they examined the attentional demands for a color-word Stroop task (standard) and a spatial-word Stroop task. For the spatial-word task, a box was presented on the screen and a word (above, below, within) appeared above, below, or within the box. Participants had to name the spatial relationship between the word and the box and ignore/inhibit the word printed in relation to the box. The spatial-word Stroop task yielded greater activation in the parietal region than the color-word Stroop task. Also, on the spatial-word task, the parietal region was more active during the presentation of task relevant vs. task irrelevant information which suggests it is more difficult to spatially track incongruent stimuli than congruent stimuli.

Attentional Cues

Many variations of the Stroop task exist and several studies have demonstrated that particular adaptations of the task influence the magnitude of interference effects (MacLeod, 1991). Attentional resources can be allocated to an automatic stimulus (word reading) or they can be reallocated to a controlled stimulus (ink color) so that selective attention is shifted and the processing of a stimulus is enhanced. A recent paradigm adopted by experimenters is the use of a cue to provide information regarding target location, allowing participants to narrow their attentional focus. It has been observed using this paradigm that selective spatial attention yields accurate and quick responses to target stimuli used on the Stroop task.

For example, spatially narrowing attention has been shown to reduce interference effects. Besner, Stolz, and Boutilier (1997) predicted that, if the rule of automaticity is correct and words are processed semantically, when asked to name the color of a single letter in a word Stroop interference would not be reduced. However, if naming the color of a single letter prevents processing at the semantic level fewer errors due to interference would be observed. In their study, half of the stimuli (red, blue, yellow, and green) were congruent and the remaining stimuli were incongruent. Participants were presented with a color word and asked to either: a) ignore the word and name the color of a single colored letter, or b) name the color of the word. The authors found that changing the color of a single letter in a word significantly reduces interference as compared to conditions that present a fully colored word. Therefore, highlighting a single letter dampened the activation of the full word at the lexical level, which enabled participants to name the ink color quickly and with few errors. The results suggest that the view of automaticity does not hold true in all contexts of the Stroop task. Other studies have shown that cueing a single letter in a word rather than cueing a fully colored word (Besner & Stoltz, 1999) and using peripheral cues to spatially direct attention to relevant stimuli are methods that provide evidence of a reduction in interference (Hartley, 1993; Brink & McDowd, 1999). Cues are useful because they eliminate uncertainty about the target. The expectancy about the upcoming target is affected with the manipulation of cues. Information about the target reduces processing time provided that the cue is valid. Valid cues enhance performance on the Stroop task when compared with conditions that provide no cue at all (Hartley, Kieley, & Slabach, 1990).

Aging Attentional Systems

Literature on normal cognitive aging provides evidence that older adults have difficulty inhibiting task irrelevant information, switching tasks, and dividing and sustaining attention. According to the inhibitory deficit hypothesis, proposed by Hasher and Zacks (1988), weakened inhibitory processes due to age-related changes in cognitive abilities lead to three types of performance. First, the ability to hold back irrelevant information from entering working memory is decreased. Older adults tend to hold stronger beliefs and values than those of younger adults, thus older adults tend to integrate their personal schema when processing information. In this case, information within the schema that is irrelevant to the current task goal will most likely enter working memory, which will ultimately lead to a decrease in inhibitory efficiency. Second, older adults are less capable of deleting task irrelevant information from working memory. As off-goal information is increased and sustained in working memory, reaction time and accuracy is reduced. Lastly, older adults show a decreased ability to prevent the occurrence of a dominant or automatic response that is incorrect. Failure to respond appropriately can be attributed to off goal information competing with the demands of the task. Attending to off-goal information leaves aspects of task relevant information unprocessed, thus target information competes with irrelevant information at retrieval (Hasher & Zacks, 1988; Butler & Zacks, 2006).

Although Hasher and Zacks (1988) portrayed inhibition as a single mechanism, others have suggested that this view may not be correct. McDowd (1997) criticizes the inhibitory deficit hypothesis stating that current research provides evidence of a dissociation of inhibitory functioning in older adults. On some tasks, age differences are apparent, and on others, older and younger adults perform equally. McDowd (1997) concludes that more testing is needed to specify the existence and function of these multiple inhibitory mechanisms involved in selective attention. Kramer et al. (1994) point out that although there is sufficient data that supports the inhibitory deficit hypothesis, there is evidence that response competition may be largely responsible for interference on tasks that require suppression of an automatic response (e.g. Stroop; Hasher & Zacks, 1988; MacLeod & Dunbar, 1988; MacLeod, 1991; Dulaney and Rogers, 1994; Lindsay and Jacoby, 1994). Kramer et al. (1994) also questioned which inhibitory mechanisms were affected by normal aging and argue that there are a number of tasks that fail to display age differences in inhibition; the decrease of inhibition in normal aging may be selective and not general.

