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**AGE DEFICITS IN THE CONTROL OF PREPOTENT RESPONSES: INHIBITORY
DECLINE OR GOAL NEGLECT**

By

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ABSTRACT

AGE DEFICITS IN THE CONTROL OF PREPOTENT RESPONSES: INHIBITORY DECLINE OR GOAL NEGLECT

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Older adults have difficulty on behavioral control tasks that require the suppression of an incorrect response. Two models have been proposed to account for this finding. The inhibitory deficit hypothesis of aging posits that this impairment is related to age-related decline in the ability to restrain an incorrect response from being executed. The goal neglect hypothesis of aging suggests that older adults are as good as young adults at restraint in these situations, but older adults have difficulty maintaining the current task goal. When goal maintenance is not optimal a competing task may gain access to response processes, slowing correct task performance or causing response errors.

In Experiment 1, the likelihood of goal neglect was manipulated by requiring the maintenance of the current goal over different task intervals in two paradigms, a spatial Stroop task and an antisaccade task. Although the response-to-stimulus interval manipulation led to a pattern of data consistent with goal neglect on the spatial Stroop task, it did not do so on the antisaccade task. In addition, the goal neglect hypothesis of aging was not supported because the effects of increasing the likelihood of goal neglect were equivalent for young and older adults. In Experiment 2, a different manipulation of the likelihood of goal neglect was tried and, in addition, the difficulty of the inhibitory task was varied. Again, there was no evidence in support of goal neglect occurring in

either young or older adults. Increasing the difficulty of the inhibitory task disrupted the performance of older adults more than the performance of younger adults supporting the inhibitory deficit hypothesis of aging.

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After beating the previously undefeated Greco-Roman wrestler, “Superman”, in the 2000 Olympics, Rulon Gardner told reporters his strategy for achieving this win was learned working on his parents’ farm as a kid. When you grow up on a farm you learn that when you have a hard job to do you put your head down and keep going. My own parents, Ed and Christine Yager, taught me this lesson as well and I thank them for the knowledge that I can do anything I put my mind to.

As much as these words served as my mantra during the completion of this dissertation, there were many people who helped me along the way and without whom this dissertation might not have been completed. I thank you all.

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1 Introduction

Older adults have difficulty directing their behavior when the required response is in competition with a prepotent or highly practiced response. In an eye movement control task that requires the suppression of a reflexive response toward an onset stimulus in order to move the eyes in the opposite direction, older adults are more likely to incorrectly look toward the onset stimulus than young adults are (Butler, Zacks, & Henderson, 1999; Olincy, Ross, Youngd, & Freedman, 1997). Older adults also have more difficulty withholding a response in a stop-signal paradigm (Kramer, Humphrey, Larish, & Logan, 1994; May & Hasher, 1998; Williams, Ponesse, Schachar, & Logan, 1999). In addition, in a Stroop task older adults have more difficulty than young adults naming the color a word is presented in when the word itself names a color (e.g., West, 1999; but see Verhaeghen & De Meersman, 1998).

Each of these tasks requires that a prepotent or automatic response be prevented. The difficulty that older adults have in these task situations may arise from a decline in the ability to suppress these inappropriate responses. The inhibitory deficit hypothesis posits that an age-related decline in the ability to suppress prepotent responses, as well as no longer relevant or distracting information, accounts for age-related changes in performance on several cognitive tasks (Hasher & Zacks, 1988; Zacks & Hasher, 1994; Hasher, Zacks, & May, 1999). Although the inhibitory deficit account has received extensive support, an alternative theory has suggested that interference effects are due to a failure to access the current goal at the moment of stimulus presentation. In this view, it is not an impaired inhibitory mechanism that is the cause of interference, but rather the inhibitory mechanism is not engaged at the proper time because the goal of the task is

momentarily inaccessible. This goal neglect account claims that the inability to access the current task requirements increases the time needed to produce the required response and, in the case where the goal is not accessed at all, may result in the execution of a more practiced or prepotent response (De Jong, Berendsen, & Cools, 1999; Duncan, 1995).

This research attempted to determine the cause of the decreased ability of older adults to stop prepotent responses. Older adults may show impairments on tasks requiring suppression of a response because an inhibitory mechanism is impaired. Alternatively, the source of their deficit may be linked to a failure to maintain or access current task goals when required, resulting in slowed correct responding or the execution of a default (prepotent) response. Of course, these two ideas are not mutually exclusive. It may be that older adults' difficulty on tasks that require suppressing an incorrect response results from a combination of impairment in both of these processes.

1.1 Inhibitory Deficit Hypothesis

A strength of the inhibitory deficit hypothesis is the breadth of the model. Not only does it explain deficits on tasks requiring behavioral inhibition, it also accounts for problems experienced by older adults on tasks requiring attentional selection. Hasher and Zacks (1988; Zacks & Hasher, 1994; Hasher et al., 1999) proposed that inhibitory processes have three functions: (1) to restrict access to working memory by keeping irrelevant information from entering, (2) to delete information from working memory that has become irrelevant to the current task, and (3) to restrain responding when a prepotent response is incorrect. Declines in the effectiveness of inhibition account for aging-related changes in performance on not only motor control tasks, but also on language comprehension and memory tasks. On a reading with distraction task, age-related

increases in the interference caused by distracting material embedded in a passage support the claim that older adults have more difficulty preventing irrelevant information from accessing working memory than young adults (Connelly, Hasher, & Zacks, 1991). In addition, when told to explicitly forget information, as in a directed forgetting paradigm, or when it is clear that a previous interpretation was incorrect, older adults are more likely to retain this irrelevant information than young adults; they have more difficulty deleting the information from working memory (Zacks, Radvansky, & Hasher, 1996; Hartman & Hasher, 1994; Hasher & Zacks, 1988; Zacks, Hasher, Doren, Hamm, & Attig, 1987). Support for an impairment in the restraining function of inhibition, as stated above, includes findings that older adults have a harder time stopping a response they have already begun to prepare (Kramer et al., 1994; May & Hasher, 1998) and preventing the execution of a reflexive response (Butler et al., 1999) than young adults. Older adults show more disruption on tasks that seem to require inhibition than young adults do.

The performance deficits displayed by older adults on an antisaccade task seem to provide critical support for the restraint impairment proposed by the inhibitory deficit model of aging. In an antisaccade task, the viewer is asked to look in the opposite direction of a peripheral onset stimulus. The antisaccade procedure elicits two competing response programs: an involuntary eye movement toward the peripheral stimulus and a voluntary response in the opposite direction. The participant must prevent the automatic response while programming and executing the voluntary eye movement. This task is difficult, as indexed by incorrect saccades toward the peripheral onset (Hallet, 1978; Hallet & Adams, 1980; see Everling & Fischer, 1998, for a review). Older adults have more difficulty performing antisaccades than young adults; They are more likely to

incorrectly look toward a peripheral onset than young adults in an antisaccade task (Butler et al., 1999; Olincy et al., 1997; Nieuwenhuis, Ridderinkhof, de Jong, Kok, & van der Molen, 2000; Klein, Fischer, Hartnegg, Heiss, & Roth, 2000) and they need to take more time to correctly produce antisaccades than young adults when compared to a control condition (Munoz, Broughton, Goldring, & Armstrong, 1998; Nieuwenhuis et al., 2000; Fischer, Biscaldi, & Gezeck, 1997).

Saccade direction errors in the antisaccade task have come to be interpreted as the failure of an inhibitory mechanism. This conclusion follows from evidence suggesting that on each trial a reflexive and voluntary saccade are being programmed simultaneously and that errors are the result of the reflexive response program gaining access to response production. This explanation is supported by error latencies and recovery from errors. Incorrect responses toward the peripheral onset are as fast, or faster, than saccades toward the onset in a control condition, indicating that participants are automatically programming them. When an incorrect response is made, individuals usually will correct it and look to the correct location. The time needed to initiate the saccade to the correct location is much shorter than the time needed to program an intentional saccade (e.g., Roberts, Hager, & Heron, 1994; Nieuwenhuis et al., 2000) indicating that the correct response was being programmed prior to the execution of the incorrect saccade, but the incorrect response gained access to the system and was executed before the completion of the voluntary saccade program.

Although the inhibitory deficit hypothesis has received support from several studies using different paradigms (for reviews see Hasher et al., 1999; Stoltzfus, Hasher, & Zacks, 1996; Zacks & Hasher, 1994), the model has been criticized because it is

lacking in specificity and because attempts to identify a measure of inhibitory functioning have been unsuccessful (e.g., Burke, 1997; McDowd, 1997; but see Zacks & Hasher, 1997). In addition, the inhibitory deficit hypothesis relies on a model of working memory that includes an inhibitory mechanism (or mechanisms) that work to control the contents of working memory. Some researchers have proposed that an inhibitory mechanism is not necessary to explain how working memory functions during task performance.

Implemented in the ACT-R production system architecture, Kimberg and Farah's working memory model does not rely on an inhibitory mechanism to suppress prepotent responses (Kimberg & Farah, 1993, 2000; Kimberg, D'Esposito, & Farah, 1997). Instead, it posits that whether the prepotent responses gains control of the system is a function of two parameters: (1) the strength of the connection between the current task goals (e.g., looking away from something that suddenly appears in peripheral vision) and the stimuli that trigger those goals and (2) the preexisting associations of other task goals to the stimuli in the current task set (e.g., looking toward a change occurring in peripheral vision). The relative strengths of these two types of associations determine the extent to which interference effects will be observed. Interference effects increase when correct task associations and preexisting associations have similar strengths. Age-related weakening of the strength of the connections between stimuli and new task goals decreases the difference between the strength of correct task associations and preexisting associations. Because the difference between association strengths is reduced the likelihood that the prepotent response (e.g., looking toward the change) will be triggered by the stimulus and gain control of the system is increased. This model has been used to account for performance, not only on an antisaccade task, but on several other tasks

thought to require inhibition, including the Stroop task, the Wisconsin Card Sort Test, and an A-not-B task.

Increasing competition between experimentally-defined and preexisting associations is difficult to distinguish from increasing difficulty of suppressing a reflexive or prepotent response and so testing the difference between these two hypotheses is not the goal of this dissertation. An additional alternative to the inhibitory deficit hypothesis is the idea that older adults have more difficulty keeping the current task goal active and it is this goal neglect that leads to increased difficulty on a task that requires the suppression of a prepotent response. This proposal is similar to the Kimberg and Farah model of working memory, but its differences allow it to make unique predictions from those made by the inhibitory deficit hypothesis. These differences are considered below.

1.2 Goal Neglect Hypothesis

Goal neglect has been advanced as an explanation for interference effects. Unlike the Kimberg and Farah model, goal neglect allows for an inhibitory mechanism, but proposes that it is not a failure of the inhibitory mechanism that leads interference effects, but rather that sometimes the inhibitory mechanism is not engaged because of a failure to access the task goals (De Jong et al., 1999). According to the goal neglect view of interference effects, different schemas contain the task requirements for the current task, the previous tasks, and other practiced tasks. In order for the current task to be executed without interference from other task schemas, the current task goal must be maintained at a high level of activation. When the current goal is active enough (i.e., when there is sufficient “goal drive”), the goal-to-schema translation mechanism will operate well, selecting the correct task schema and executing the correct task. As a result of schema

selection, competing task schemas are suppressed through lateral inhibition. If there is insufficient “goal drive”, the goal-to-schema translation mechanisms are ineffective and competing schemas may gain access to response production incorrectly. When the task goal is not active enough it may not be accessible even though the requirements of the task are understood. This causes slower correct responding or even incorrect responses consistent with an automatic or prepotent response (see also, Duncan, 1995).

A critical difference between the goal neglect hypothesis (De Jong et al., 1999) and the inhibitory deficit hypothesis is the point at which inhibition plays a role. In the goal neglect hypothesis, inhibition is the result of the selection of the correct task schema which relies on a high level of goal activation. The task goal activation process is effortful and is affected by the efficiency of working memory, but it is unrelated to the strength of the competing response. Only the strength of the current task goal determines if interference will occur. In the inhibitory deficit hypothesis, inhibitory mechanisms work in the service of correct task performance. The functioning of the inhibitory mechanism is not directly related to the preparation for the current task to be performed. Kimberg and Farah’s working memory model (1993, 2000) also differs from the goal neglect view in that it claims that interference is the result of the relative strength of associations of stimuli to correct and incorrect tasks. In this view, strong stimuli-correct task associations may be sufficient to overcome weak preexisting associations, but as the preexisting associations become stronger, interference will increase.

Support for a goal neglect hypothesis has come from many different paradigms that used different methods of manipulating the likelihood that goal neglect would occur. Because goal maintenance is an effortful process, the current activation of the task goal

will vary across task performance. The farther the presentation of the stimulus is from the instantiation of the task goal (a process thought to occur during task performance) the less likely the task goal will be at a high level of activation. Therefore, increasing the amount of time between task performance and the presentation of the next stimulus will increase the likelihood of goal neglect (De Jong et al., 1999). In a spatial Stroop task, the response-to-stimulus interval (RSI) was manipulated to vary the likelihood of goal neglect. It should be harder to keep the goal in a highly active state when there is a long interval before the next trial begins compared to when there is a short interval. At a short response-to-stimulus interval (RSI) of 200 ms, when attention was presumably tightly focused on the task of location naming, no interference between location naming and the location word was found; by contrast, following a long RSI of 2000 ms, when attention was presumably less focused and sometimes accessing the current task goal was delayed, interference was found. It is not clear how lengthening the duration of the RSI would have made inhibiting the word reading response more difficult and so it appears that goal neglect is the better explanation for this interference effect.

The larger interference effect observed in the long RSI condition was attributed to insufficient activation of the task goal, location naming, on some trials. This claim was supported by an examination of cumulative response distribution functions. A cumulative response distribution is created by ordering each subjects' reaction times in each condition and separating the reaction times into an equal number of bins. Then the mean reaction times for each bin in each condition are calculated. By comparing the plot of the congruent and incongruent reaction times, the interference effects when reaction times are fast can be compared to the interference effects when reaction times are slow (see

Figures 4a and 4b for an estimation of De Jong et al.'s (1999)). The cumulative response distributions from the spatial Stroop experiment showed that the interference effect found in the slow paced condition was only apparent at the slow end of the distribution indicating that when a quick response could be made (i.e., attention was focused) the interference effect was reduced.

Along slightly different lines, the goal neglect model has been applied to task switching behavior. In a task switching experiment, participants switch between different tasks throughout a block of trials. The appropriate task for the current trial is indicated by a switch cue, a task instruction, the nature of the stimulus, or the ordering of the trials. A standard finding in the task switching literature is that even when ample preparation time is given to reconfigure the current task set before a new task is performed, response times on the first trial following a task switch, the switch trials, are slower than responses on nonswitch trials (e.g., Rogers & Monsell, 1995). Rogers and Monsell (1995) suggested that these residual switch costs are due to an inability to completely reconfigure the task set until the stimulus is presented.

Another idea proposed by De Jong and colleagues (1999; De Jong, 2000) is that under some conditions, goal neglect, the failure to engage in advanced preparation for the task switch, can better account for residual switch costs than models that propose a limitation on the amount of preparation that can occur before a task switch. To evaluate this hypothesis the cumulative response distributions for switch and nonswitch trials from conditions with short and long preparation intervals were compared. At short preparation intervals goal neglect should not play a role in processing because no one has time to prepare for the upcoming task, but trials in the long preparation conditions should be

separable into those on which preparation occurred and those trials where preparation was not done. It was found that the fast reaction times on switch trials from the long preparation condition resembled reaction times on nonswitch trials. It seemed that on some switch trials participants could completely prepare for the new task and so their reaction times were the same as for nonswitch trials. In contrast, the reaction times from the switch trial that were responded to slowly were similar to the reaction times from trials with short preparation intervals suggesting that on some switch trials with long preparation intervals participants did not engage in advanced preparation and so their performance was the same as if there had not been time to prepare. This mixture model provided a good fit to the observed data (De Jong, 2000; but see Mayr & Keele, 2000, for an inhibitory account of residual switch costs).

Evidence that antisaccade performance may be disrupted by goal neglect comes from studies that have examined the relationship between working memory and antisaccade performance. In one study, individuals with low and high working memory abilities, as measured by an operation span task, were compared on the antisaccade and prosaccade tasks (Kane, Bleckley, Conway & Engle, 2001). In the first experiment of this study eye movements were not directly measured. Instead, performance identifying a target that appeared for a short time at the location participants were supposed to look at was used as a measure of success on the eye movement task. It was assumed that if participants looked in the wrong direction they would not be able to identify the target. Low span individuals were less likely to correctly identify the target than high span individuals in the antisaccade condition suggesting that the low span individuals were more likely to make a saccade direction error, but only when the prosaccade task was

performed after the antisaccade task. Kane and colleagues suggested that when the requirements of the antisaccade condition were made less novel by first performing prosaccades, the difference in antisaccade performance between low and high span individuals was eliminated. Reducing the novelty of the antisaccade task should have also made it easier to maintain that task goal, and so, this finding may indicate that when the likelihood of goal neglect is reduced, antisaccade performance improves, especially in low span individuals.