Current studies on the neuroscience of normal aging and attentional processes have shown that older adults' deficits may be related to the reduction of volume in the frontal lobe. As previously mentioned the dorsolateral prefrontal cortex (DLPFC) plays a large role in WM executive functioning and the anterior attentional system and is susceptible to age-related shrinkage. In contrast, structural changes in the posterior cortices are minimal and the posterior attentional system shows little age-related decline. Using MRI data and neuropsychological tests (e.g. tests measuring WM capacity, priming effects, explicit memory, and executive functioning), Raz, Gunning-Dixon, Head, Dupuis, & Acker (1998) conducted a comprehensive investigation of the relationship between brain regions and cognitive processes affected by age. Raz et al. administered tasks measuring working memory, explicit memory, repetition priming, and executive functioning. They hypothesized that structures dependent on the frontal cortices would show significant deficits with age; whereas, there would be few age differences on tasks that activate structures located within the parietal cortices. The authors found that perseverations increased with age, as well as errors on non-verbal WM tasks. Their results confirmed that, due to age-related deterioration of the prefrontal cortex, processes that heavily rely on this region are highly susceptible to errors. Changes due to a decrease in volume of the parietal cortices were not associated with age. Raz, Briggs, Marks, and Acker (1999) also examined whether age-related shrinkage in the DLPFC was related to WM deficits. They measured DLPFC volume after the administration of several working memory span tasks (e.g., computational span, listening span, and absolute span) for a sample of individuals aged 19-77 years. Their results suggested that a reduction in volume in the DLFPC as a result of aging is linked with slower processing speed and decreased accuracy on tasks that require working memory. Executive functioning requires the ability to monitor past performance, maintain a goal in memory, and inhibit a prior or automatic response in order to respond appropriately to the demands of a particular task (West, 1996; Raz et al., 1998).The Wisconsin Card Sorting Task (WCST) is often used when measuring the effects of age on executive functioning. The observation of perseverative errors on the task is related to DLPFC volume reduction. For instance, Gunning-Dixon and Raz (2003) measured DLPFC volumes with MRI technology and assessed executive functioning and working memory by administering the WCST and the computational and listening span tasks. They found a significant effect of DLPFC shrinkage and age on WCST perseverative errors.

Age Differences on the Stroop

Previous research has consistently shown age related increases in interference on the Stroop task that may be related to changes in WM executive functions. Cohn, Dustman, and Bradford (1984) administered the Stroop task to adults of all ages (young, middle aged, old) and found that the increase in interference for older adults begins around 60 years of age. Although older adults performed as well as young adults on measures that required simple reading, older adults exhibited poor inhibitory control on the Stroop task. Theoretically, extended practice of color naming for incongruent trials should increase the ability to inhibit word naming on subsequent administrations of the Stroop task, yet the practice effect also differs between younger and older adults on the Stroop task. Dulaney and Rogers (1994) investigated whether practicing color naming would enable older adults to learn to inhibit, or suppress, reading the name of the color word. Stroop interference was reduced for both younger and older adults; however, during a posttest, younger adults had adopted a reading suppression strategy whereas older adults continued to display poor inhibitory control and an inability to develop a reading suppression strategy when given opportunity to practice extensively. The results of these experiments may be due to an age-related decrease in WM executive functioning. Because WM capacity is heavily involved in processes that engage selective attention, it is not surprising that older adult's ability to inhibit conflicting information and maintain task goals on the Stroop decreases with age (Dulaney & Rogers, 1994; Long & Prat, 2002; Kane & Engle, 2003).

Although research on aging and the Stroop effect consistently shows that Stroop interference increases with age, Verhaegen and De Meersman (1998) posit that this change in selective attention is due to decreased processing speed. The authors suggested that there is a problem with the way data for Stroop interference scores have been interpreted. For example, in past studies, Stroop interference scores were typically calculated by subtracting the reaction times in the baseline (neutral) condition from reaction times in the interference (incongruent) condition. While all participants, regardless of age, take longer to name the ink color of incongruent stimuli, age differences are predicted to be larger in the interference condition due to response latency. Because processing speed declines with age, it appears that younger adults perform better than older adults. The authors claimed that in order to assume that the Stroop effect is age sensitive, processing speed should be taken into account when making baseline and treatment comparisons. They also make note of general slowing theories that predict higher age-related interference effects because older adults may need more time to process incongruent stimuli. Verhaegen and De Meersman (1998) conducted a meta-analysis to examine whether age differences in the Stroop task were present when reaction time was irrelevant by controlling for age differences in processing speed. They observed few age differences in interference effects and attributed the findings of previous studies to slower processing speed. Their meta-analysis offers no support for the inhibitory deficit hypothesis and suggested that inhibitory mechanisms may not be susceptible to age related decline.

Other evidence, however, suggests that age-related changes in processing speed do not account for age differences in Stroop interference. Cohn and her colleagues (1984) found that the Stroop was more sensitive to aging than tasks that measured simple reaction times, which suggests that the Stroop effect could not be attributed to a general slowing in response time. Spieler, Balota, and Faust (1996) controlled for age differences in response times using Lindsay and Jacoby's (1994) process dissociation analysis and ex-Gaussian distributions. The process dissociation analysis does not use reaction time data. It provides estimates of the contributions to accuracy made by color naming and word reading processes. Ex-Gaussian Analyses are used to transform reaction time data and control for baseline speeds. Spieler and his colleagues found results consistent with most other research in that compared to younger adults, healthy older adults had difficulty responding correctly to a word when it conflicted with the color naming response (incongruent). Healthy older adults were more likely to read the word name than younger adults.

West and Baylis (1998) suggested that an increase in age differences on the Stroop task in the color naming process may be attributed to a disturbance in context processing, where context was defined as the congruent, incongruent, and neutral stimuli used in the task. They conducted two experiments, examining whether age differences on the Stroop task were the result of response dominance or contextual disintegration. Response dominance is related to the theory of automaticity in that word reading and color naming compete for output and because word reading is an automatic process, it dominates over color naming, which requires controlled processing. The contextual disintegration model suggests that age differences in interference are the result of failure to use contextual information to guide performance on a task. West and Baylis (1998) manipulated the proportion of congruent and incongruent trials in the Stroop task. Some participants received mostly congruent trials while others received mostly incongruent trials. Because older adults have more difficulty controlling automatic responses than younger adults, West and Baylis (1998) statistically adjusted the scores to control for this effect. Because they controlled for response dominance, if any age differences were observed they could be attributed to contextual disintegration. They hypothesized that eliminating the age-related increase in response dominance would reduce interference effects and eliminate age differences between younger and older adults. In line with their predictions, they found no age differences in the Stroop effect when the list was composed of mainly congruent trials, but age differences were greater when a higher percentage of the trials were incongruent. According to the authors, older adults had difficulty maintaining a color naming strategy to guide their performance. The results of this study also implied that a reduction in WM capacity might affect older adults' ability to employ and maintain strategies that will enable them to inhibit irrelevant information (West & Baylis, 1998; Long & Prat, 2002; Kane & Engle, 2003).

Hartley (1993) supports the view that age-related attentional deficits are due to a decline in inhibitory function and found that providing a cue may allow for behavioral observations of disengagement or shifts in attention during the Stroop task (Hartley et al., 1990; Posner & Peterson, 1990; Hartley, 1993; Hopfinger, Woldorff, Fletcher, Mangun, 2001; Fan et al., 2002). Hartley (1993) administered two versions of the Stroop task. In the first version of the task, Hartley separated the dimensions of the Stroop (the color and the word) and used stimuli that consisted of a color block with a color word printed in black above or below. Before the stimulus appeared, a cue was given to direct the participant to the location where the stimulus would appear to ensure that attention was oriented to the location of the stimulus. This allowed the participant to spatially filter out the word printed above or below. No age differences were observed on this task. The second version of the task was similar, except that the stimuli were like the color-word version of the Stroop task. In this case, the cue had no value. Participants had to inhibit the word and name the ink color, which produced significant age differences. Therefore, when there is no uncertainty about the location of the stimulus, older adults perform as well as young adults; but when the target location is ambiguous, older adults perform poorly. Hartley (1993) suggested that these results provide evidence that the posterior attentional system is unaffected by aging, whereas the anterior attentional system is compromised. The use of cues engages the posterior attentional system, the area that controls spatial localization and orienting. When the cue pointed participants in the direction they were supposed to look, there were no age differences. Without cues, participants had to rely on the anterior attentional system which is affected by age.

Like Hartley (1993), Mutter, Naylor and Patterson (2005) hypothesized that separating the color and the word dimensions might ease attentional demands to select ink color and not color word, thus eliminating age differences in interference. In their study, using the Stroop Priming Task (Kahneman & Henik, 1981; Lowe & Mitterer, 1982), two words were presented on either side of a fixation point; the target word was presented in colored ink and the prime word was presented in black ink. For example, instead of presenting the word *yellow* printed in *blue* ink, a neutral target word would be presented in *blue* ink next to the prime word *yellow* printed in *black* ink. Participants name the color of the non-black target word presented on the computer screen and the amount of time (in milliseconds) to do so is measured. The position of the colored word varies from trial to trial. Using this task, Lowe and Mitterer (1982) found that when participants were presented with a high proportion of congruent trials, their attentional focus included both the target word (for which they were to identify ink color) and the prime word. During a high proportion of incongruent trials, participants developed a strategy that narrowed their attentional focus and enabled them attend selectively to the target.

In line with Lowe and Mitterer, Mutter et al. (2005) found that older and younger adults responded similarly to lists of varied compositions. Older adults were able to understand the demands of the task and modify their responses accordingly on lists that presented a consistent proportion of congruent and incongruent trials. However, the Stroop priming task did not eliminate age differences in interference. Participants were asked to name the print color of the target word and ignore the prime word; however, older adults were more likely to respond to the prime word on the task than younger adults. Even when the environment provided support for suppressing activated word information, older adults were inefficient at controlling the activation of conflicting word information. Mutter et al., suggested that the difference between their results and Hartley's (1993) was that in their experiment, the location of the target was ambiguous; for instance, the target word randomly appeared on either the left or the right of the fixation point and participants had to maintain a broad attentional focus. Hartley (1993) separated the color and word dimensions of the Stroop task; however, he used of spatial cues to direct participants' attention to the location of the target. The cues enabled them to narrow their attentional focus. Participants in the Mutter et al. (2005) experiment were uncertain about the location of the target and which required them to maintain a broad attentional focus. They therefore had to rely on the anterior attentional system – the system that is most susceptible to decline with age.

Current Study

The Stroop task is a useful measure designed to assess inhibitory processes involved in selection attention (Stroop, 1935; MacLeod, 1991). Many variations of the task exist and all reliably measure two major attentional processes: facilitation and interference (MacLeod, 1991). Findings regarding the Stroop effect have given rise to many theories and models. A widely accepted explanation is the theory of automaticity, which states that reading the word interferes with naming the color, but naming the color does not interfere with reading the word. The relative speed of processing model or "horse race" model is similar to the theory of automaticity and states that word reading and color naming compete during processing and the faster process (word reading) interferes with the slower process (color naming). However, research suggests that there is more to be accounted for in the Stroop effect than automaticity or relative speed of processing (Stroop, 1935; MacLeod & Dunbar, 1988; Cohen, et al., 1990; MacLeod, 1991; Dulaney & Rogers, 1994; Lindsay & Jacoby, 1994). Recent studies have suggested brain systems involved during the task. For instance, the anterior attentional system is engaged when there is a processing conflict between incongruent stimuli and the posterior attentional system is involved in orienting to cued target locations and controlling attentional shifts.