In a second study of working memory's role in antisaccade performance, Roberts, Hager, and Heron (1994) found that a concurrent working memory load led to increases in saccade direction errors and saccade latencies, but only in the antisaccade condition. They suggested that the critical aspect of performance on the antisaccade task was attentional vigilance. "Successful performance seems dependent on maintaining a high enough level of activation of the relevant self-instructions to make an eye movement to the opposite side at the moment the cue is presented (pp. 391, Roberts et al., 1994)." When the self-instruction activation level declines, e.g., when attention must be devoted to a concurrent task, goal neglect occurs and the prepotent response is executed. However, despite this relationship of working memory load to antisaccade performance, saccade direction errors, antisaccade latency, and target task performance were not correlated with performance on a version of Daneman and Carpenter's (1980) sentence span task or a counting span task. This finding is contrary to the differences in performance based on working memory span found by Kane et al. (2001). This discrepancy may be accounted for by the smaller variation in working memory span scores for participants in the Roberts et al. (1994) study. Kane et al. (2001) selected

participants with extremely low or high scores on the span measure to compare, whereas Roberts et al. (1994) did not.

Duncan and colleagues also proposed that goal neglect may be the source of performance difficulty experienced by individuals with impaired frontal lobe functioning, including older adults, individuals with frontal lobe damage, and individuals with low ability to reason and solve problems as measured by fluid intelligence, (Duncan, 1995; Duncan, Emslie, Williams, Johnson, & Freer, 1996). Although Duncan's definition of goal neglect, the inability to adhere to task requirements even when those requirements are understood, is the same as that of De Jong et al.'s (1999), the conceptualization of the role of goal activation is somewhat different. Duncan suggests that after very little practice with the task requirements, or once the task is performed correctly, goal neglect should no longer occur, suggesting that goal activation is no longer effortful. De Jong et al. (1999) claimed that goal activation is effortful across the entire period typically associated with an experimental task and so goal neglect may occur on trial $n+1$ even if trial n was performed correctly. This research will consider goal neglect to be an effortful attentional process that occurs throughout task performance.

Although goal neglect may account, in part, for performance on some interference tasks it is not clear that it will account for the age-related increase in performance difficulty seen on tasks that require a prepotent response. The next section will consider some experimental evidence that does indeed support a goal neglect account of **larger** interference effects seen with older adults.

1.2.1 Evidence for a goal neglect account of aging

Older adults may be more susceptible to goal neglect than young adults and this increase in susceptibility may result in the incorrect generation of a prepotent response or difficulty generating the correct response when a prepotent response is possible. The results from a Stroop interference task that required participants to switch between color naming and word reading made an argument similar to the increased susceptibility to goal neglect of older adults (West, 1999). In this paradigm, the task to be performed was cued by the stimulus. When a gray word was presented it was supposed to be read and when a colored word was presented the color was supposed to be named. The proportion of word reading to color naming trials was varied. When the activation of the competing goal, word reading, was increased by increasing the proportion of word reading trials, the presumed result was greater difficulty maintaining the task-relevant color naming goal, especially for older adults. As a result older adults showed a greater interference effect in color naming performance relative to young adults as the proportion of word naming trials increased. This finding suggests that older adults had more difficulty maintaining the current task goal than young adults. Alternatively, if practicing word reading within the experimental context makes it more difficult to suppress the word reading response it could account for the

An interesting parallel to the maintenance of task goals is the maintenance of the intention to perform a prospective memory task. In a prospective memory task, as individuals perform a background task they are required to maintain the intention to perform a second task much in the same way that goals to perform a task must be maintained in a conflict situation. Generally, older adults have more difficulty on

prospective memory tasks than young adults, but these age differences are reduced when a cue is presented at the moment that the prospective memory task is to be executed (e.g., West & Craik, 1999). Age differences on prospective memory tasks support the idea that older adults are more susceptible to goal neglect. In addition, the elimination of age differences when prompts are given suggests that external cues that signal the task to be performed aid the performance of older adults more than the performance of young adults.

Another piece of evidence in support of a goal neglect account of age-related prospective memory failure comes from a retrieve-delay prospective memory paradigm (Einstein, McDaniel, Manzi, Cochran, & Baker, 2000). In this task an event signals that the required response should be made, but the response must be delayed until a different phase of the experiment. The intention to respond to the prospective memory cue has to be kept active either while an unrelated task is performed or during an unfilled interval when no other task is performed. In both filled and unfilled delay conditions older adults had more difficulty maintaining a goal across an interval as short as 10 seconds. Admittedly, the interval over which a prospective memory cue must be maintained is much short than the difference found between RSIs of 200 and 2000 ms, but note that the measure in the prospective memory tasks is failure to perform altogether whereas the measure on the spatial Stroop task that varied RSI was an increase reaction times on incongruent trials. Perhaps at short prospective memory intervals differences in response time to prospective memory cues would be observed.

Goal neglect may play a role in older adults' performance on an antisaccade task as well. Nieuwenhuis and colleagues (2000) examined the antisaccade performance of

older adults under conditions that varied the amount of external information available to participants about the correct eye movement response. In their study, as in others (e.g., Rogers et al., 1994; Butler et al., 1999), a target for a perceptual task was displayed a short time after the presentation of the peripheral onset at the location that was the goal of the correct saccade. The requirement to identify the target after completing the eye movement is used to motivate the participants to try to perform the saccade task correctly and quickly. However, if the correct antisaccade is not programmed quickly the onset of the target may visual trigger the correct antisaccade (e.g., Guitton, Buchtel, & Douglas, 1985).

In Experiment 1, Nieuwenhuis and colleagues (2000) varied the cue-to-target interval and found that for older adults, but not young adults, antisaccade latencies were slower as the interval increased, suggesting that older adults were relying on the onset of the target to guide their response. In Experiment 2 this source of environmental support was eliminated by having distracting stimuli onset at the other potential target locations simultaneous with the onset of the target. This procedure forced older adults to utilize the initial cue, the peripheral onset, to generate their correct antisaccades. When the environmental support was eliminated, the age differences in correct antisaccade latencies and corrective saccade latencies following saccade direction errors were reduced at long cue-to-target intervals. The age difference in saccade direction accuracy was also much larger in Experiment 2 at the long intervals. Nieuwenhuis et al. (2000) suggested that under antisaccade instructions maintaining the goal is difficult, especially for older adults, and so they look for an easier strategy for performing the task. In Experiment 1, older adults were able to utilize the onset of the target to guide their eye

movements. At short cue-to-target intervals this led to faster and more accurate antisaccade performance, but at long cue-to-target intervals this slowed their responses because they were waiting for the target to occur. When an alternate method for performing the task was not available, older adults made more saccade direction errors than they did in Experiment 1 with short cue-to-target intervals. In addition, the difference in antisaccade latencies compared to prosaccade latencies was greater for older than younger adults. As with prospective memory tasks, older adults were able to perform the task better when external prompts signaled the correct response, but unlike prospective memory tasks, even with external prompts older adults had more difficulty than younger adults.

Older adults may be more susceptible to goal neglect than young adults. In addition, difficulty maintain the current task goal may lead to more problems for older adults when the current task requires the production of a controlled response, but the stimuli are associated with different automatic or prepotent responses. The specific question of this research is whether behavioral control difficulties displayed by older adults are better accounted for by an impaired inhibitory mechanism, reduced ability to stay on task, or both.

1.2.1 Ideas related to goal neglect

As was described above, Duncan and colleagues' (Duncan, 1995; Duncan et al., 1996) view of goal neglect is quite similar to the goal neglect hypothesis put forward by De Jong and colleagues (De Jong et al., 1999, De Jong, 2000) with one exception being that goal activation is more transient in De Jong's model. Consistent with this transient view of goal activation, research using the prospective memory paradigm has suggested

that the activation of the intention to perform a prospective memory task may fluctuate across the course of an experiment and that older adults may be more prone to these fluctuations.

Maylor (1996) examined how performance on a prospective memory task may fluctuate over time by calculating forgetting of the task once it had been successfully performed and recovery from that forgetting. Older adults were more likely than young adults to forget to perform the prospective memory task after they had previously successfully responded, and conversely, older adults were less likely to recover from that forgetting (Maylor, 1996; West & Craik, 1999). Because the success of prospective memory performance fluctuated across the course of the experiment the errors were termed momentary lapses of intention, short periods of time when the activation of the intention to perform an action falls below the threshold for responding (Craik & Kerr, 1996; West & Craik, 1999). Not only has this idea been applied to failures to respond on prospective memory tasks, but it has been proposed as a means of accounting for word reading errors on the color-naming version of the Stroop task (West, 1999). In the Stroop task, a momentary lapse of intention results in a failure to perform the current task, color-naming, allowing the more natural or automatic response to control the response system and resulting in a response error (West, 1999, 2001; West & Alain, 2000). Older adults appear to be more susceptible to momentary lapses of intention on the Stroop task as well as on prospective memory tasks (West, 1999).

1.3 Summary

When the conditions of a situation require the production (or withholding) of a response in an intentional manner, despite the fact that a different prepotent response is

associated with that situation, how does the system select the correct response? One view posits that an inhibitory mechanism suppresses the reflexive response and that this inhibitory mechanism may not function as well in older adults compared to young adults. In contrast, it may be that the inhibitory process functions well, but the control processes responsible for engaging inhibition are sometimes impaired resulting in a failure to engage the inhibitory mechanism. Although these two hypotheses make distinct predictions about how performance should be impaired in older adults, they are not mutually exclusive. It may be the case that older adults have an impaired inhibitory mechanism, as well as an increased susceptibility to goal neglect.

2 Experiment 1

The difficulty that older adults have on interference tasks may be due to difficulty maintaining the activation of the intended goal. If goal neglect is an adequate explanation of the deficit that older adults experience then, under conditions that increase the likelihood of goal neglect, older adults should show a greater disruption of performance than young adults. In this experiment the difficulty of maintaining the goal was manipulated by varying the interval between the response on trial n and the beginning of trial $n + 1$, the response-to-stimulus interval (RSI). As was described above, De Jong et al. (1999) used this manipulation in a spatial Stroop task and found evidence in support of the goal neglect hypothesis. Because goal maintenance is an effortful process the average activation of the goal following long intervals will be lower than the activation following short intervals. Higher goal activation will lead to better performance than low goal activation.

Young and older adults were tested on two interference tasks, the spatial version of the Stroop task and the antisaccade task. In order to evaluate the goal neglect account of age-related increases in interference effects, the likelihood of goal neglect was manipulated between subjects. Participants performed each of these tasks with either long or short RSIs in a similar manner to that used by De Jong et al. (1999) in the spatial Stroop task. In both tasks, the RSI was timed from the button press response made on the previous trial until the presentation of the next response stimulus. At short RSIs individuals should be better able to maintain the current task goal and performance on the interference trials should be less often influenced by the competing task compared to performance following long RSIs.

In the spatial Stroop task, the interference effect, as measured by the difference in reaction time between congruent and incongruent trials, should be larger in the long RSI condition than in the short RSI condition as De Jong et al. (1999) found. In the antisaccade task, interference will be measured as the frequency of incorrect eye movements toward the peripheral onset in the antisaccade condition and the difference between correct saccade latencies in the prosaccade and antisaccade conditions. Increasing the likelihood of goal neglect should lead to slower reaction times and more frequent saccade direction errors in the antisaccade condition because of the increased likelihood that the nongoal task, looking toward the onset, will interfere with performance. Following a long RSI, if the activation level of the goal is, on average, lower at the time the onset occurs, then the incorrect response, looking toward the peripheral onset, will more often interfere with correct performance. The increased probability of interference in the long RSI condition will result in a larger interference effect in the spatial Stroop task and more frequent saccade direction errors and greater latency differences in the antisaccade task.

The question of most interest for this research is the effect of the RSI manipulation on older adults' performance. If this group of individuals has more difficulty maintaining the current goal state than young adults, then the effect of the time manipulation should be more pronounced for them compared to young adults in both the spatial Stroop and antisaccade tasks. Participants in this study completed the eye movement tasks before the Stroop task, but for the exposition purposes the Methods and results from the Stroop task will be reported first.

2.1 Method

2.1.1 Participants

Thirty-four young adults (Age range = 18 - 23 years) were recruited from undergraduate psychology courses and participated in the experiment for partial course credit. One young subject (in the long RSI condition) frequently anticipated the presentation of the peripheral cue and was excluded from the analysis.

Forty-one community-dwelling older adults (Age range = 63 – 80 years old) were recruited from the Lansing, MI area and paid \$10/hour for their participation. The data from one older adult were excluded from both the Stroop and eye movement analyses because of frequent anticipations in the eye movement task and a failure (or an inability) to follow instructions in the Stroop task. Thirty-eight older adults completed the Stroop task. Two older adults did not complete this portion of the experiment because of time limitations. Thirty-two of the older adults completed the eye movement tasks satisfactorily and were included in the eye movement analyses. The data from three individuals were excluded because of frequent anticipations, eye movements before the presentation of the peripheral onset, – two in the long and one in the short RSI condition. In addition, eye movement data were not obtained from five older adults who could not be reliably tracked during the eye movement tasks because of droopy eyelids and/or excessive blinking; these individuals did complete the Stroop task, however. Young and older adults reporting learning disabilities, psychoactive medications, or a history of brain trauma (including stroke) were excluded from the sample. All participants were able to discriminate letters that subtended less than .6° of visual angle. Mean ages, vocabulary test scores, and education levels of the participants in each group in both tasks are

presented in Table 1. There was no difference between the RSI conditions in mean age or education levels, $F_s < 1$. However, despite the random assignment, individuals in the short RSI condition had lower mean vocabulary scores than individuals in the long RSI condition, $F(1, 68) = 4.8$, $MSE = 9.3$, $p = 0.032$). This difference is small and unlikely to have an impact on performance in the experimental tasks. In addition, older adults had more years of education and higher vocabulary test scores than young adults, $F_s(1, 69) = 90.8$ and 17.3 , $MSEs = 9.3$ and 3.9 , $p's < 0.001$, respectively. These differences should ensure that observed age differences are not due to a low functioning older adult population.

	Young	Old
Short RSI		
Age (years)	19.4	72.5
Education	13.2	15.2
Vocabulary (mean	27.9	34.3
n	18	19
Long RSI		
Age (years)	19.7	72.4
Education	13.4	15.2
Vocabulary (mean	29.0	36.4
n	16	21

Table 1. Experiment 1 Participant Characteristics

2.1.2 Design

The spatial Stroop task had a two age group (young or old) by two RSI (218 ms or 2028 ms) by two item type (congruent or incongruent) design with age group and RSI as the between subjects variables and item type as the within subjects variable. The eye movement tasks had a two age group (young or old) by two RSI (1200 ms or 3200 ms) by two eye task (prosaccade or antisaccade) design with age group and RSI as between

subjects variables and eye task as a within subjects variable. Participants were in the same RSI condition for both the eye movement and Stroop tasks, i.e., participants in the short RSI condition of the eye movement tasks also completed the short RSI version of the Stroop task and vice versa.

2.1.3 Apparatus and Stimuli

Spatial Stroop task. Stimuli for the Stroop task were displayed using E-prime software running on a NEC Multisync XE15 monitor controlled by a Pentium PC-compatible computer (Psychological Software Tools, Inc., 2000). The experiment program set the RSI from the button press on trial n to the stimulus display on trial $n + 1$ at 200 and 2000 ms for the short and long RSI conditions, respectively. Because the computer program took time to prepare the stimuli for presentation after the RSI had elapsed the actual RSIs were slightly longer. This stimulus preparation time was on average 18 ms in the short RSI and 28 ms in the long RSI conditions and varied at most 1 ms from trial to trial. This resulted in an actual RSI of 218 ms in the short RSI condition and 2028 ms in the long RSI condition. This small difference in timing from the De Jong et al. (1999) experiment should have had a minor effect on our results and will not be discussed further.

The stimulus display contained a row of four asterisks in the center of the screen that subtended 3.1° . The word ABOVE or BELOW appeared above or below the row of asterisks in 18 point Sans Serif font. The letters subtended a visual angle of 0.8° in height and 0.5° in width. The entire word subtended a visual angle of 3.3° and the space between the asterisks and the word was 0.2° . The sizes of these stimuli were chosen to approximate the sizes of those used by De Jong et al. (1999).

Participants completed 10 blocks of trials with 100 trials in each block. Each block contained 50 congruent trials, e.g., the word ABOVE appearing above the row of plus signs, and 50 incongruent trials, e.g., the word ABOVE appearing below the row of plus signs. The trials were presented in a random order.

Antisaccade task. Eye movements were recorded with an ISCAN RK-416 high-speed eyetracker that uses an infrared video-based system to compute and horizontally track the center of the pupil in the right eye. Signals were generated by the eyetracker at a frequency of 120 Hz allowing saccade latencies to be calculated with a temporal resolution of 8.33 ms. The spatial resolution of the apparatus is 0.2° of visual angle. Stimuli were displayed at a resolution of 800 by 600 pixels on the computer system described above.

A chin and forehead rest was used to stabilize the participant's head at a viewing distance of 49 cm. The fixation display contained a white cross in the center of a black screen flanked by two white boxes to the left and right. The fixation cross and boxes subtended visual angles of 0.8° and 1.2° , respectively, and the distance from fixation to the inside edge of the box was 10.5° . The target arrow and nontarget double-headed arrow each appeared inside one of the boxes on each trial and both subtended 0.8° . The onset was defined by the inside of one of the boxes changing from black to white.

Participants completed two blocks of prosaccade and four blocks of antisaccade trials. The second prosaccade block was completed at the end of the experiment. Each block contained 40 trials, 10 of each peripheral onset location (left or right) by target arrow direction (up or down) combination. The trials were presented in a different random order for each subject. The three prosaccade and two antisaccade task practice

blocks each contained an equal number of trials from each onset location by arrow direction combination presented in a random order. Two of the prosaccade and one of the antisaccade practice blocks contained 12 trials and the remaining practice blocks contained 24 trials.

In order to manipulate the RSI while maintaining an accurate calibration of the eye movement monitor, strings of trials were performed punctuated by brief periods to check calibration. The 40 experimental trials in each block were presented as 5 strings of 8 trials each. Within a string of trials, the eye movement monitor was not recalibrated so that the interval between the response on trial n and the presentation of the peripheral onset on trial $n+1$ could be precisely controlled to be either 1200 or 3200 ms.

2.1.4 Materials

Acuity test. Before beginning the eye movement task each participant was asked to read letters from a photocopied miniature version of the Snellen vision chart taped to the computer monitor. While sitting with their face in the chin and forehead rest participants were asked to read as many of the letters as they could starting at the top of the chart. Participants were said to be able to discriminate letters at a particular visual angle if they incorrectly identified no more than one letter in the row of that size.

Vocabulary test. At the end of the eye movement tasks participants completed the Shipley Institute of Living Scale - Vocabulary Test (Shipley, 1940), a 40-item multiple choice test.

2.1.5 Procedure

Before beginning the experiment, the apparatus was explained to the participant and the participant signed a consent form. Then, while sitting in the chin and forehead

rest, the participant's acuity to discriminate letters presented at a distance of 49 cm was tested.

Antisaccade task. Following the acuity test, instructions describing the prosaccade condition were read by the participant and then the participant was shown a booklet that illustrated the displays and the order they would be shown, with the experimenter explaining what the participant should be doing during each display. The instructions emphasized that it was important to look as quickly and as accurately as possible toward the peripheral onset when it occurred and to press the button that corresponded to the direction that the arrow was pointing, either up or down. Participants were instructed to guess if unsure about the direction of the arrow. One prosaccade block was always performed before the antisaccade blocks to allow participants to become familiar with the displays and timing parameters (see Butler et al., 1999).

Before beginning the practice trials, the eye movement monitor was calibrated horizontally by sampling the center of the pupil while the eyes were looking at a point on the far right and a point on the far left center of the screen. After the calibration was checked for accuracy, the participant was reminded of the instructions and then began the first of three blocks of practice trials. In the first block of 12 trials, an opportunity was given after each trial to ask questions. Then participants were told that during the actual experiment several trials would be presented consecutively without pauses between them and so it was important, after pressing the button, to move the eyes back to the center of the screen and get ready for the next trial to begin. The second practice block allowed participants to practice responding to several trials in a row by presenting four strings of three consecutive trials each for a total of 12 trials. In the final block of practice, the

experimental procedure was used. Participants completed three strings of eight trials for a total of 24 trials in this practice block. Next the first experimental block of 40 prosaccade trials was completed. Then participants read the antisaccade instructions to look at the box in the opposite direction from where the peripheral onset was presented. For the antisaccade task, participants completed two blocks of practice trials, a block of 12 trials with pauses after each, and then a block of 24 trials presented in three strings of eight trials each. The antisaccade practice was followed by four blocks of 40 antisaccade experimental trials and a final block of 40 prosaccade trials. Participants were reminded of the task instructions following the initial calibration in each block. They were also given short breaks after each practice and experimental block of trials. In addition, after the second block of experimental trials, participants filled out a background questionnaire that asked about medications, mental illness, and learning disabilities and following the final block of eye movement trials participants completed the vocabulary test. Following another break participants completed the spatial Stroop task. The entire experiment took approximately 1.5 hours for young adults and 2 hours for older adults.

The sequence of events for each trial in the eye movement tasks is explained below and illustrated in Figure 1. At the beginning of a block of trials the fixation display, the fixation cross flanked by box place markers, was presented. After checking the calibration the experimenter initiated the string of trials. At the beginning of each string the fixation display was visible for an additional 1000 or 3000 ms (in the fast and slow RSI conditions, respectively). The trial began when the fixation cross disappeared, and then, after 200 ms, the peripheral onset was presented, i.e., the inside of one of the boxes changed from black to white. After 400 ms the target display was presented for 150 ms.

The target display consisted of a single-headed arrow in the box that was the goal of the correct saccade and a double-headed arrow in the opposite box. The perceptual identification target was only presented in the box that was the goal of the correct saccade to motivate the participant to move their eyes as quickly as possible in the correct direction. In the prosaccade condition, the single-headed arrow replaced the peripheral onset. In the antisaccade condition, the single-headed arrow appeared in the box opposite from where the peripheral onset had been. After the target display disappeared, both boxes appeared empty until a button press response was made. Following the button press, the fixation cross flashed in the center of the screen for 500 ms at 50 ms intervals as a cue to move the eyes back to fixation. Then the fixation display remained on the screen until either 500 or 2500 ms had elapsed (in the fast and slow-paced conditions, respectively), at which time the next trial began. During each experimental block the experimenter wrote down the initial looking direction on each trial and coded whether a trial should be excluded because of poor calibration or failure of the participant to maintain fixation.

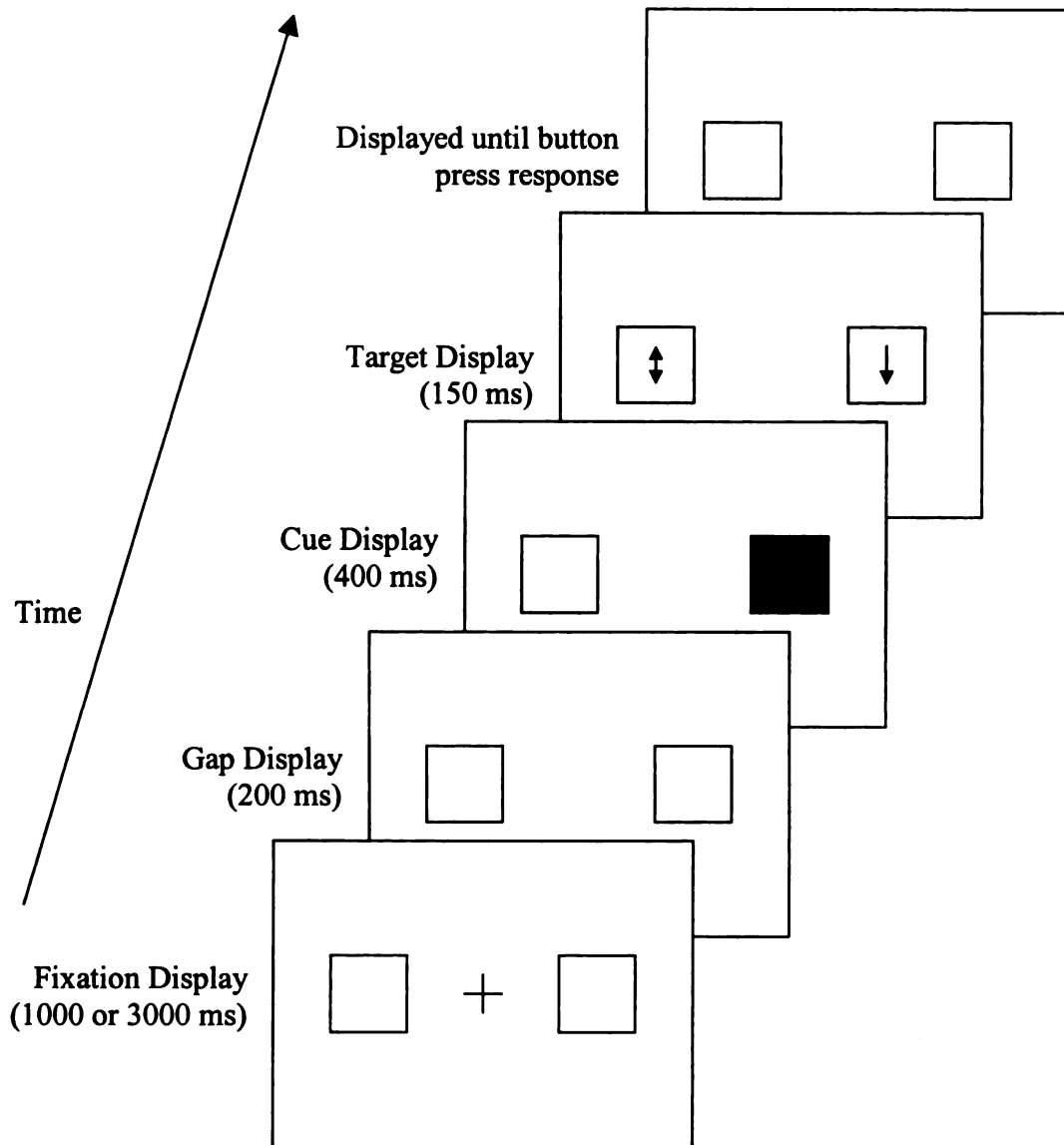


Figure 1. Illustration of a prosaccade trial. In the antisaccade condition, the double-headed arrow would have replaced the peripheral onset and the single-headed arrow would have appeared in the opposite box. In the actual displays stimuli were white presented on a black background.

Spatial Stroop Task. The procedures used in the spatial Stroop task were taken from De Jong et al. (1999). After completing the eye movement tasks and the vocabulary

test, participants were given a break. For the spatial Stroop task, the instructions, presented on the computer screen, told participants to press a button to indicate whether the word appeared above or below the row of plus signs. The instructions emphasized that responses should be made as quickly as possible while keeping errors to a minimum. Participants were asked to respond by pressing the “1” key on the number pad with their left index finger and the “3” key with their right index finger. The keys were labeled above with the words “ABOVE” and “BELOW”. The mapping of keys to labels was counterbalanced for each age group by RSI condition.

For each trial, a row of asterisks was presented in the center of the screen with the word ABOVE or BELOW above or below it. The word disappeared from the screen when the participant pressed a button. During the RSI nothing was presented on the screen. After 218 ms in the short RSI condition or 2028 ms in the long RSI condition the next stimulus was presented. Ten blocks of 100 trials each were presented with the first block serving as practice. If performance during the practice block was worse than a 90% accuracy rate, a message appeared on the screen reminding the participant to respond to the location of the word on the screen as quickly as possible while keeping errors to a minimum. Participants were given a break after each block and initiated the next block by pressing the space bar.

2.1.6 Data Analysis

The power to detect a moderate size main effect ($f = .25$, Cohen, 1977) with 32 participants in each cell was good according to Cohen’s suggested criteria, power = .79. The power to detect an interaction of age with RSI with 16 participants in each cell was rather low, power = .55.

Spatial Stroop task. For the spatial Stroop task the first block of trials was considered practice and was excluded from the analyses. In addition the first trial from each block was excluded because the participant had to press the space bar to begin the block and may not have been fully prepared to perform the task on the first trial. Also, trials with reaction time less than 100 ms were excluded as anticipations accounting for less than 0.1% of the data. Accuracy rates were calculated based on the remaining trials. Mean reaction times for each participant by item type were based on the reaction times for correct responses. Mean correct response reaction times and accuracy rates in the congruent and incongruent conditions were submitted to separate 2 age group (young or old) by 2 RSI (short or long) by 2 item type (congruent or incongruent) repeated measures ANOVAs with age group and RSI as the between subjects variables and item type as the within subjects variable.

Analyses were also run on mean reaction times based on two different sets of data. The first set of data was created by using the criteria stated above, with the additional restriction that trials following an error were excluded. The second method excluded both trials following an error and trials that were more than 3 standard deviations from the individuals mean reaction time for that item type. The results of analyses using the two latter methods were the same as those reported here.

Antisaccade task. For the eye movement data, the first step of the data analysis was to determine the position and duration of fixations. During data acquisition, eye movement position was sampled at 120 Hz allowing a new sample to be recorded every 8.33 ms. To reduce the size of the data files, a new sample (including the horizontal position, start time and end time of the sample) was recorded only if the position of the

eye changed more than $.4^{\circ}$ from the initial sampling position. The end time of a sample was the time at which the eye position changed more than $.4^{\circ}$ from the initial sampling position. Any samples of less than 15 ms were removed from the eye tracking record as representing saccades. Fixations were coded as the time between saccades and the position of the fixation was calculated by averaging the position of the samples during that continuous time period weighted for the duration of each sample. The initial saccade was the first change in fixation position that was greater than 1° from the previous fixation and that occurred following the presentation of the peripheral onset. The latency of the initial saccade was the time from the presentation of the peripheral onset until the end of the fixation prior to the initial saccade. The initial saccade was considered to have been made in the correct direction if it was toward the location of the peripheral onset in the prosaccade condition, or if it was toward the box opposite from the peripheral onset in the antisaccade condition. Trials were excluded from all analyses if the initial fixation was not within 4° of the center of the screen which could have occurred because of either poor calibration or an anticipatory eye movement. In addition, any trial that the experimenter had hand-coded as having poor calibration because of subject movements was also excluded. The accuracy of button press responses were calculated for trials not excluded from the eye movement analysis, but including trials on which a correct or incorrect eye movement response was made. Mean reaction times were calculated from the correct button press responses.

Four measures from the prosaccade and antisaccade conditions were submitted to repeated measures ANOVAs with age group and RSI as between subjects variables.

These measures were saccade direction accuracy, mean correct saccade latencies, button press accuracy, and mean correct button press reaction times.

2.2 Results

2.2.1 Spatial Stroop Task

Reaction Times. The mean reaction times for each age group and RSI condition are presented in Table 2 by item type. Responses to congruent trials were faster than responses to incongruent trials ($M_s = 533$ and 555 ms, respectively), $F(1, 68) = 54.2$, $MSE = 333.4$, $p < 0.001$, and young adults were faster than older adults ($M_s = 464$ and 623 ms, respectively), $F(1, 68) = 42.3$, $MSE = 21329$, $p < 0.001$. Consistent with the findings of De Jong et al. (1999), individuals were faster in the short RSI condition than in the long RSI condition ($M_s = 508$ and 580 ms, respectively), $F(1, 68) = 8.6$, $MSE = 21329$, $p < 0.01$, and the effect of RSI did interact with item type, $F(1, 68) = 14.2$, $MSE = 333.4$, $p < 0.001$. The effect of item type was reduced in the short RSI condition compared to the long RSI condition (differences of 11 and 38 ms, respectively). The interference effect in the short RSI condition is the same size as the difference found by De Jong et al. (1999) which they reported to be nonsignificant. In contrast, when the mean reaction times for only the short RSI conditions were submitted to an ANOVA in this experiment, the effect of item type was still significant, $F(1, 34) = 10.5$, $MSE = 205.5$, $p < 0.01$.

	Young		Old	
	Mean	Acc	Mean	Acc
Short RSI				
Congruent	431 (20)	96.5%	574 (22)	98.5%
Incongruent	443 (24)	96.1%	584 (25)	98.2%
Difference	12		10	
Long RSI				
Congruent	478 (24)	97.6%	647 (24)	99.0%
Incongruent	505 (29)	96.5%	688 (27)	98.1%
Difference	27		41	

Table 2. Mean reaction times (msec) for correct trials in Stroop task

Surprisingly, age did not interact with any variables, $F_s < 1.6$. Although the difference in reaction time between congruent and incongruent trials was slightly larger for the older adults than for the young adults (interference effects of 26 and 19 ms, respectively), the difference was not statistically significant, $F < 1$. Because the goal neglect hypothesis predicted that the age difference in the interference effect would be more pronounced in the long RSI condition than in the short RSI condition, mean reaction times in the long RSI condition were analyzed separately. Again the interaction of age group and item type was not significant, $F = 1.8$. Under conditions that presumably increased the likelihood of goal neglect (long RSI condition) older adults were not more adversely affected than young adults.