Research on aging and the Stroop shows that age differences may be due to an age related decline in the anterior attentional system. Extensive evidence shows that structures in the frontal lobe are more susceptible to age-related deficits than other regions of the brain. Deterioration of the frontal lobe leads to impairments similar to those with frontal lobe lesions, such as poor performance on measures of working memory, as well as poor performance on attentional and WM executive tasks, such as the WCST (Posner & Peterson, 1990; Posner, 1992; Hartley, 1993; Kramer et al., 1994, West & Bell, 1997; Raz et al., 1998; Raz et al., 1999; Brink & McDowd, 1999; Banich et al., 2000; MacLeod & McDonald, 2002; Miller & Cohen, 2001; Fan et al., 2002; Milham et al., 2002; Gunning-Dixon & Raz, 2003). Other behavioral evidence provided by studies on cognitive aging show that older adults perform poorly on measures of inhibition and selective attention (Cohn et al., 1984; Hasher & Zacks, 1988; Hartley, 1993). The inhibitory deficits that increase with age may be directly related to age differences observed on the Stroop.

Studies investigating the Stroop task and age typically find age differences in interference (Cohn, 1984; MacLeod, 1991; Hartley, 1993; Dulaney & Rogers, 1994; West & Baylis, 1998; West, 1999; Long & Prat, 2002; Kane & Engle, 2003; Mutter et al., 2005). For example, Cohn et al. (1984) found that an increase in interference begins around 60 years of age. Dulaney and Rogers (1994) found that older adults have a hard time adjusting their responses and associations, which results in the inability to develop new strategies that are specific to the task. In addition, varying the proportion of congruent and incongruent trials affects the pattern of interference for older adults on the Stroop task (West & Baylis, 1998). West (1999) found an increase in age differences for older adults in the color naming process because older adults fail to let the current goals of the task guide their processing and selection. However, Hartley (1993) found that cues provided older participants the opportunity to spatially filter out information unrelated to the target, thereby narrowing participants' attentional focus. The results suggest that deficits in the frontal lobe due to normal aging may compromise older adults' ability to detect target information and inhibit conflicting information. According to Hartley, cues eliminate uncertainty regarding the location of the target and allow participants to use only the posterior attentional system. The posterior system is immune to the effects of aging.

The purpose of the current study was to investigate whether reducing the involvement of the anterior attentional system by pre-cuing the location of the target stimulus will eliminate age differences in interference in the Stroop Priming task. Younger and older adults were presented with a list of congruent, incongruent, and neutral trials in which the target location was cued along with a valid, invalid, or ambiguous cue. Hartley (1993) suggested that spatial cueing engages the posterior attentional system and because age does not lead to a decline in this system, no age differences in interference should be observed on trials in which the target location is indicated with a valid cue. However, when the target location is uncued, or when the cue is invalid, the anterior attentional system should be required to suppress or dampen activation of the primed color word and boost activation of the ink color of the target. Because age leads to a decline in this system, age differences in interference should be present on trials with invalid and ambiguous cues.

CHAPTER 2

Method

Participants

Thirty younger adults (ages 18-30) and thirty older adults (ages $\geq$ 60) were recruited for participation in this experiment (see participant characteristics in Table 1). Young adults were recruited from the Western Kentucky University Study Board and received both extra credit and a small stipend for participation. Older adults were recruited from the community through means of mass mailings (accessible from voters' registration database) and advertisements (flyers) and were paid a small stipend for participation. All participants were screened for colorblindness, using Ishihara's Test for Color Blindness (Ishihara, 1994). Older adults were screened for cognitive impairment using the Mini Mental State Examination and all participants were asked to submit basic demographic information such as: age, race, gender, SES, education, and marital status. Participants were reportedly in good health for their age group. Those using medication or with health problems that are known to alter/impair cognitive functioning were excluded from the study. Several standard individual difference tasks measuring frontal and temporal lobe functioning as well as measures of processing speed, working memory, comprehension, and semantic knowledge were given to each participant (see Table 1).

Design and Materials

The research design was a 2 X 3 X 3 factorial with age (young vs. old) as a between- subjects variable and trial type (congruent vs. incongruent vs. neutral) and location cue (valid vs. invalid vs. ambiguous) as within-subjects variables. The dependent

Table 1.

Mean and Standard Deviations for Participant Characteristics

Measure	Older		Younger	
Education	15.82	2.30	14.11	1.51
Digit Symbol	63.78	13.60	83.71	11.14
Mill Hill Vocabulary	37.56	6.10	33.04	5.48
Reading Span	1.53	.80	2.68	1.30
WCST (Perserverative Errors)	12.06	8.96	6.25	3.19

Table 2.

Assessments Used to Measure Cognitive Functioning

Assessment	Measure of Cognitive Functioning	Measures
Modified Wisconsin Card Sorting Task	Frontal Lobe	# of categories achieved
Controlled Oral Word Association	Frontal Lobe	# of words; strategies
Pattern Comparison	Processing Speed	Total score of correct responses
Stroop Task	Frontal Lobe	Inhibition
WAIS Digit Symbol	Processing Speed	Total score of correct responses
WAIS Digit Symbol Incidental Learning	Temporal Lobe	Total score of correct responses
Mill Hill Vocabulary	Semantic Knowledge	# of correct responses
Reading Span	Frontal Lobe	Total score of correct responses
WMS Verbal Paired Associates I	Temporal Lobe	Total score of correct associations

variable was the recorded response time (in milliseconds) for naming the ink color of a target word on the computer screen.