It is possible that the large amount of practice in this experiment eliminated an age difference in the interference effect. To evaluate this hypothesis, performance in the first block of experimental trials was analyzed separately. The results of the first block and whole experiment analyses were the same indicating that, even early in task performance, the interference effects were equivalent for older and young adults.

In the long RSI condition, the size of the interference effect was larger for the older adults than for the young adults, but not significantly so. If the slower responding of older adults in the congruent condition is taken into account, this difference may be eliminated. The logic for this suggestion is that this general slowing exhibited by older adults is the result of the slowing of each stage of information processing, and that stages of processing that take more time will be slowed to a greater extent. Thus, when comparing conditions that take different amounts of time to complete (like congruent and incongruent conditions) the condition that takes more processing time (incongruent) will be slowed to a greater extent resulting in a larger interference effect. The slower response times of older adults was controlled by considering the interference effect as a proportion of the speed of responding. This proportion was calculated by dividing each participant's interference effect by their congruent trial reaction time. Young adults were 5% slower on incongruent trials in the long RSI condition, older adults were 6% slower, $F < 1$, suggesting that older and younger adults were slowed to the same extent in the long RSI condition. Admittedly, if RSI had a moderate effect on age differences this experiment would have detected it only 55% of the time.

Accuracy Rates. In general accuracy rates were quite high, 97.3%. The results of the ANOVA were similar to the results from the reaction time analysis. Accuracy was higher in the congruent condition than in the incongruent condition, $F(1, 68) = 22.6$, $MSE = 0.000069$, $p < 0.001$, although the difference was less than 1% (98.0 vs. 97.3%, respectively). RSI did modulate this effect though, with the difference in accuracy rates between the congruent and incongruent conditions being greater for the long RSI condition than for the short RSI condition, 1.2% vs. 0.3%, respectively, $F(1, 68) = 6.6$,

MSE = 0.000069, $p < 0.02$. In addition, older adults were more accurate than young adults (98.4 and 96.5%, respectively), $F(1, 68) = 14.2$, MSE = 0.0008, $p < 0.001$, but age did not interact with any other variable, $F_s < 1$. The increased accuracy of older adults coupled with their slower reaction times compared to young adults suggests that the age difference in overall performance on the spatial Stroop task may be attributed to a speed/accuracy trade-off, at least in part.

2.2.2 Antisaccade Task

Trials were excluded from the eye movement analyses if the calibration was misaligned for that trial, if the participant was not looking at the center of the screen when the onset occurred, or if a saccade was not made within 1000 ms of the beginning of the trial.¹ These criteria excluded 6.3% of the young adults' data and 15.8% of the older adults' data, a statistically significant difference, $F(1, 61) = 14.0$, MSE = 0.02078, $p < 0.001$. In addition, a greater percentage prosaccade trials were excluded than antisaccade trials, probably because the prosaccade task was performed first and participants were more likely to move (misaligning the calibration) early in the experiment ($M_s = 12.0$ and 9.9 %, respectively), $F(1, 61) = 4.6$, MSE = 0.00326, $p = 0.036$. There was no difference in percent of trials excluded based on RSI and this variable did not interact with any other variables, $F_s < 1$.

Saccade Direction Accuracy Rates. Mean saccade direction accuracies are presented by age group, eye movement task, and RSI condition in Figure 2. Antisaccade responses were less accurate than prosaccade responses ($M_s = 80.9$ and 96.7%, respectively), $F(1, 61) = 106.4$, MSE = 0.00765, $p < 0.001$, and older adults were less

accurate than young adults ($M_s = 85.6$ and 92.0% , respectively), $F(1, 61) = 11.8$, $MSE = 0.01103$, $p = 0.001$. Age and eye movement task interacted to indicate that older adults had more difficulty producing correct antisaccades than young adults, $F(1, 61) = 19.0$, $MSE = 0.00765$, $p < 0.001$. Accuracy was better in the short RSI condition than in the long RSI condition ($M_s = 90.6$ and 87.0% , respectively), $F(1, 61) = 4.0$, $MSE = 0.01103$, $p = 0.05$, and this difference was larger in the antisaccade condition than in the prosaccade condition, $F(1, 61) = 6.7$, $MSE = 0.00765$, $p = 0.012$. Although RSI did have a larger effect on saccade direction accuracy in the antisaccade condition, it did not enter into any interactions with age, $F_s < 1.1$.

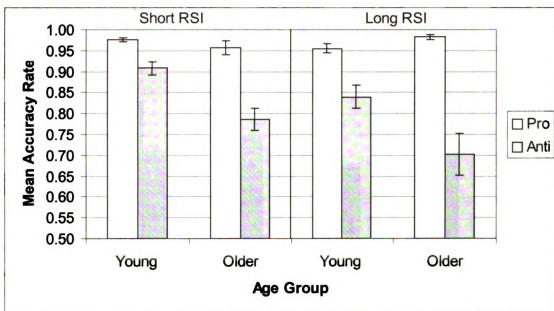


Figure 2. Mean saccade direction accuracy rate of the initial saccade in the antisaccade and prosaccade conditions by RSI, short or long, and age group, young or old. Error bars are equal to 1 standard error. Anti = Antisaccade; Pro = Prosaccade.

¹ Anticipation errors and misalignment errors were indicated by the same eye movement pattern (the eyes more than 4 degrees from fixation when the peripheral onset was presented). Therefore these types of errors will not be considered separately.

Correct Saccade Latencies. The mean latencies by age group, RSI, and eye movement task are presented in Figure 3. Antisaccades were initiated more slowly than prosaccades ($M_s = 345$ and 255 ms, respectively), $F(1, 61) = 289$, $MSE = 915$, $p < 0.001$, and older adults were slower than young adults ($M_s = 338$ and 261 ms, respectively), $F(1, 61) = 58.6$, $MSE = 3252$, $p < 0.001$. Age interacted with eye movement task as well, $F(1, 61) = 5.4$, $MSE = 915$, $p = 0.023$. Older adults' eye movements slowed down more from the prosaccade to the antisaccade conditions ($M_s = 287$ and 390 ms, respectively) than the eye movements of young adults ($M_s = 223$ and 301 ms, respectively) indicating that they had more difficulty than young adults producing antisaccades.

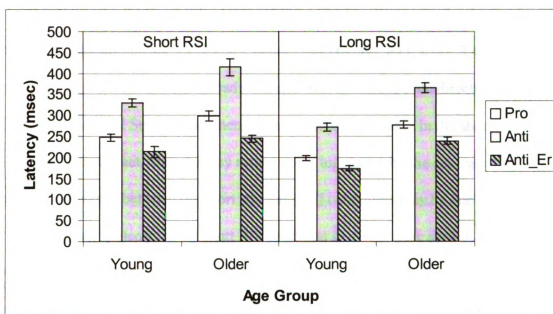


Figure 3. Mean latency of the initial eye movement in the correct direction from the antisaccade and prosaccade conditions and for incorrect eye movements in the antisaccade condition by RSI, short or long, and age group, young or old. The mean saccade latency of incorrect antisaccades for young adults in the short RSI condition excluded 2 young subjects that had fewer than 7 saccade direction errors on which to base a subject mean. Error bars are equal to 1 standard error. Anti = Antisaccade, Pro = Prosaccade, Anti_Er = Incorrect eye movements in the antisaccade condition.

A possible explanation of the larger difference between antisaccade and prosaccade latencies for the older adults is that it is the result of overall slower responses

by the older adults. To address this possibility, the difference between each individuals' antisaccade and prosaccade latencies was converted to a proportion by dividing the difference by the prosaccade latency. Indeed, when saccade latency differences were considered as a proportion of saccade latency, the age difference was eliminated, $F < 1$. Both young and older adults were 36% slower to initiate antisaccades than prosaccades.

Surprisingly, saccade latencies were slower in the short RSI condition than in the long RSI condition, $F(1, 61) = 19.3$, $MSE = 3252$, $p < 0.001$. As was found in the accuracy data, there was a marginally significant interaction of eye movement task and RSI indicating that the difference between the short and long RSI conditions was a bit larger in the antisaccade condition ($M_s = 372$ and 319 ms, respectively) than in the prosaccade condition ($M_s = 272$ and 238 ms, respectively), $F(1, 61) = 3.4$, $MSE = 915$, $p = 0.070$. The effect of RSI on saccade latencies was in the opposite direction of the effect found in the spatial Stroop task where reaction times were faster in the short than long RSI condition. In fact, these latency results taken together with the accuracy data suggest that the difference between the short and long RSI conditions may be due to a speed/accuracy tradeoff; in the short RSI condition saccades were slower, but more accurate, than saccades in the long RSI condition.

Reflexive saccades (correct prosaccades and incorrect antisaccades). Saccade direction errors in the antisaccade condition occurred when the participant looked toward the peripheral onset before looking at the opposite box. If these error saccades were instances when the reflexive response was made instead of a more controlled response, then error saccades should have been faster than antisaccades. In fact, the error saccade latencies should have been as fast as prosaccade latencies because prosaccades were also

saccades toward a peripheral onset. The mean saccade latencies for incorrect responses in the antisaccade condition were compared to the saccade latencies of prosaccades. As can be seen in Figure 3, incorrect antisaccades were faster than prosaccades, $F(1, 61) = 58.5$, $MSE = 782$, $p < 0.001$. The eye movement condition did not interact with any other variable.

Target Identification Responses. The mean accuracy rates and reaction times for target arrow identification responses are presented in Table 3. The identification accuracy rate analysis mirrored the saccade latency analysis. In conditions that resulted in slower eye movement latencies, target identification accuracy rates were lower. This is not surprising because if the eyes moved slowly the participant would have had less time to view the target stimulus, the arrow. Older adults did worse than young adults ($M_s = 87.1$ and 96.4% , respectively), $F(1, 61) = 17.8$, $MSE = 0.01554$, $p < 0.001$, and antisaccade performance was worse than prosaccade performance ($M_s = 89.1$ and 94.4% , respectively), $F(1, 61) = 21.2$, $MSE = 0.00421$, $p < 0.001$. In addition, older adults showed a greater decline in identification accuracy from the prosaccade to the antisaccade condition compared to young adults, $F(1, 61) = 4.9$, $MSE = 0.00421$, $p = 0.031$. A main effect of RSI indicated that in the short RSI condition (the slower eye movement condition) participants were more likely to incorrectly identify the direction of the arrow than in the long RSI condition ($M_s = 89.0$ and 94.5% , respectively), $F(1, 61) = 6.3$, $MSE = 0.0155$, $p = 0.015$. This variable did not interact with any other variable, however, $F_s < 1.8$.

	Accuracy		Reaction Time	
	Pro	Anti	Pro	Anti
Young Adults				
Short RSI	97.2%	93.0%	1061	1053
Long RSI	98.3%	97.0%	1033	1023
Older Adults				
Short RSI	87.3%	78.5%	1264	1311
Long RSI	94.7%	88.0%	1243	1252

Table 3. Experiment 1 Target Identification Responses

Mean button press reaction times were also examined to determine if they were affected by RSI. There was no effect of RSI and this variable did not interact with age or eye task, $F_s < 2.3$. Older adults responded more slowly than young adults ($M_s = 1268$ and 1042 ms, respectively), $F(1, 61) = 64.9$, $MSE = 25403$, $p < 0.001$. Age interacted with eye task as well indicating that although there was little difference in the button press reaction times of young adults between the prosaccade and antisaccade conditions, the older adults were slower to respond correctly in the antisaccade condition than in the prosaccade condition, $F(1, 61) = 8.0$, $MSE = 1401$, $p = 0.006$. When performing optimally young and older adults had their eyes at the location of the target arrow when it onset and their button press accuracy rates and reaction times were not affected by the previous eye movement task. Only on trials where the participant took longer to look at the target location, and perhaps did not view the target long enough for discrimination, were the button press reaction times and accuracy rates disrupted. This situation was more likely for older adults in the antisaccade condition.

To explore this suggestions two additional analysis were conducted. In the first, each subjects' mean antisaccade latency and mean button press reaction time were correlated. Because of differences between the age groups and RSI conditions in mean

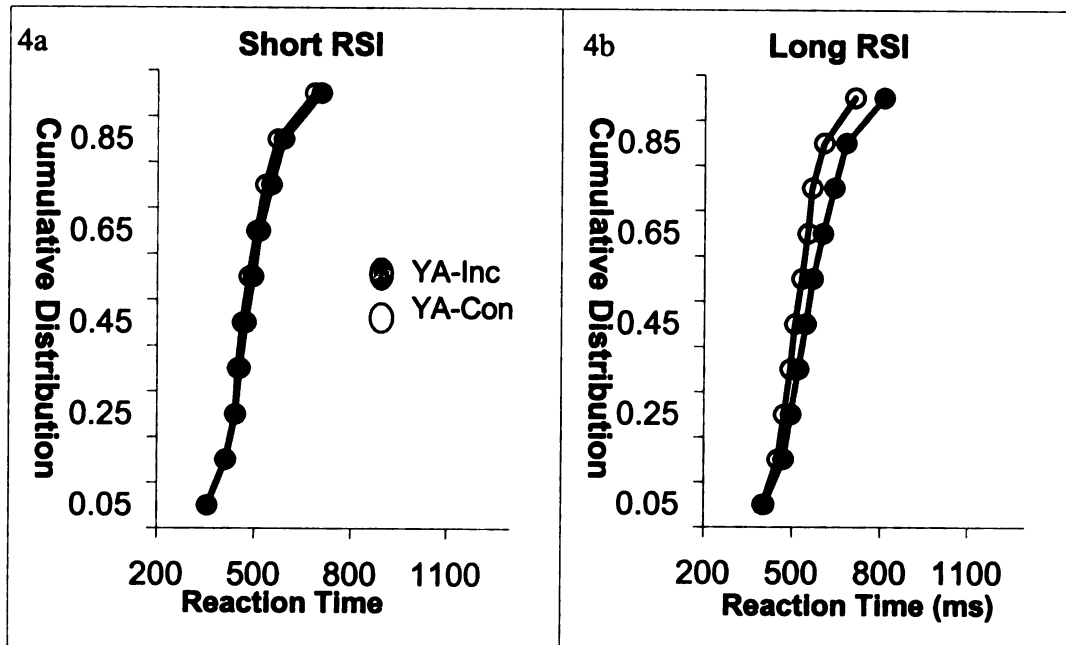
saccade latencies the correlations were calculated separately for each of the four groups. The correlations ranged from .43 to .66 confirming the suggestion that performance on the target identification task was related to how quickly an individual could move their eyes to look at the target. The second analysis was made of target identification accuracy when the initial eye movement was a saccade direction error because in these conditions participants should have been less likely to view the target and so target identification accuracy would be reduced compared to trials on which a correct eye movement had been made. Only the antisaccade conditions was examined because enough saccade direction errors did not occur in the prosaccade conditions to compute a reliable accuracy measure. Target identification accuracy was lower and target identification reaction times were slower following an initial saccade direction error than following a correct initial saccade supporting the idea that target identification was affected by the time needed by the participant to move their eyes to the correct location (Ms = 83.9% and 1178 ms for young adults in the short RSI condition, 91.7% and 1083 ms for young adults in the long RSI condition, 65.4% and 1463 ms for older adults in the short RSI condition, and 76.1% and 1455 ms for older adults in the long RSI condition).

2.2.3 Cumulative Response Distributions

In support of their view that Stroop interference results from a failure to maintain the current goal, De Jong et al. (1999) presented cumulative response distributions of reaction times by item type and RSI conditions. The cumulative response distribution is constructed by ordering each subject's reaction times in a particular condition and then dividing the ordered reaction times into reaction time bins containing equal proportions of responses (e.g., 10%). Then each subjects' average reaction time for each bin by item

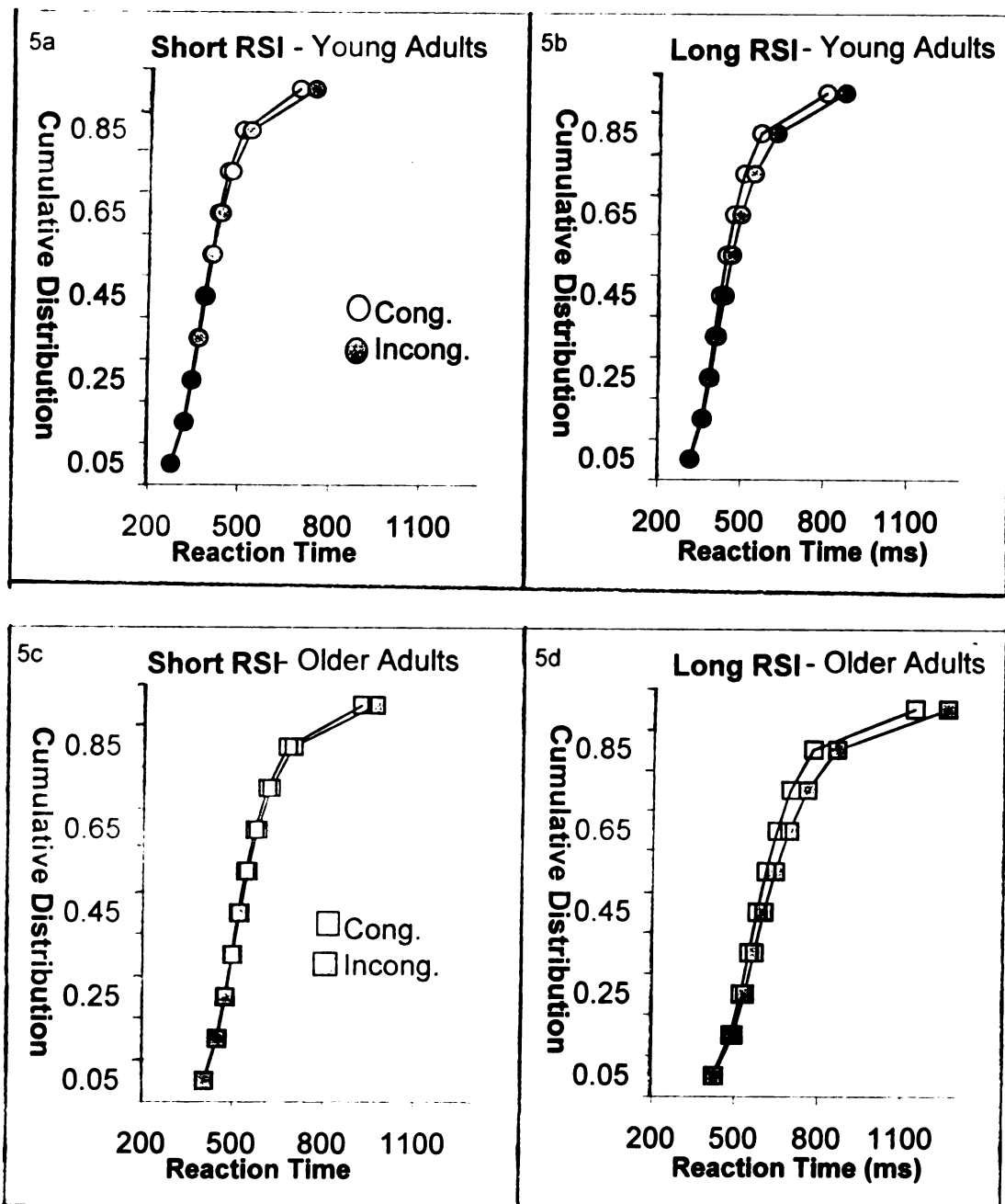
type is averaged and plotted. The plot illustrates where the differences between the item types is localized (or not) on the distribution. Figures 4a and 4b are an estimate of De Jong et al.'s (1999) data from young adults in the short and long RSI conditions, respectively. In the short RSI condition, across the entire distribution there is little difference between the congruent and incongruent conditions. However, in the long RSI condition the difference between congruent and incongruent reaction times becomes larger as reaction times become slower. De Jong and colleagues took this pattern as support for a goal neglect account of the interference effect. On trials with sufficient goal activation for immediate task schema selection (like those in the short RSI condition and the fast end of the long RSI condition distribution) reaction times were fast for both congruent and incongruent trials and an interference effect was not indicated. On trials with reduced goal activation (the slow end of the long RSI condition distribution), incongruent trials were slowed to a greater extent than congruent trials and a large interference effect was observed. Cumulative response distributions were calculated and graphed for both the spatial Stroop task and the eye movement tasks.

Spatial Stroop task. The cumulative response distributions from this experiment for the young and older adults are presented in Figures 5a-5d. The cumulative response distributions for the young adults are similar to those reported by De Jong et al. (1999). In the short RSI condition, the difference between the congruent and incongruent reaction times was small across the entire distribution whereas in the long RSI condition the difference between the two curves increased through the slower end of the distribution. Given that the interference effects for young and old in the long and short RSI conditions were not statistically different, it was not surprising that the cumulative response



Figures 4a and 4b. Estimates of the cumulative response distributions reported by De Jong et al. (1999) for young adults in short (Figure 4a) and long RSI (Figure 4b) conditions of a spatial Stroop task. Incog. = incongruent, Cong. = congruent.

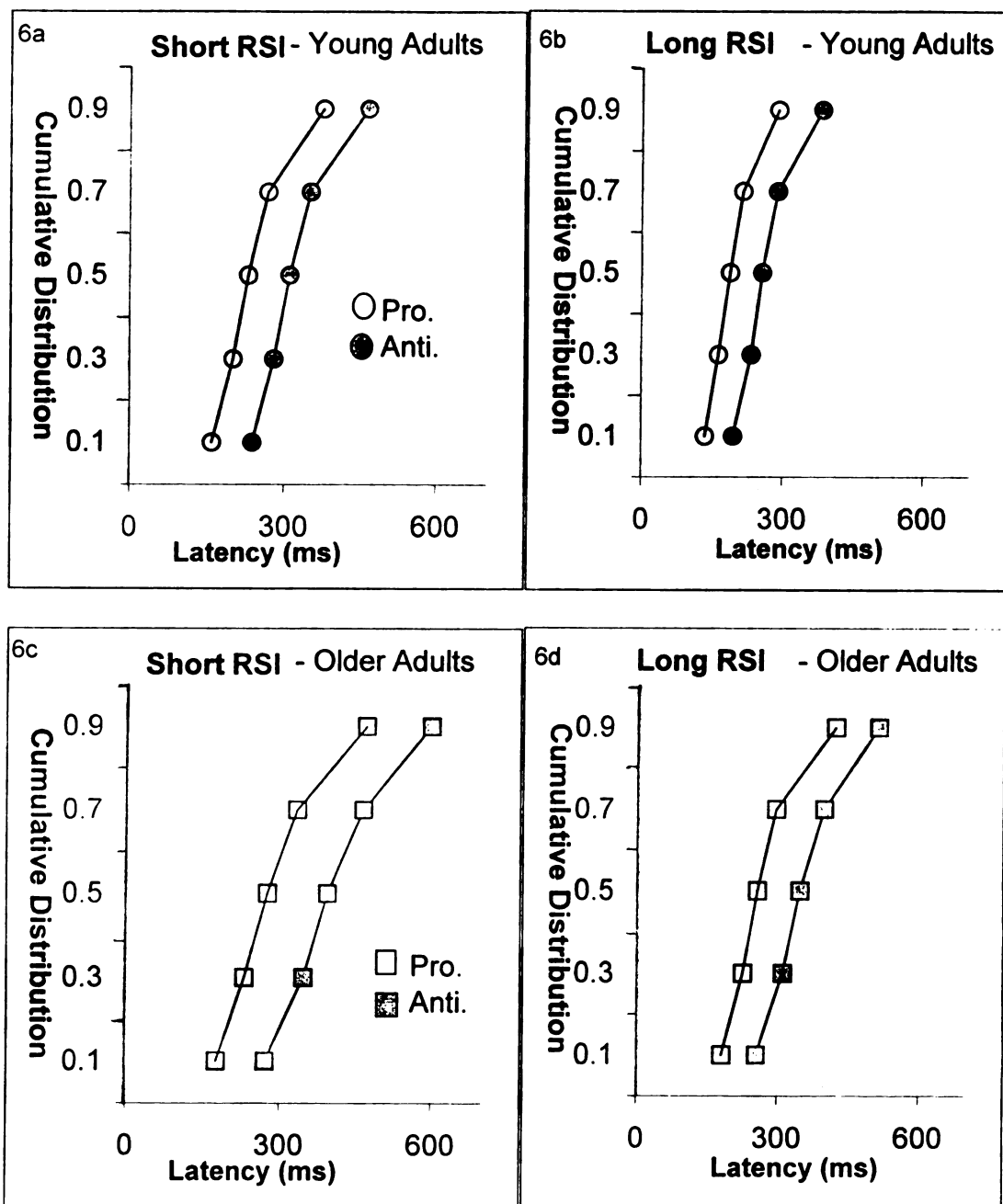
distributions for the older adults displayed the same pattern. These qualitative assessments were confirmed by a mixed ANOVA with item type and bin as within subjects variables and age group and RSI as between subjects variables. As De Jong et al. (1999) found, there was a significant bin by RSI by item type interaction, $F(9, 612) = 3.1$, $MSE = 821$, $p = 0.001$, that indicated that the difference between reaction times to congruent and incongruent stimuli was greater at the slow end of the distributions in the long RSI condition than at both the fast end of the long RSI distributions and for the all bins of the short RSI distributions. This finding suggested that the incorrect word reading response only interfered when responses were slow. When responses were fast, presumably because attention was tightly focused on the task of location naming, the interference effect was eliminated. In addition, bin interacted with age group, $F(9, 612) = 5.74$, $MSE = 821$, $p < 0.001$, indicating that the difference in mean reaction time between



Figures 5a-d. Cumulative response distributions for the spatial Stroop task in Experiment 1 for young adults in the short RSI (Figure 5a) and long RSI (Figure 5b) conditions and older adults in the short RSI (Figure 5c) and long RSI (Figure 5d) conditions. Incong. = incongruent, Cong. = congruent.

young and older adults performance was larger at the slow end of the distributions for both the short and the long RSI conditions, but age did not enter into any other interactions with bin, $F_s < 1.1$.

Antisaccade task. The cumulative response distributions for correct saccade latencies can be seen in Figures 6a-6d. These distributions divided the data into only 5 bins because fewer trials were completed in the eye movement tasks. In addition, the data from 3 young and 3 older adults in the long RSI condition and 2 older adults in the short RSI condition were excluded from this analysis because they had fewer than 50 correct prosaccades or antisaccades leaving less than 10 observations to go into each bin. The shapes of these curves are markedly different from those for the Stroop task. Not surprisingly, in both the short and the long RSI conditions there are large differences between antisaccade and prosaccade latencies reflecting the difference between generating a voluntary and a reflexive saccade. Unlike the Stroop data, however, these differences are larger in the short RSI condition than in the long RSI condition suggesting that the interference effect was larger in the short than in the long RSI condition, although this difference is difficult to interpret because of the speed/accuracy trade-off associated with the RSI manipulation. In addition, the curves in the long RSI condition appear to be parallel suggesting that the in this condition interference was as likely to occur when attention was tightly focused (fast end of the distribution) as when it was not (slow end of the distribution). In contrast, in the short RSI condition the antisaccade and prosaccade conditions diverge at the slow end of the distribution as they did in the long RSI condition of the spatial Stroop task suggesting, if anything, that goal neglect was occurring in the short RSI condition of the antisaccade task. These observations were confirmed by the mixed ANOVA. Bin interacted with RSI, $F(4, 212) = 4.8$, $MSE = 497$, $p = 0.001$, and bin interacted with eye movement task, $F(4, 212) = 3.6$, $MSE = 497$, $p = 0.007$. Bin also interacted with age group, $F(4, 212) = 17.8$, $MSE = 497$, $p < 0.001$, to



Figures 6a-d. Cumulative response distributions for the antisaccade task in Experiment 1 for young adults in the short RSI (Figure 6a) and long RSI (Figure 6b) conditions and older adults in the short RSI (Figure 6c) and long RSI (Figure 6d) conditions. Anti = antisaccade, Pro = prosaccade.

indicate that older adults' distributions were more spread out than young adults'

distributions. Bin did not enter into any higher order interactions, $F_s < 1.3$.

2.2.4 Relationship between Measures of Interference

In this experiment young and older adults were compared on two interference tasks. Antisaccade error rates and the difference between antisaccade and prosaccade latencies are two measures of the interference between a prepotent and a voluntary response. In the Stroop task, the interference effect was the difference between generating a response when the meaning of the word indicates the alternate response compared to when the correct response and the word meaning indicate the same response. (Note: This interference measure contains a facilitation component as well, but it is assumed that the facilitation component of Stroop performance would be unaffected by this manipulation.) Are individuals who are more likely to have difficulty generating an antisaccade also more likely to have trouble responding to incongruent trials compared to congruent trials in the Stroop task?

To answer this question, two sets of correlations were done: one comparing the interference effect (incongruent trial reaction times – congruent trial reaction times) with antisaccade saccade direction accuracy rates and another set comparing them with the difference between correct antisaccade and prosaccade latencies. Because antisaccade accuracy rates varied by age group and RSI, correlating accuracy with Stroop interference across these groups may lead to significant correlations caused by group differences, rather than a true relationship between the two measures. To avoid this potential problem, the correlations were done separately for each age group by RSI. Only one of the correlations was significant at the $p < 0.05$ level with a one-tailed test, for the young adults in the long RSI condition, the Stroop interference effect was correlated with antisaccade accuracy rate, $r = -0.47$. On examination of the scatter plots, one outlier

seemed to be driving this correlation. With this person's data removed the correlation was eliminated, $r = 0.05$. The interference effect in the Stroop task was unrelated to performance in the antisaccade task suggesting that these two measures reflect different types of processing. In addition, this finding is consistent with the observation that older adults had more difficulty in the antisaccade task compared to young adults, but that the interference effect in the Stroop task was not affected by age.

2.3 Discussion

In this experiment the delay between the end of trial n and the beginning of trial $n+1$ was manipulated between subjects in an antisaccade and a spatial Stroop task. It was expected that in both tasks goal neglect would be more apparent in the long RSI condition than in the short RSI condition. In addition, if older adults are more susceptible to goal neglect than young adults, there should be a larger age difference in performance under conditions that increase goal neglect, i.e., in the long RSI conditions.

The RSI manipulation had the predicted effect in the spatial Stroop task, but not in the antisaccade task. Replicating the findings of De Jong et al. (1999) in the spatial Stroop task, a larger interference effect was found in the long compared to the short RSI condition. In the antisaccade task, although error rates were higher in the long than in the short RSI condition, this effect was tempered by a speed/accuracy trade-off. Unlike the spatial Stroop task, saccade latencies were faster in the long RSI condition than in the short RSI condition making it difficult to determine whether the increase in error rates in the long RSI condition was due to an increased likelihood of forgetting the current task goal or, alternately, to a lower threshold for initiating a response that led to faster reaction times and an increase in error rates.

Were age differences in performance modulated by the RSI manipulation, as a goal neglect account of interference effects would suggest? In the Stroop task, where the RSI manipulation had the intended effect, there was not a significant difference between the interference effects of older and young adults when difference scores were analyzed and when those scores were considered as a proportion of congruent reaction times. Counter to the prediction, older adults were not slowed to a greater extent when the likelihood of goal neglect was higher in the long RSI condition.

In the eye movement task, older adults made more saccade direction errors in the antisaccade condition than young adults for both the short and long RSI conditions. This finding confirms previous research indicating that older adults have more difficulty correctly performing antisaccades than young adults (Butler et al., 1999, Olincy et al., 1998, Nieuwenhuis et al., 2000). In addition, the difference between antisaccade and prosaccade latencies was greater for older adults than young adults, but not when that difference was considered as a proportion of prosaccade latency implying that a larger antisaccade-prosaccade interference effect for older adults may be due to general slowing rather than an inhibitory deficit or goal neglect.

Although the proportion analysis did not indicate an age difference in the antisaccade-prosaccade interference effect when age-related slowing was controlled, the larger difference between latencies represents a failure to replicate the saccade latency findings from Butler et al. (1999) that indicated the size of the antisaccade-prosaccade interference effect was the same for young and older adults. This discrepancy may be due to a difference between the two studies in target presentation. Nieuwenhuis et al. (2000) found that older adults will use target presentation as a means of visually triggering their

correct antisaccades when that information indicates the correct response, but when the target location is not the only visual change occurring (i.e., the changes on the screen can not trigger the correct antisaccade) older adults' antisaccade-prosaccade interference is greater than that of young adults. Butler et al. (1999) used conditions that allowed older adults to rely on visual triggers to generate antisaccades, but this experiment did not. Because older adults could not rely on target presentation to visually trigger their antisaccades they had to program the correct antisaccade voluntarily and this slower process was affected to a greater extent by the slower responding of older adults.