On each trial, one neutral target word (far, most, slant, manual), presented in either red, blue, green, or orange ink was paired with either a neutral or color word prime (red, blue, green, orange, far, most, slant, manual) presented in black ink. For the congruent trials, the print color of the target matched the color named by the prime (e.g., the target *manual* in blue ink paired with the prime *blue* in black ink). For the incongruent trials, the print color of the target conflicted with the color named by the prime (e.g., the target *manual* in red ink paired with the prime *orange* in black ink). For the neutral trials, the prime was always a non-color word (the target *far* in red ink paired with the prime word *slant* in black ink).

Thirty-two (32) unique congruent target-prime pairs were created by combining four neutral words with each of the four ink colors, paired with the appropriate same color word prime to the left and to the right of the fixation point; ninety-six (96) unique incongruent stimuli were created by combining four neutral words with four ink colors, paired with each of the three different color word primes to the left and to the right of the fixation point; and 96 unique neutral stimuli were created by combining the four neutral word with the four ink colors, paired with the three neutral, non color word primes to the left and to the right of the fixation point. Each unique congruent, incongruent, and neutral stimulus was combined with each of the three location cues to produce 96 congruent, 288 incongruent, and 288 neutral stimuli.

These stimuli were used to generate a 288 trial-test list consisting of 96 congruent trials, 96 incongruent trials and 96 neutral trials. In this list, valid cues pointed to the location of the target on 80% of the cued trials. Invalid cues pointed to the location of the prime on 20% of the cued trials. Trials with an ambiguous cue provided no information on the target location. The number of valid, invalid, and ambiguous cue trials within each cue condition is shown in Table 3. A 36-trial practice list with the same proportion of valid, invalid, and ambiguous cue trials were constructed using stimuli not used in the test list. In both the practice and test list, congruent, incongruent, and neutral stimuli were randomly assigned to list positions with the stipulation that a color prime on one trial never followed a target in the same print color on the next trial. In addition, the same color word or target word print color was never presented on the same side of the fixation point on the following trial. These constraints were followed in order to prevent negative and positive priming effects.

Target and prime word pairs, fixation cross (+), and location cues (<< / >>)/ (< >), were presented on a Power Macintosh computer. The location cue was valid, invalid, or ambiguous. These stimuli were presented in the center of the monitor screen in 24-point Arial font in capital letters against a white background. Each target and prime pair was between 1.57° and 3.58° in width from a viewing distance of 16 inches. The words were positioned such that the nearest contour of each word is 1.79° from the center of the fixation cross and the total distance between the end of each word and beginning of the next word is 3.58°.

Table 3.

Number of Congruent, Incongruent, and Neutral Trials across Three Cue Conditions

Cue Condition	Congruent Trials	Incongruent Trials	Neutral Trials	Totals
Valid	58 29 left 29 right*	58 29 left 29 right*	58 29 left 29 right*	174
Invalid	14 7 left 7 right*	14 7 left 7 right*	14 7 left 7 right*	42
Ambiguous	24 12 left 12 right*	24 12 left 12 right*	24 12 left 12 right*	174

Note. *Target location of stimuli: to the left or to the right of the fixation point

<u>Procedure</u>

Participants were tested individually in a session lasting approximately two hours. All testing was conducted in the Cognition Laboratory. Young and older adults completed the same procedures. Upon arrival, participants completed informed consent procedures, a demographic and health questionnaire, and Ishihara's Test for Color Blindness (Ishihara, 1994).

Participants were seated in front of a computer at a distance of 16 inches (40.64 cm) from the screen and their head position was fixed using a chin rest throughout the remainder of the session. They were told that they would see a series of trials and that each trial would begin with a fixation cross (+) centered on the screen immediately followed by a location cue (<< / >>)/(< >), and then a pair of words, one in black and the other in colored ink. Participants were instructed to look at the fixation cross until the cue appears, and when the word pair appears, they should name the color of the non-black ink word as quickly as possible and before a warning tone was sounded. They were informed that the word in colored ink may appear either to the left or to the right of the fixation cross. For the location cues, participants were told that the cue would most often point to the ink color they should name. They were also instructed that at times the location cue would be invalid or would be ambiguous and that in such cases, they should still name the ink in which the target word was printed.

A 36-trial practice list was presented to familiarize participants with the task before beginning the experimental lists. Both the practice and experimental trials were the same for younger and older adults. In each trial the fixation cross remained on the screen for 1200 milliseconds, the location cue appeared for 180 milliseconds before the word pair and then both location cue and word pair remained on the screen together for 120 milliseconds. Participants were given 1700 milliseconds to make a vocal response. To induce a quick response, a warning tone was presented if a response was not made within 1700 milliseconds. A SV-1 Voice Key detected the participant's response and recorded the reaction time. The experimenter also recorded whether the response was correct, incorrect, a false start (cough, sneeze, etc), or no response. Once the response was recorded, participants viewed a white screen for 2,500 ms before the next trial.

After completion of the experimental task, participants were given a battery of tests measuring cognitive functioning. These measures include tests of the following: frontal lobe functioning, temporal lobe functioning, processing speed, working memory, and semantic knowledge (see Table 1). Participants were debriefed upon completion of the session and given monetary compensation for their time.