Neither of these age differences in performance was moderated by the RSI. Older and younger adults were affected in the same way by the RSI manipulation, responding more quickly and less accurately in the long RSI compared to the short RSI condition.

In neither the spatial Stroop nor in the antisaccade task did older adults show more interference in performance as a result of a long compared to a short RSI. This finding suggests that goal neglect may not account for older adults' impaired performance on interference tasks. However, this conclusion hinges on the assumption that maintaining a goal across a long interval is more difficult than maintaining a goal across a short interval. This issue is considered below.

It is puzzling that the RSI manipulation had different effects in the spatial Stroop and eye movement tasks. In the spatial Stroop task both young and older adults had more difficulty responding under interference conditions in the long RSI condition than in the short RSI condition, but for the eye movement task the manipulation of RSI did not lead to a pattern of data that suggested goal neglect in either young or older adults.

One potential explanation is that the task structures of the spatial Stroop and antisaccade tasks differ in an important way. This idea is supported by the lack of correlation between antisaccade error rates and Stroop interference. In the spatial Stroop task, optimal performance depends on the ability to ignore the meaning of the word and prevent the response associated with the word meaning from interfering with performance. The meaning of the word is irrelevant to the correct response. The situation is different in the antisaccade task. Although participants are told not to look at the peripheral onset, they must code the location of that onset in order to know the correct direction to move their eyes. The location of the peripheral onset must be explicitly attended on every trial for the correct response to be programmed. Attending to the location that is in the direction of the incorrect response, may prime the incorrect task schema leading to a need for a controlled inhibitory mechanism to be instantiated for the correct response to be generated. In essence, attending to a location is presumed to be equivalent to activating the task schema to respond to that location. The premotor theory of attention posits that, indeed, the processes associated with attentional shifts are the same as the processes required for the programming of a response to a particular location (Rizzolatti, Riggio, & Sheliga, 1994; Craighero, Fadiga, Rizzolatti, & Umiltà, 1999).

According to the description above, interference can arise from two points in processing. If the incorrect task schema is accessed because it overlaps with the correct task schema the incorrect task schema must be inhibited in a controlled manner. If the early stages of the incorrect and correct task schemas do not overlap, as in the spatial Stroop task, controlled inhibition of the incorrect task schema is not required. Automatic processing of the identity of the word was unnecessary for the determination of the

location of the word and thus in early stages of stimulus processing there was no overlap between the two task schemas associated with the stimuli. Therefore, in the spatial Stroop task a controlled attentional mechanism is not required. Interference occurs when the current task goal is not active enough to allow the task to be executed and more interference occurs when the task goal is harder to maintain, e.g., across a long RSI.

Another potential explanation for the difference in the effect of the RSI manipulation on performance in the Stroop and antisaccade tasks comes from studies of foreperiod effects. Although the RSI manipulation was used as a means of varying the likelihood of goal neglect it could also be seen as a manipulation of the time provided to prepare for the stimulus to occur, the preparation interval or foreperiod. In foreperiod studies, a warning signal is presented sometime before the imperative stimulus and serves to alert the participant to the impending presentation of the stimulus. Because the warning signal does not provide any information that is necessary for performing the task, systematic variation in reaction times following changes in the length of the foreperiod are said to result from nonspecific preparation occurring during the interval. In studies that vary foreperiod across blocks, short preparation intervals result in faster reaction times to the imperative stimulus than longer preparation intervals (Niemi & Näätänen, 1981).

An RSI manipulation can be seen as a variation of the preparation interval if the response on the previous trial (or the onset of the delay screen) is considered to be the warning signal for the presentation of the stimulus on the current trial. This mapping makes the prediction that when the RSI (or preparation interval) is short, reaction times will be faster compared to when the RSI is long. In this spatial Stroop task and in that of

De Jong et al. (1999), the RSI and foreperiod could be viewed as the same interval and, in fact, the difference in reaction times between the RSI conditions is consistent with the foreperiod literature.

In the eye movement tasks, however, the foreperiod and RSI were not confounded though. In both the short and the long RSI conditions a second warning stimulus was presented before the onset occurred. This warning stimulus was the offset of the fixation point 200 ms before the peripheral onset, a time interval that is about 75 ms longer than the interval that leads to optimal levels of preparation in choice reaction time tasks (Bertelson, 1967). In this task, RSI and foreperiod are dissociated by the presentation of the second warning stimulus, thus the failure to find the predicted effect of RSI may be due to an unconfounding of foreperiod and RSI.

The distinction between foreperiod and RSI may not be an important one for a theory of goal neglect. Both the historically more accepted view, that foreperiod effects are the result of expectancy and time uncertainty (Niemi & Näätänen, 1981), and the more recent argument, that foreperiod effects are controlled by the parameters of trace conditioning (Los & Van Den Heuvel, 2001), could accommodate goal activation as part of the nonspecific preparation associated with foreperiod processing. If manipulating the RSI is equivalent to manipulating the foreperiod, with goal activation being part of the nonspecific preparation processes, then in the eye movement task the warning signal 200 ms before the trial began may have acted to reactivate the task goal eliminating any differences between the RSI conditions in goal activation. If this is indeed the case, it also suggests that reactivation is not more difficult for older adults. The relationship between goal neglect and foreperiod effects remains to be worked out.

In Experiment 2, a different method was used to manipulate goal neglect in the antisaccade task. It was expected that the activation of the current goal would be compromised by requiring participants to switch often between the prepotent and controlled tasks. In addition, the difficulty of suppressing the reflexive response was manipulated by using two different types of direction cues, a peripheral onset and a centrally presented arrow cue.

3 Experiment 2

In Experiment 1, the likelihood of goal neglect was manipulated by varying the RSI. The impact of this manipulation on performance in the antisaccade task was unexpected and did not support the prediction that goal neglect would be more frequent following a long RSI than following a short RSI. In this experiment, a different method, task switching, was employed to observe the effects of reduced goal activation on young and older adults' performance on the antisaccade task. In addition, the influence of the inhibitory mechanism on task performance was examined by using different cues; in the antisaccade condition one required more inhibition than the other.

3.1 Task switching

Task switching is a condition in which participants must switch between different tasks within a single block of trials. These task switches may be cued by an instruction proceeding the stimulus, by the type of stimulus itself, or by the sequence of trials (e.g., switch after every second trial). Jersild (1927) was the first to report that performance of a task within a mixed task block was worse than performance of the same task in single task block. This effect has been referred to as mixing cost (e.g., Meiran, Gotler, & Perlman, 2001), alternation cost (e.g., Pashler, 2000), or general switch cost (e.g., Kray & Lindenberger, 2000). One processing difference between single and mixed task blocks is the need to activate and switch between different task goals across the mixed task blocks compared to maintaining only one task goal in the single task blocks. Because maintenance of task goals requires effort, when there are more goals to be maintained the likelihood that the current goal will not be active enough to access the correct task set is increased; the current goal is more likely to be temporarily neglected.

Mixing tasks should make more difficult to maintain the current task goal because more task goals must be maintained at least at a minimal level of activation across the experiment. Not only is performance slowed in mixed block conditions, but it is slowed to a greater extent when there is a switch from one task to another. Switch costs are the difference between performance on trials where the task was changed from the previous trial, switch trials, to performance on trials where the same task was performed on the previous trial, nonswitch trials. Typically, performance is slower and more error prone on switch trials than on nonswitch trials, particularly when short task cue-to-response stimulus intervals are used. One explanation of switch costs is that they represent the time needed to reconfigure the task set for the new task to be performed on the switch trial; on the nonswitch trial task set reconfiguration does not need to be performed (Rogers & Monsell, 1995). Switch costs are reduced when more time is given to prepare for the upcoming task switch but significant switch costs (called residual switch costs) are usually still obtained (e.g., Sudevan & Taylor, 1987). Rogers and Monsell (1995) found that switch costs were reduced as the preparation interval was increased from 150 to 600 ms, but residual switch costs were not reduced when the interval was further increased from 600 to 1200 ms.

One explanation of residual switch costs is derived from the goal neglect hypothesis (De Jong et al., 1999, De Jong, 2000). According to this account, when the activation of the goal to prepare for the upcoming task is high enough, individuals use the preparation interval to reconfigure the task-set, but on the remaining trials, when the preparation goal is not active enough, they fail to engage in advance preparation. This results in fast responses on some trials for which preparation was engaged, but slower

responses on the remaining trials when the task-set reconfiguration has to occur after the response stimulus is presented. It is the combination of these two types of performance that leads to residual switch costs.

In task switching experiments, the increased difficulty of responding in mixed task blocks compared to single task blocks is larger for older adults than young adults (e.g., Kray & Lindenberger, 2000; Mayr, 2001). Mixing costs are greater in older adults than in younger adults. Factors found to increase the magnitude of the age difference in mixing costs include overlap of the response sets for the different tasks and the presence of stimuli that are ambiguous as to the task that should be performed (Mayr, 2001).

Although mixing costs show substantial age differences, the age-related difference in switch costs tend to be much smaller (e.g., Kray & Lindenberger, 2000; Mayr, 2001; for a brief review see Meiran et al., 2001), and may even disappear under moderate levels of practice (Kramer, Hahn, & Gopher, 1999). Even when no age differences in switch costs are observed, large mixing costs are still present (Kray & Lindenberger, 2000). Taken together, these findings suggest that with long task instruction to response stimulus intervals older adults seem able to prepare for the current trial as well as young adults (Kramer et al., 1999; Kray & Lindenberger, 2000; Meiran et al., 2001).

3.2 Inhibitory Difficulty

In addition to the task switching manipulation, this experiment also varied the difficulty of the inhibitory task by varying the type of cue used to indicate the correct looking direction. In the standard antisaccade condition, the inhibitory demands are great because a peripheral onset indicates to the participant the direction not to look. As was described in the introduction, peripheral onsets automatically attract attention and an eye

movement is programmed to that location (Abrams & Jonides, 1988). Thus, in order to perform the correct task, looking in the opposite direction, the incorrect eye movement program must be suppressed.

To reduce the inhibitory demand associated with making a saccade in the opposite direction of a cue, a different type of direction cue, a centrally presented arrow, was used. Inhibiting responses to peripheral onsets in an antisaccade condition should be more difficult for peripheral changes than for centrally presented direction cues. Evidence that it is easier to suppress saccades to peripheral onsets than saccades programmed from central arrow cues comes from a stop-signal paradigm. In this paradigm participants respond to a stimulus, but are told that on some trials a signal will occur after the stimulus and if it does they should try to withhold their response. The onset time of the signal following the stimulus is varied. In order for saccade initiation to be stopped, the presentation of a signal to abort the saccade must be presented sooner after programming has begun for saccades to peripheral onsets than saccades in the direction indicated by a central arrow (Logan & Irwin, 2000). It is more difficult to withhold a response programmed from a peripheral onset than from a central arrow.

The instructions were the same for the peripheral and central cue conditions ensuring that the goal structure of each condition was the same. In the prosaccade condition, participants were instructed to look toward the peripheral onset or the box the arrow was pointing at; in the antisaccade condition, the instructions were to look in the opposite direction from that indicated by the direction cue. In the antisaccade condition, centrally presented cues (unlike peripheral cues) should not elicit an automatic eye movement program, reducing the inhibitory demands by eliminating the need to suppress

an incorrect eye movement program. Because the goal structure of the task with central or peripheral cues is the same, any differences between the cue conditions in antisaccade accuracy rates or the difference between correct antisaccade and prosaccade latencies can be attributed to differences in inhibitory demand.

3.3 Predictions

In this experiment, participants performed the standard single task blocks of antisaccade and prosaccade trials and then performed blocks of trials in which they switched between the two types of eye movement responses. The mixed task condition used a trial-by-trial task cuing procedure with a long task cue-to-response stimulus interval of 2800 ms. The long preparation interval was used to ensure that young and older adults were equally prepared to perform the upcoming task. The trial-by-trial cuing procedure has produced substantial age differences in mixing costs while minimizing the working memory demands of keeping track of how many trials of a particular task had already been performed (Mayr, 2001). Participants either performed these tasks with central arrow cues or peripheral onset cues.

Goal neglect was measured in two ways: (1) by comparing single and mixed task block performance and (2) by comparing switch and nonswitch trial performance in the mixed task condition. If failure to maintain the current goal at a high level of activation accounts for lower saccade direction accuracy rates and slower saccade latencies in an antisaccade condition, then correctly performing antisaccades should be more difficult in the antisaccade condition when participants switch between antisaccade and prosaccade trials, and when the switch conditions are compared to the single task condition in which only one goal needs to be maintained.

The functioning of the inhibitory mechanism was evaluated by comparing saccade direction accuracy rates in the antisaccade condition and the difference between antisaccade and prosaccade latencies in the peripheral and central arrow conditions. Under both cue conditions in the antisaccade condition, participants were instructed to look in the opposite direction of the direction specified by the cue, but when a central arrow cue was used, inhibition of a competing response was not as difficult. Increased difficulty performing antisaccades in the peripheral cue condition compared to the central cue conditions will indicate the functioning of the inhibitory mechanism. Saccade direction errors in the antisaccade condition with central cues would indicate a role of goal neglect in this task.

Because the goal structures of prosaccade and antisaccade tasks were the same for the central and the peripheral cue conditions, the increase in the likelihood of goal neglect from the single to the mixed task blocks should be equivalent for the two conditions. That is, if goal neglect accounts for difficulty in the antisaccade condition and the goal structure of the central and peripheral cue conditions are the same, it is expected that the lower saccade direction accuracy rates and slowed antisaccade latencies will be equivalent for the both cue conditions.

As has been found previously with peripheral cues, it was predicted that older adults would make more saccade direction errors in the single task antisaccade condition and that the difference between their prosaccade and antisaccade latencies would be larger than found for young adults. If these measures reflect the difficulty of the inhibitory task, the effects should be smaller with central arrow cues than with peripheral onsets. If these measures reflect susceptibility to goal neglect than the effects should be

larger in the mixed task condition compared to the single task condition. Performing correct antisaccades should be more difficult in the mixed task blocks than in the single task block for both age groups.

If age differences in performance on the antisaccade task are due to goal neglect, older adults should make more saccade direction errors in the antisaccade condition and be slowed more in producing correct antisaccade in both the central and peripheral onset conditions than young adults. In addition, residual switch costs in both of these measures should be greater for older adults than for young adults. If an inhibitory deficit is the source of the difficulty experienced by older adults in an antisaccade task with peripheral onsets, that deficit should not be apparent when the inhibitory demands of the task are limited, i.e., when central arrow cues signal the correct direction to look. It is possible that both an increased susceptibility to goal neglect and a decline in inhibitory functioning will contribute to age-related impairments on this antisaccade task.

3.4 Method

3.4.1 Participants

Thirty-three young adults (Age range = 18 - 23 years) were recruited from undergraduate psychology courses. Eight were paid \$7/hour for their participation and the remaining twenty-five were given partial course credit. One young subject in the central cue condition was excluded because his eye movements could not be reliably tracked.

Forty-four community-dwelling older adults (Age range = 61 – 85 years old) were recruited from the Lansing, MI area and paid \$10/hour for their participation. The data from two older adults were excluded from the eye movement analyses because they were not performing the task correctly. In addition, eye movement data were not obtained from

five older adults who could not be reliably tracked because of droopy eyelids and/or excessive movements during task performance. Young and older adults reporting learning disabilities, psychoactive medications, or a history of brain trauma (including stroke) were excluded from the sample. All participants were able to discriminate letters that subtended .6° degrees of visual angle. Mean ages, vocabulary test scores, and education levels of the participants in each group are presented in Table 4. The education levels of the four groups did not differ by age group, $F=2.87$, or by cue condition, $F < 1$. Older adults had higher vocabulary scores than young adults, $F(1, 60) = 42.0$, $MSE = 14.8$, $p < 0.001$, but vocabulary scores did not differ based on cue, $F=2.93$. Within each age group, age did not vary based on cue condition, $F < 1$ and $F = 3.0$, for young and older age groups, respectively.

	Young	Old
Peripheral Cue		
Age (years)	20.9	71.9
Education (years)	14.8	15.6
Vocabulary (mean score)	27.8	34.7
n	16	16
Central Cue		
Age (years)	21.1	74.9
Education (years)	15.1	15.9
Vocabulary (mean score)	30.1	35.7
n	16	16

Table 4. Experiment 2 Participant Characteristics

3.4.2 Design

This experiment had a two age group (young or old) by two eye movement task (prosaccade or antisaccade) by two cue type (central or peripheral) by two block type (single or mixed task) design with age group and cue type as between subjects variables and eye movement task and block type as within subjects variables.