CHAPTER 3

Results

All tests were conducted using an alpha of $p < .05$. Prior to analyzing the data, errors and outliers were eliminated from each participant's data file. First, trials with incorrect responses were removed from the data, then outliers were eliminated by removing trials with response latencies less than or greater than three standard deviations from the participant's mean for the respective trial types (Congruent, Incongruent, and Neutral) by cue type combination (Valid, Invalid, Ambiguous). Response latency scores were then transformed into interference scores (Interference score = Incongruent – Neutral) and facilitation scores (Facilitation score = Neutral – Congruent).

<u>Error Analysis</u>

Error rates for the younger and older participants for the congruent, incongruent, and neutral trials are shown in Table 4. The errors found for the invalid and ambiguous cue conditions were intrusion errors, whereas the errors for the incongruent trials and neutral trials may have been from color naming or word reading. To analyze age differences in error rates we conducted a 2 (Age) x 3 (Trial Type: Congruent, Incongruent, Neutral) x 3 (Cue Type: Valid, Invalid, Ambiguous) factorial analysis of variance (ANOVA). We found an effect of age, F (1, 58) = 5.05 MS_e = .09, p = .03, η_p^2 = .08 showing that the older adults responded with the conflicting word more often than did the younger adults. There was also an effect of trial type, F (2, 58) = 46.35, MS_e = .17, p = .00, η_p^2 = .44, and an effect of cue type, F (2, 58) = 13.45, MS_e = .02, p = .00, η_p^2 = .19, as well as a significant interaction between Age x Trial type, F (2, 58) = 3.04, MS_e = .011, p = .051, η_p^2 =.050, and a significant interaction between Age x Cue Type, F (2, 58)

= 4.78, MS_e = .00, p = .01, η_p^2 =.07. There was no significant interaction for Age x Trial Type x Cue Type, F (4, 58) = 2.14, MS_e = .00, p = .07, η_p^2 =.04.

To examine the Age x Trial Type interaction further, we collapsed the errors over cue type and ran a one-way ANOVA for age within each trial type. The effect of age on error rates for congruent trials was not significant, F (1, 58) = 2.63, *MSe* = .01, p = .11; however, the effect of age on error rates in both incongruent, F (1, 58) = 4.16, *MSe* = .14, p = .05, and neutral trials, F (1, 58) = 4.07, *MSe* =.04, p = .05 was significant, suggesting that these trial types were more difficult for older adults than for younger adults. To examine the Age x Cue Type data further, we collapsed the errors over trial type and ran a one-way ANOVA for age within each cue type. The effect of age on error rates for the valid cue condition was not significant, F (1, 58) = 1.47, *MSe* = .00, p = .22; however, the effect of age on error rates in both the invalid cue, F (1, 58) = 6.50, *MSe* = .02, p =. 01, and ambiguous cue conditions F (1, 58) = 4.92, *MSe* = .01, p = .03 was significant. The age differences in errors for incongruent word pairs show that the older adults were more likely than the younger adults to fail to maintain the task goal of naming the ink color and ignoring the prime word. Errors are generally higher on incongruent trials and lowest for congruent trials for both younger and older adults. The error rates were generally low for both age groups on all trial types. These findings are thus consistent with research on aging effects in the Stroop task (Spieler et al., 1996, West & Baylis, 1998, Mutter et al., 2005).

Table 4.

Means and Standard Deviations for Proportion of Errors for younger and older participants

	Valid Congruent		Valid Incongruent		Valid Neutral	
Older	.02	.02	.06	.06	.03	.05
Younger	.01	.01	.05	.05	.02	.02
	Invalid Congruent		Invalid Incongruent		Invalid Neutral	
Older	.03	.06	.14	.15	.04	.05
Younger	.01	.03	.07	.10	.02	.03
	Ambiguous Congruent		Ambiguous Incongruent		Ambiguous Neutral	
Older	.01	.03	.08	.07	.04	.07
Younger	.01	.03	.03	.05	.01	.08

Response Latencies

To analyze age differences in response latencies, 2 (Age) x 3 (Cue Type: Valid, Invalid, Ambiguous) factorial ANOVA's were conducted for the interference data and facilitation data. For the interference data, there was a main effect of age, F (1, 58) = 4.86, MSe = 8330.64, p = .03, η_p^2 = .07, showing that interference scores were higher for older adults than for younger adults. There was also a main effect of cue type, F (2, 58) = 23.99, MSe = 15250.63, p = .00, η_p^2 = .29, showing that the response times in the three cue conditions varied. There was also an Age x Cue Type interaction, F (2, 58) = 4.14, MSe = 2629.28, p = .02, η_p^2 = .06. To examine the Age x Cue Type interaction further, we ran a one-way ANOVA for age within each cue type. The effect of age was significant when the cue was ambiguous, F (1, 58) = 7.08, MSe=7705.95, p = .01, revealing that interference was greater for the older than for the younger adults in this cue type condition (see means in Table 5). Interference was also greater for the older than for the younger adults when the cue was invalid, *F* (1, 58) = 4.15, *MSe*=5845.41, *p* = .05, but there was no age effect for the valid cue condition, *F* (1, 58) = .07, *MSe*=37.82, *p* = .78, showing that when there uncertainty about the location of the target word was reduced, the level of interference was similar for both older and younger adults. Pairwise comparisons within each age group showed that younger adults exhibited less interference in the valid cue condition, than in the invalid cue, *MD* = -13.84, *p* = .02, and ambiguous cue conditions, *MD* = -17.84, *p* = .00. There was no significant difference between the invalid cue and ambiguous cue conditions, *MD* = -4.003, *p* = .56 The same result was found for older adults where there was less interference in the valid cue condition, than in the invalid cue, *MD* = -35.22, *p* = .00, and ambiguous cue condition *MD* = -42.14, *p* = .00. Again, there was no significant difference between the invalid cue and ambiguous cue conditions, *MD* = -6.93, *p* = .37.

There was no main effect of age for the facilitation data, *F* (1, 58) = .66, *MSe* = 385.05, *p* = .42, η_p^2 = .01, showing older adults responded as quickly as younger adults to the target word. There was a main effect of cue, *F* (2, 58) = 6.22, *MSe* = 3053.97, *p* = .03, η_p^2 = .10, as well as an Age x Cue Type interaction, *F* (2, 58) = 3.89, *MSe*= 1908.32, *p* = 02, η_p^2 = .06. To explore the Age x Cue Type interaction, we ran a one-way ANOVA for age within each trial type. When the cue was invalid, *F* (1, 58) = 3.75, *MSe*=3723.70, *p* = .78, facilitation was greater for older adults than for younger adults, suggesting that older adults exerted less control over word reading than younger adults in this condition. There were no age differences for the valid cue, *F* (1, 58) = .17, *MSe*=36.17, *p* = .69, or ambiguous cue, *F* (1, 58) = 1.23, *MSe*=441.83, *p* = .27, conditions. Pairwise comparisons within each age group revealed that younger adults showed more facilitation in the valid cue condition, than in the invalid cue, *MD* = 13.73, p = .02, and ambiguous cue condition, *MD* = 12.17, p = .01. There was no significant difference between the invalid cue and the ambiguous cue conditions, *MD* = -1.56, p = .83. Older adults showed greater facilitation in the valid cue and invalid cue condition, *MD* = -3.61, p = .54 than in the ambiguous cue condition, *MD* = 16.05, p = .00, and there was a significant difference between the invalid cue and ambiguous cue condition, *MD* = 19.67, p = .00.

Table 5.

Means and Standard Deviations for Color Naming Latencies for younger and older participants

	Valid Congruent		Valid Incongruent		Valid Neutral	
Older	657.71	100.37	701.59	100.16	679.71	100.16
Younger	594.48	69.83	642.41	69.99	617.36	63.13
	Invalid Congruent		Invalid Incongruent		Invalid Neutral	
Older	685.72	129.70	767.07	129.25	714.56	114.71
Younger	609.60	69.59	655.20	65.23	620.97	63.09
	Ambiguous Congruent		Ambiguous Incongruent		Ambiguous Neutral	
Older	666.71	105.23	738.42	118.67	674.39	100.09
Younger	601.91	61.11	657.78	70.50	612.09	66.35

Table 6.

Means and Standard Deviations for Interference and Facilitation Scores for younger and older participants

	Interference Data					
	Valid Cue		Invalid Cue		Ambiguous Cue	
Older	22.60	25.29	57.82	41.77	64.75	38.13
Younger	24.19	17.77	38.03	31.93	42.04	25.85
	Facilitation Data					
	Valid Cue		Invalid Cue		Ambiguous Cue	
Older	21.64	13.92	25.26	33.67	5.59	17.35
Younger	23.20	14.97	9.46	28.85	11.03	17.35

CHAPTER 4

Discussion

In the current study, we examined age differences in the use of the anterior and posterior attentional systems using a variation of the Stroop Priming task. The main prediction was that, when the task required the involvement of the anterior attentional system age differences would emerge, but when the task recruited from the posterior attentional system, age differences would be eliminated. This hypothesis was supported. Age differences in interference were eliminated on trials with valid cues but not on trials with ambiguous and invalid cues. When stimuli were spatially separated and the valid cue indicated the target location, anterior attention system involvement was not necessary and age differences in interference were not observed. However, when the cue was ambiguous or invalid the location of the target was either unpredictable or incorrect and the anterior attentional system was required to suppress the activated word information and boost the color of the target. In these conditions, the typical age effects were observed.

For the facilitation data, no effect of age was expected in the valid cue condition because both younger and older adults should benefit from the valid cue in naming the color of the target word and inhibiting the word information. Also, it is not clear whether we are measuring facilitation in the valid cue condition because younger and older participants presumable did not read the word. Analysis of the facilitation data revealed that the facilitation effect for the ambiguous cue condition was similar for both older and younger adults but for the invalid cue condition this effect was greater for older than younger adults. Together with the interference results, these findings suggest that reducing the involvement of the anterior attentional system by pre-cuing the location of the target stimulus in the valid cue condition eliminated age differences in interference and facilitation in the Stroop Priming task. However, when the anterior attentional system was recruited in the conditions where the target location was ambiguous or invalid, age differences in interference and facilitation were present.