3.4.3 Apparatus & Stimuli

The apparatus was the same as that described for Experiment 1. The size and locations of the peripheral boxes and fixation cross were the same as was described in Experiment 1. The central arrow cue subtended the same visual angles as the fixation stimulus, 0.8° . The type of eye movement task was indicated by the word "TOWARD" in the prosaccade condition or "OPPOSITE" in the antisaccade condition presented in the center of the screen in 30 point Arial Unicode font. The horizontal visual angles subtended by the words "TOWARD" and "OPPOSITE" were 4.2° and 4.7° , respectively, and they both subtended $.7^{\circ}$ vertically. The arrow direction identification task used in Experiment 1 was changed in this experiment to minimize confusion between the target task and the eye movement response to the central arrows in the central cue condition. Instead of pushing a button to indicate whether the target arrow was pointing up or down, participants were asked to indicate the location of an opening in a circle, top or bottom, which was presented inside the box at the target location. The circle subtended 0.6° degrees of visual angle and the hole was 0.2° in size. A complete circle was displayed in the box at the nontarget location.

Trials in each experimental block were presented in five strings of eight trials each as described in Experiment 1. The single task blocks were performed before the mixed task blocks because recent reports have indicated that older adults take much longer to return to single task performance levels following task switching than young adults (Mayr & Liebscher, 2001; Meiran et al., 2001). In the single block condition, participants completed one block of 40 prosaccade trials followed by one block of 40 antisaccade trials. Each of the single task blocks had an equal number of trials from each

cue direction (left or right) by target (hole on top or bottom) combination. In the mixed block condition 4 blocks of 40 trials each were presented for a total of 160 trials, 80 prosaccade and 80 antisaccade with an equal number of trials coming from each cue direction by target combination.

The four mixed task blocks had different trial orders that were the same for each participant. As was described in Experiment 1 each block of 40 trials was performed as five strings of eight trials each. To limit the ability of participants to predict when a task switch would occur within a string of trials, task run lengths of one, two, and three trials in a row were used. Each string of eight trials contained one task run of one trial, two task runs of two trials, and one task run of three trials resulting in three task switches in each string. Two of the four trial orders were created by selecting ten strings of 8 trials that were unique combinations of 1, 2, and 3 trial task runs. Then half of the strings were assigned the prosaccade task as the first task to be performed and half were assigned the antisaccade task. Two strings beginning with the prosaccade task and three strings beginning with the antisaccade task were assigned to trial order 1 and the remaining five strings were assigned to trial order 2. Trial orders 3 and 4 were created by using the same orderings of trial runs but reversing the eye movement task that was performed first. Thus, there were an equal number of one, two, and three trial runs in each eye movement task and, across the 160 trials, ten strings began with the prosaccade condition and ten strings began with the antisaccade condition. The trial orders were presented in a Latin squares design and each trial order was performed as the first mixed task block for two participants in each age group by cue type condition.

The practice blocks for the single task blocks contained an equal number of trials from each cue direction by target combination presented in a random order. The practice blocks for the mixed blocks contained task runs of one, two, or three trials from each eye movement condition.

3.4.4 Materials

The acuity and vocabulary tests completed in Experiment 1 were also completed by the participants in this experiment.

3.4.5 Procedure

The general procedures through the single task blocks were the same as described in Experiment 1. Following the single task blocks participants completed the background questionnaire and read the instructions for the mixed blocks. Participants completed two practice blocks of mixed trials, a 12 trial block with opportunities to ask questions after each trial and a 24 trial block run in three strings of eight trials with three task switches in each string. Next, the participants completed four blocks of mixed trials with 40 trials in each block.

The timing of events for each trial in a string for the prosaccade, antisaccade, and mixed blocks is illustrated for the prosaccade condition with a central cue in Figure 7. The experimenter initiated each string by pressing a button. The fixation display was presented for 300 ms followed by the task instruction, the word “TOWARD” or “OPPOSITE” presented in the center of the screen for 800 ms. The task instruction was replaced by the fixation screen for an additional 1800 ms. The fixation cross was removed from the screen 200 ms before the direction cue was presented for a task instruction-to-stimulus interval of 2800 ms. For both cue conditions, the cue was

presented for 400 ms followed by the target display for 150 ms. The target and nontarget stimuli were extinguished and both of the peripheral boxes remained empty until the button press indicating the location of the opening in the circle was made. Following the button press, the fixation point flashed for 500 ms at 50 ms intervals to indicate to the participant to look back to the center of the screen to prepare for the next trial.

In the central cue condition, the direction cue was a single-headed arrow presented at fixation. In the peripheral cue condition, the direction cue was a change of the interior of one of the boxes from black to white. In addition, a double-headed arrow was presented at fixation simultaneous with the presentation of the peripheral cue. The double-headed arrow was presented in this condition to equate the peripheral cue condition with the central cue condition on the need to disengage the oculomotor system from fixation before the eye movement response can be initiated. Participants were told to perform the task specified by the task instruction and that in the single task blocks the task would always be the same, but in the mixed tasks blocks the task would change from trial-to-trial. When the task instruction was “TOWARD”, participants were told to look toward the box the arrow was pointing at in the central cue condition or to look toward the box that changed in the peripheral cue condition. When the task instruction was “OPPOSITE”, participants were told to look at the box opposite from the one the arrow pointed at in the central cue condition or to look at the box opposite from the change in the peripheral cue condition. For both eye movement task conditions participants were to indicate the location of the hole or gap in the circle by pressing the button on the top or bottom. The experiment took approximately 1.5 hours for young and older adults to complete.

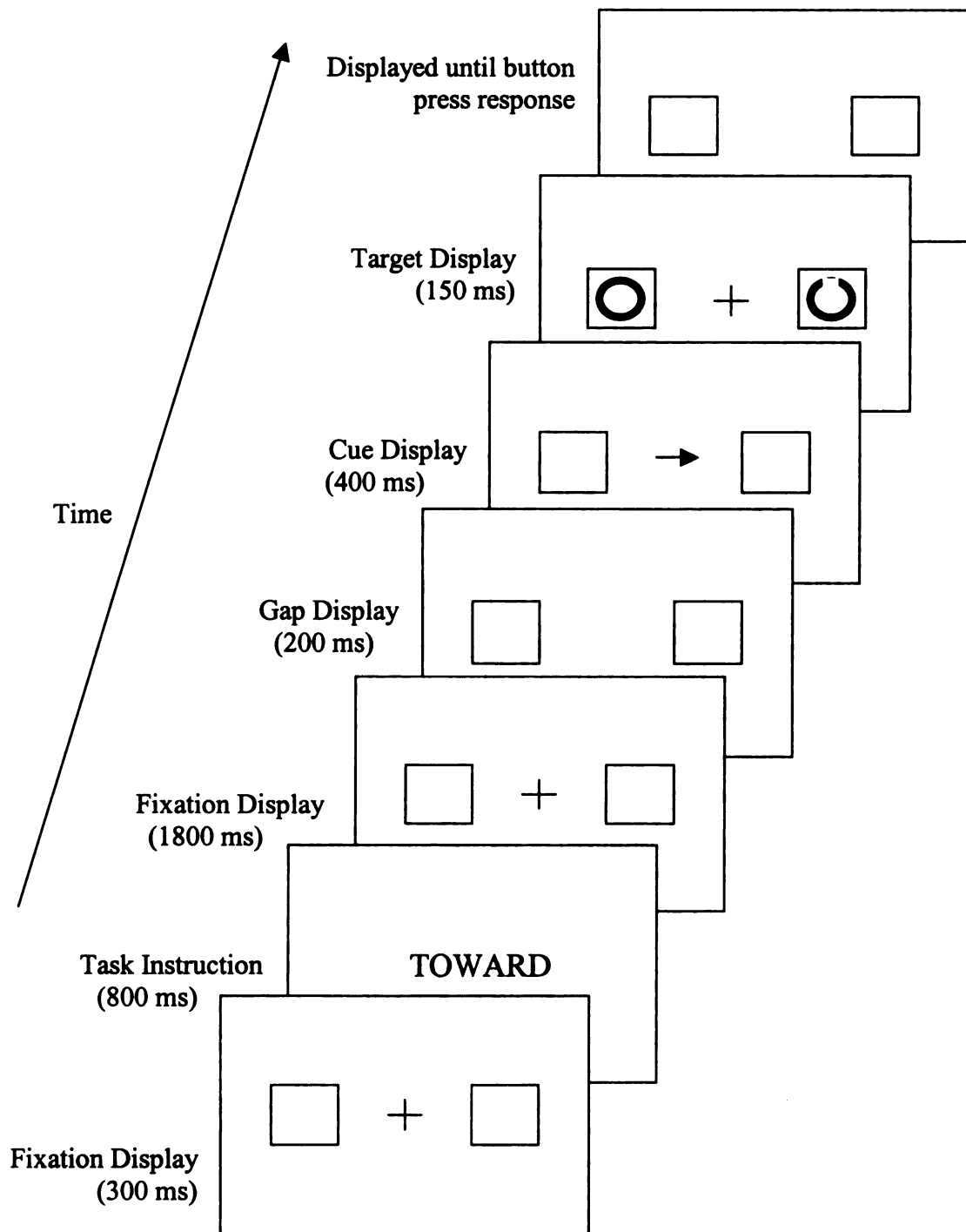


Figure 7. Illustration of a prosaccade trial for the central cue condition of Experiment 2. In the antisaccade condition, the task instruction was "OPPOSITE" and the target appeared in the box opposite from the cue. In the peripheral cue condition, a double-headed arrow was presented at fixation when the peripheral onset occurred. In the actual displays stimuli were white presented on a black background.

3.4.6 Data analysis

Saccade direction accuracy, saccade latencies, button press accuracy and button press reaction time measures were calculated in the same way as described for Experiment 1. Because of a ceiling effect in the saccade accuracy measure of young adults in the single task prosaccade condition in both cue conditions, but only for the central cue condition for older adults, the omnibus ANOVA was not performed on this measure. The analyses that were done are described below. Mean correct saccade latencies, button press accuracy rates, and mean button press reaction times for each block type and eye movement task were entered as repeated measures into a mixed ANOVA with age group and cue condition as between subjects variables. The power to detect a moderate size main effect ($f = .25$, Cohen, 1977) with 32 participants in each cell was good according to Cohen's suggestion, power = .79. The power to detect an interaction 16 participants in each cell was rather low, power = .55.

Switch costs. Because participants paused in performing the tasks at the end of each string of trials, each string was treated separately in determining when the task switched and did not. Within each string of 8 trials, trials were coded as nonswitch or switch trials based on whether the same or a different task had been performed on the previous trial. The first trial of each string was not included in either group. The mean latencies and mean saccade direction accuracy rates were calculated for each type of trial and submitted to a two age group (older or young) by two eye movement task (prosaccade or antisaccade) by two cue condition (central or peripheral) mixed ANOVA with age group and cue condition as between subjects variables and eye movement task as the within subjects variable.

3.5 Results

Trials were excluded from the eye movement analyses if the calibration was misaligned for that trial, if the participant was not looking at the center of the screen when the onset occurred, or if a saccade was not made within 1000 ms of the beginning of the trial. These criteria excluded 20.9% of the older adults' data and 6.0% of the young adults' data. More data were excluded for the older adults than for the young adults, $F(1, 60) = 35.8$, $MSE = 0.0393$, $p < 0.001$, and more data were excluded in the peripheral cue condition than in the central cue condition, $F(1, 60) = 9.1$, $MSE = 0.0393$, $p = 0.004$, (17.2 and 9.7 % respectively). The larger number of trials excluded in the peripheral cue condition was probably due to anticipatory eye movements related to directing attention peripherally to detect the presentation of the cue. In the central cue condition, attention was directed at fixation. There was no difference in percent of trials excluded based on the eye movement task or block type and these variables did not enter into any interactions, $F_s < 2.1$.

3.5.1 Saccade Direction Accuracy Rates

The saccade direction accuracy rates are presented in Figure 8 by cue condition, age group and block type. Because the performance of young adults, but not older adults, was at ceiling in the prosaccade single task blocks two separate analyses were performed on this measure. In the first analysis, antisaccade accuracy rates were submitted to an age group by block type by cue condition ANOVA to determine if older adults were less accurate than young adults and whether this age difference was larger for the peripheral cue condition compared to the central cue condition (indicating inhibitory difficulty) and/or if the age difference was more pronounced in the mixed blocks than in the single

task blocks (indicating goal neglect). Older adults did have more difficulty making correct antisaccades than young adults ($M_s = 67.9$ and 79.4% , respectively), $F(1, 60) = 9.1$, $MSE = 0.0456$, $p = 0.004$, and antisaccade accuracy was less accurate in the mixed task blocks than in the single task blocks ($M_s = 70.6$ and 76.7% , respectively), $F(1, 60) = 16.0$, $MSE = 0.0076$, $p < 0.001$. Surprisingly, the main effect of cue was not significant and age and cue type did not enter into any interactions, $F_s < 1.6$. Older adults had more difficulty than young adults looking in the opposite direction in response to both a peripheral onset and a centrally presented arrow cue, but this effect was not modulated by either the type of cue or the need to switch between tasks.

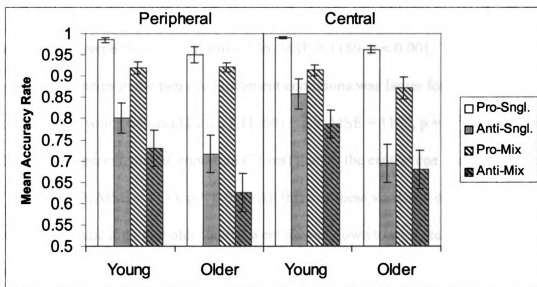


Figure 8. Mean saccade direction accuracy rate of the initial saccade in the antisaccade (gray bars) and prosaccade (white bars) conditions by block type, single task in solids or mixed tasks in stripes, age group, young or older, and cue type, peripheral or central. Error bars are equal to 1 standard error.

The second analysis compared performance in the prosaccade and antisaccade conditions, but only in the mixed task blocks because in these conditions no participants performed at ceiling. In the mixed blocks, older adults performed worse than young adults ($M_s = 77.5$ and 83.8% , respectively), $F(1, 60) = 6.9$, $MSE = 0.01893$, $p = 0.011$,

particularly in the antisaccade condition (difference of 11% accuracy compared to 2% in the prosaccade condition), $F(1, 60) = 4.1$, $MSE = 0.01387$, $p = 0.048$. In addition, the difference between antisaccade and prosaccade accuracy was greater in the peripheral cue condition (24%) than in the central cue condition (16%), $F(1, 60) = 4.0$, $MSE = 0.01387$, $p = 0.051$. Although performance with peripheral cues was more disrupted in the antisaccade condition this effect was of the same magnitude for young and older adults, $F < 1$. The saccade accuracy data do not support either an inhibitory deficit or a goal neglect account of aging.

3.5.2 Saccade Latencies

As can be seen in Figure 9, antisaccades were slower than prosaccades ($M_s = 365$ and 315 ms, respectively), $F(1, 60) = 136$, $MSE = 1159$, $p < 0.001$. The difference between latencies in the two eye movement conditions was larger for older adults (58 ms) compared to young adults (41 ms), $F(1, 60) = 3.9$, $MSE = 1159$, $p = 0.052$, and it was larger in the peripheral cue condition (71 ms) than in the central cue condition (28 ms), $F(1, 60) = 25.3$, $MSE = 1159$, $p < 0.001$. All three of these variables entered into an interaction indicating that older adults were slowed down to a greater extent in the antisaccade condition when they were responding based on a peripheral cue ($M_s = 340$ and 430 ms for older adults and $M_s = 260$ and 311 ms for the young adults, in the prosaccade and antisaccade conditions, respectively) compared to when they were responding based on a central cue, $F(1, 60) = 6.4$, $MSE = 1159$, $p = 0.014$, ($M_s = 373$ and 399 ms for older adults and $M_s = 289$ and 320 ms for young adults, respectively). This finding supports the view that older adults have more difficulty suppressing reflexive saccades than young adults.

To determine if the age difference in the size of the prosaccade and antisaccade latency difference was greater for older adults than young adults because of the overall slower responding of the older adults, the difference between the antisaccade and prosaccade latencies of each subject were converted to a proportion based on the subjects' mean prosaccade latency. Different proportions were computed for the single and mixed task conditions and submitted to a mixed ANOVA with block type as the repeated measure and age group and cue type as the between subjects variables. Unlike the results of the proportional analysis of Experiment 1, controlling for the slower responding of the older adults did not eliminate the interaction although it was reduced, $F(1, 60) = 3.17$, $MSE = 0.0256$, $p = 0.080$. The results of this analysis indicated that antisaccades in the peripheral onset condition were initiated 21.6% slower than prosaccades by young adults, but 28.2% slower by older adults.