The current study was a follow-up to Mutter et al.'s (2005) experiment in which participants were provided with an environment where to-be-ignored information should have been easily inhibited. Specifically, those authors used the Stroop Priming task to spatially separate the color and word dimensions of the Stroop task in order to aid attentional selection. They predicted that spatially separating the ink color from the color word would enhance older adults' ability to ignore the prime word and name the target ink color. However, Mutter et al. found that older adults were inefficient at suppressing activated word information and naming the ink color in both the standard Stroop task and in the Stroop Priming task. The ambiguous condition in the present experiment was similar to the Stroop Priming task used in the Mutter et al. experiment. For the ambiguous cue condition, the target word randomly appeared either to the left or to the right of the fixation point and the cue was not informative as to the target location. This introduced uncertainty in the task and may have required that participants maintain a broad attentional focus as was suggested in Mutter et al. study (2005). As a result, it was necessary to inhibit activation from the competing word information. In the invalid cue condition, participants were focusing on the location where the color word was presented and thus had to both shift attention to the correct location of the target word and inhibit the color word information. However, in the valid cue condition, participants knew where the target stimulus would appear, which enabled them to focus their attention on the color information in the target location and spatially filter out the word information that was irrelevant to the goal of the task.

Older participants were more likely than younger adults to respond with the conflicting (prime) word in the ambiguous and invalid cue conditions showing that they were less efficient than younger adults at suppressing the activation of irrelevant information in these conditions. The findings for these two cue conditions are similar to findings reported by Mutter et al. (2005) and to the extensive body of previous research showing age-related inhibitory deficits in the Stroop task. For example, Cohn et al. (1984) administered the Stroop to both younger and older individuals and found that older adults were slower than their younger counterparts at naming the ink color. The authors concluded the increase in response time for incongruent trials on the Stroop task was due to an age-related slowing of cognitive processing. Panek, Rush, and Slade (1984) also administered the Stroop task to a younger and older adults and observed that older adults were much slower in all three conditions of the task. They suggested that age differences were a result of response dominance, in that it is much more difficult for the older adults to restrain automatic word reading. In the current study, when the cue was ambiguous, the broad attentional focus that was required in this condition may have led older adults to process the word name prime on incongruent trials. Inhibiting this information required activating structures in the anterior attentional system responsible for conflict monitoring and inhibition. Because of age-related decline in this system, older adults were less able to inhibit the prime word. This allowed the task irrelevant information to enter working memory and older adults were more likely to give a response that was inconsistent with the goals of the task.

For the invalid cues, older adults showed both more interference and facilitation than young adults, suggesting that as predicted, this was the most difficult condition for them. In the invalid condition, older adults may have had difficulty shifting attention as well as inhibiting the activation of word information for the prime. Previous findings have shown that older adults have trouble shifting their attention to temporally and spatially unpredictable targets. Greenwood, Parasuraman, and Haxby (1993) and Greenwood and Parasuraman (1994) found results suggesting that older adults have trouble with voluntary attentional shifts when processing valid and invalid cues. Here, the initial shift in attention to a target location was not affected by age, but when an invalid cue was presented, there was a greater cost for older adults to disengage and shift attentional focus. We originally proposed that older adults would display the greatest interference in the invalid cue condition, followed by the ambiguous cue condition. Although there were no significant differences in interference between the ambiguous cue condition and the invalid cue condition, the data suggest that disengaging and switching attentional focus in the invalid cue condition was more costly for older adults because the invalid cue condition was the only one in which older adults showed both greater facilitation and greater interference effects. This supports the notion that it was more difficult for older adults to control word reading in the invalid cue condition than the ambiguous cue condition. Processing and resolving conflict involves the anterior attentional system.

The valid cue allowed both young and older participants to focus on the correct target location thus eliminating age differences in interference and facilitation in this condition. Incorporating a valid cue engages the posterior attentional system, which is relatively immune to the effects of aging (Hartley, 1993; West & Bell, 1997). Past findings regarding the posterior attentional system indicate that it is involved in the allocation of attention to visual space, (Posner & Peterson, 1990; Posner, 1992; Posner, 1994; Hartley, 1993; West & Bell, 1997; Banich et al., 2000; MacLeod & McDonald, 2000; Miller & Cohen, 2001; Fan et al., 2002; Milham et al., 2002). The present findings for the valid cue condition are in line with previous research on this attentional system in showing that tasks that engage the posterior attentional system reveal few to no age differences. For example, Hartley (1993) found that older adults were less susceptible to interference when the color and word dimensions of the Stroop task were spatially separated and a central cue was used to direct attention to the target. Again, however, when the word name and ink color were integrated, the cue was inconsequential and older adults performed poorly on the task. Hartley's findings suggested that when performance on the Stroop task involved the posterior system, older adults performed as well as younger adults, but when the task required the anterior attentional system to monitor conflict between the competing processes of word reading and color naming older adults' performance on the Stroop task declined. The current study was similar in that the color word stimuli were separated and the use of a valid cue enabled participants to predict the location of the target.

The results from the current study are also in line with findings by West and Bell (1997) who used electroencephalogram (EEG) data to test Hartley's (1993) hypothesis concerning anterior involvement in the integrated Stroop task and posterior involvement in the spatially separated task. They found no differences between younger and older adults when the color and word stimuli were spatially separated. In addition, activation was the same for older and younger adults across the scalp. However, when the dimensions of the task were integrated and incongruent the interference effects were significant and there was more activity in the medial frontal and lateral frontal regions for older adults than younger adults. They concluded that decline in integrity of the frontal cortices may have lead to older adults' poorer performance on the Stroop task.

In summary, this study shows that when the color and word dimensions of the Stroop stimuli are spatially separated rather than integrated, and the location of the target word is predictable, older adults perform as well as younger adults. However, older adults are less efficient than younger adults in the Stroop Priming task when the location of the relevant color information is uncertain and when the cue directs their attention to the wrong location. This suggests that age differences on the Stroop Priming task will be reduced only when the involvement of the anterior attentional system is also reduced.

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