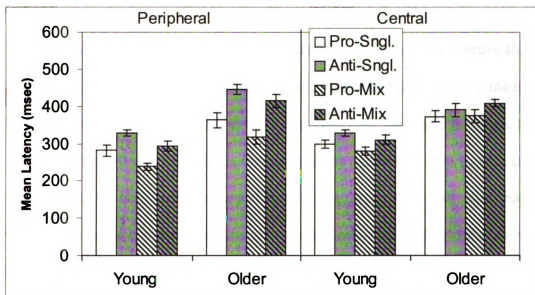


Figure 9. Mean latency of the initial eye movement in the correct direction from the antisaccade and prosaccade conditions by block type, single or mixed task, age group, young or older, and cue type, peripheral or central. Error bars are equal to 1 standard error. Anti = Antisaccade, Pro = Prosaccade, Sngl. = Single task, Mix = Mixed tasks.

The task switching manipulation had an unexpected result. Responses were faster in the mixed task blocks than in the single task blocks ($M_s = 329$ and 351 ms, respectively), $F(1, 60) = 15.1$, $MSE = 2003$, $p < 0.001$, and this difference was larger in the peripheral cue condition (39 ms) than in the central cue condition (4 ms), $F(1, 60) = 9.6$, $MSE = 2003$, $p = 0.003$. Age did not enter into any interactions with block type, $F_s < 1.7$. A possible reason that no mixing costs were obtained is that the single task blocks were performed before the mixed task blocks and extensive practice with the antisaccade and prosaccade tasks during the mixed task blocks improved performance to a level better than was observed in the single task conditions. Averaging across the poor performance in the first mixed task blocks and the improved performance in the latter two blocks may have resulted in mixed task mean saccade latencies that were slightly faster than single task latencies. However, a comparison of single task performance with performance in the first and last blocks of the mixed condition indicates that this is not the case. In the prosaccade condition, young adults' performance did improve slightly from the first to the last mixed task block ($M_s = 270$ and 255 ms), but even the means in the first mixed block were faster than the mean prosaccade latency in the single task condition ($M = 290$ ms). In addition, for young adults performing antisaccades and older adults performing both antisaccades and prosaccades there was no indication that performance improved across the four mixed task blocks (For young adults $M_s = 303$ and 300 ms on antisaccade trials and for older adults $M_s = 418$ and 416 ms on antisaccade and 343 and 344 on prosaccade trials in the first and fourth mixed task blocks). Increasing the demands on maintaining the current goal did not differentially affect older adults compared to young adults in the mixed task condition.

Much like the RSI manipulation, there is little evidence that having to switch between the two tasks had any net effect on task performance. In the mixed task blocks, saccade direction errors were more frequent, but that increase in error rate was accompanied by a decrease in saccade latencies, a speed/accuracy trade-off. Switching between the two eye movement tasks may not compromise the activation of the current goal.

3.5.3 Residual Switch Costs

In this analysis, the effect of trial type (switch or nonswitch) on saccade latency was marginally significant, $F(1, 60) = 3.0$, $MSE = 587$, $p = 0.088$, but indicated, surprisingly, a 5 ms advantage in saccade latency for switch compared to nonswitch trials ($M_s = 325$ and 330 ms, respectively). The trial type did not interact with any other variables, $F_s < 1.5$. When the saccade direction accuracy rates were considered, switch trial performance was less accurate than nonswitch trial performance ($M_s = 78.8$ and 82.5% , respectively), $F(1, 60) = 12.8$, $MSE = 0.0067$, $p = 0.001$. A marginal interaction of trial type with age suggested that the improvement in performance from switch to nonswitch trials was smaller for older adults than for young adults, $F(1, 60) = 3.7$, $MSE = 0.0067$, $p = 0.059$. The type of trial also affected saccade direction accuracy differently for the two eye movement conditions as well, $F(1, 60) = 6.8$, $MSE = 0.0042$, $p = 0.011$. Prosaccade performance improved 6% from switch to nonswitch trials, but antisaccade performance only improved 1%. Trial type did not enter into any other significant interactions, $F_s < 2.6$.

3.5.4 Reflexive saccades (correct prosaccades and incorrect antisaccades)

For the antisaccade condition saccade direction errors occurred when the participant looked toward the peripheral onset before looking at the opposite box. In the peripheral onset condition, these errors should be fast, reflexive saccade programs that were not inhibited, in the central arrow condition these errors should be slower intentional saccades. The mean saccade latencies for incorrect responses in the antisaccade condition were compared to the saccade latencies of prosaccades. As can be seen in Figure 10, incorrect antisaccades were faster than prosaccades, $F(1, 59) = 26.0$, $MSE = 1575$, $p < 0.001$, and this effect was larger for the peripheral cue condition than for the central cue conditions, $F(1, 59) = 9.1$, $MSE = 1575$, $p = 0.004$. Age also interacted with type of eye movement and cue condition, $F(1, 59) = 4.5$, $MSE = 1575$, $p = 0.038$, to indicate that for older adults the difference between looking direction error latencies and prosaccade latencies was much larger in the peripheral cue condition ($M_s = 280$ and 340 ms, respectively) than in the central cue conditions ($M_s = 365$ and 373 ms, respectively), but for young adults this difference was much smaller ($M_s = 238$ and 260 ms in the peripheral cue condition and $M_s = 275$ and 288 ms in the central cue condition). Block type did interact with cue condition, $F(1, 59) = 4.9$, $MSE = 1995$, $p = 0.031$, and also interacted with the type of eye movement, $F(1, 59) = 40.1$, $MSE = 1040$, $p < 0.001$, but did not enter into any interactions with age group.

Prosaccade latencies for both older and young adults in the peripheral cue conditions were slower than their antisaccade error responses. If the antisaccade error response latencies reflect the time needed to program a reflexive saccade, this finding suggests that older adults may have been using more controlled processing in the

prosaccade condition than young adults. For example, a larger proportion of young adults' prosaccades may have been reflexively programmed compared to older adults' prosaccades. If this is true it actually suggests that the difference between prosaccade and correct antisaccade latencies is underestimated to a larger degree for older adults than young adults.

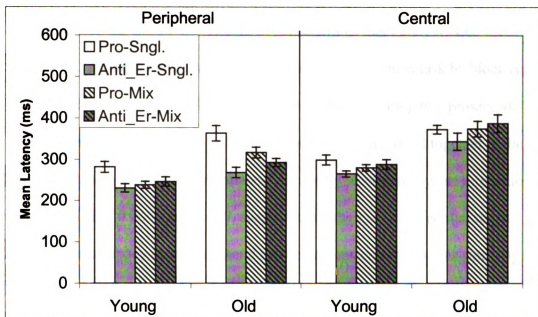


Figure 10. Mean latencies of the initial eye movement in the correct direction for the prosaccade condition and for incorrect eye movements in the antisaccade condition by cue, peripheral and central, block type, pure and mixed tasks, and age group, young and old. Error bars are equal to 1 standard error. Pro = Prosaccade, Anti_Er = Incorrect eye movements in the antisaccade condition, Sngl = Single task blocks, Mix = mixed task blocks.

3.5.5 Target Identification Responses

The mean target identification accuracy rates and reaction times are presented in Table 5. Young adults correctly identified the location of the gap in the circle 94.0% of the time, while older adults only identified it correctly on 82.2% of the trials, $F(1, 60) = 35.8$, $MSE = 0.025$, $p < 0.001$, and target identification was better in the prosaccade condition ($M = 90.7\%$) than in the antisaccade condition ($M = 85.5\%$), $F(1, 60) = 29.1$,

MSE = 0.0061, $p < 0.001$. The difference between identification accuracy in the prosaccade and antisaccade conditions was greater for older adults than young adults (differences of 8.8 and 1.9%, respectively, $F(1, 60) = 12.8$, MSE = 0.0061, $p = 0.001$. These findings are not surprising because there were differences in mean saccade latency between these conditions. In conditions where the eyes moved faster and more often in the correct direction, participants had more time to view the target and therefore were better at identifying it. There were also two interactions that barely missed the conventional significance α level of $p < 0.05$. An eye movement task by block type interaction, $F(1, 60) = 3.9$, MSE = 0.0026, $p = 0.054$, indicating that prosaccade performance was more disrupted when both tasks were performed together in the mixed task blocks than antisaccade performance. An age by block type by cue interaction, $F(1, 60) = 3.8$, MSE = 0.0043, $p = 0.057$, suggests that whereas young adults' target identification accuracy in the peripheral and central cue conditions was similarly affected by mixing the tasks together, older adults were more disrupted by mixing the tasks in the central cue condition compared to disruption in the peripheral cue condition. This seems to be because whereas older adults' initial saccades in the central cue condition were slower and less accurate in mixed compared to the single task blocks of trials, their initial saccades in the peripheral cue conditions were faster and less accurate. When they moved their eyes in the mixed blocks they were about equally likely to move them in the correct direction for the two cue conditions, but they moved them more slowly in the central condition than in the peripheral condition and therefore did not have as much time to view the target in the central cue condition.

The mean button press reaction times of young adults were faster than the reaction times of older adults ($M_s = 890$ and 1195 ms, respectively), $F(1, 60) = 61.5$, $MSE = 96812$, $p < 0.001$, and the targets were identified faster in the prosaccade than in the antisaccade task (1020 and 1064 ms, respectively), $F(1, 60) = 12.3$, $MSE = 10292$, $p = 0.001$. As with the button press accuracy data, the slowing of saccade latencies from the prosaccade to the antisaccade condition was greater for older adults (81 ms) than young adults (9 ms), $F(1, 60) = 8.1$, $MSE = 10292$, $p = 0.006$. The only effect of block type was a three way interaction with age group and cue type, $F(1, 60) = 5.1$, $MSE = 12923$, $p = 0.028$, indicating that, like in the accuracy data, older adults were disrupted more by switching between the tasks than young adults, but only in the central cue condition.

		Accuracy		Reaction Time	
		Pro	Anti	Pro	Anti
Young Adults					
Peripheral					
	Pure	0.970	0.949	873	875
	Mixed	0.922	0.912	897	904
Central					
	Pure	0.976	0.942	890	888
	Mixed	0.929	0.922	882	908
Older Adults					
Peripheral					
	Pure	0.873	0.747	1202	1267
	Mixed	0.855	0.760	1153	1251
Central					
	Pure	0.904	0.823	1098	1169
	Mixed	0.830	0.782	1164	1253

Table 5. Experiment 2 Target Identification Responses

3.6 Discussion

In this experiment the likelihood of goal neglect was manipulated using a task switching procedure and the difficulty of the inhibitory task was varied by using direction

cues that differed in the difficulty of inhibiting a response to them. Although the effects of these manipulations were not as dramatic as might have been expected, the saccade latency data suggested that older adults had more difficulty inhibiting responses to peripheral onsets than young adults even when the slower responding of older adults was controlled. There was no evidence that they were more susceptible to goal neglect in the antisaccade task than young adults.

In fact, faster reaction times coupled with higher error rates in the mixed blocks compared to the single task blocks and on the switch trials compared to the nonswitch trials suggest that antisaccade performance was affected minimally, if at all, by the task switching demands. This result was quite surprising. Switching between the prosaccade and antisaccade conditions has the characteristics that lead to large mixing costs and large age differences in those costs, response-set overlap and stimulus ambiguity (Mayr, 2001). There was complete response set overlap between the antisaccade and prosaccade conditions; the tasks shared the same eye movement responses, to look to the left or to the right. In addition, it was impossible to know which task was supposed to be performed based on the direction cues because they were identical for the antisaccade and prosaccade conditions. Therefore, it was expected that substantial mixing costs would be obtained and that these costs would be larger for older adults than young adults.

The failure to find a consistent decline in performance under switch instructions suggests that, although the mixed task blocks had the properties attributed to large mixing costs, performing antisaccades and prosaccades under single task and mixed task instructions put similar demands on information processing. It is tempting to say that the preparation interval in the eye movement tasks was sufficient to allow complete

preparation for the upcoming task and that the small and inconsistent patterns in residual switch costs were due to this long interval. This explanation does not account for why the demands of switching between two tasks did not slow performance compared to the single task conditions though. Even with complete preparation for the upcoming task in the mixed task conditions, there should have still been some dual task conditions created by the need to be prepared to perform a different task on an upcoming trial; performance should have been slowed in the mixed task blocks compared to the single task blocks.

Another possibility is that the antisaccade condition may, even under single task instructions, require a similar level of prosaccade goal activation as is needed in the mixed task blocks. For the antisaccade condition, it is always the case that the location of the direction cue, either where it onsets or where it is pointing to, needs to be encoded in order for the correct response to be determined. In essence, the prosaccade response must be encoded and rejected on every antisaccade trial under both single task and mixed task conditions and so the requirement to be prepared to switch to performing prosaccades on some trials may not increase the demands associated with antisaccade goal maintenance on antisaccade switch trials.

Although this explanation seems quite sensible for the antisaccade condition it does not explain why prosaccade performance was not more disrupted under switch instructions. There was a small residual switch cost associated with accuracy of performance on prosaccade switch trials compared to nonswitch trials, but no mixing costs in this condition. One might argue that the reflexive nature of the prosaccade response precludes the need for goal maintenance and so prosaccade performance is insensitive to the requirement to be prepared to switch to the antisaccade task. This

explanation is consistent with the lack of mixing costs in the peripheral onset prosaccade condition and the small switch cost in accuracy, but it falls short because it predicts that in the central cue condition when the prosaccade goal would have to be maintained there would be significant mixing and residual switch costs, a result that was not obtained.

The explanation discussed above indicates that performance was hard in the antisaccade condition for both the single and mixed task blocks because the stimuli and initial steps in response coding were the same. Conversely, similarity of task sets has been shown to **decrease** switch costs. When the tasks to be performed require attending to the same dimension of a stimulus or when the response labels (but not response keys) are shared, switch costs are reduced by about 80 ms compared to switching to a task that does not share properties along these dimensions (Arrington, Altmann, & Carr, 2001). Substantial switch costs, on the order of 300 ms, are still observed. The antisaccade and prosaccade conditions were similar because they required attending to the same dimension of the stimuli and because they used the same response set (i.e., look left). In addition, both tasks included a target identification component and a returning the eyes to the center component. Perhaps because the antisaccade and prosaccade conditions shared several operations and because long preparation intervals were used, residual switch costs were eliminated. In addition, the reduction in switch costs associated with task similarity might have equated single and mixed task block performance. Further research is required to answer this question.

A third potential explanation for the failure to find an effect of either mixing the tasks or switching to a new task is that the responses being performed on each trial should not be categorized as a single task. For the purposes of this experiment, all the responses

associated with a single trial were considered to be part of a single task set, but it may be the case that task switching occurred **within** each trial for both the single and mixed task blocks. For example, after moving their eyes in the direction specified by the cue, participants were also required to identify the target by making a button press and to move their eyes back to the center of the screen to prepare for the next trial. Performing each of these steps on a particular trial might have involved switching between task schemas associated with different response types (i.e., button press for target identification). Jersild (1927) found that when participants switched between two very different operations (e.g., subtraction and opposite naming) mixing costs were eliminated. Perhaps, mixing costs were not present in this experiment because on every trial three tasks, two of which involved different operations (target identification vs. eye movements), were performed. Likewise, residual switch costs may have been so miniscule because the target identification and preparation tasks preceded every eye movement trial and so every eye movement trial was a switch trial. Further research is required to determine if the component operations of a task must be considered as separate tasks in a task switching paradigm.

A second unexpected finding from this experiment was the lack of an overall effect of cue type, central or peripheral, on the eye movement measures. Typically eye movement responses to peripheral onsets are initiated much faster than responses to symbolic cues, like central arrows, because in the former case the responses are reflexive, but in the latter the responses are controlled (e.g., Logan & Irwin, 2000). The lack of a significant latency difference was probably due to a change made to the peripheral cue procedure to equate it more closely with the central cue condition. In the central cue

condition the central arrow was presented at fixation to indicate the correct looking direction. The effect of a stimulus at fixation on eye movement latencies has been widely studied (e.g., Saslow, 1967) and, it is clear that, when the eyes are fixating a stimulus it takes longer to initiate an eye movement response away from that stimulus, than when the fixation stimulus disappears before the saccade is initiated. In part, this latency difference results from the additional time needed by the oculomotor system to disengage from fixation when there is a stimulus there (Kingstone & Klein, 1993). In order to equate the peripheral and central cue conditions on the need to disengage from fixation before saccade initiation, a noninformative double-headed arrow was presented at fixation at the same time that the peripheral onset occurred.

The onset of a distractor at fixation in the peripheral cue condition did slow saccade initiation in the peripheral cue condition; saccades in the peripheral single task blocks of this experiment were 76 ms slower than saccades in the long RSI condition of Experiment 1.² Walker, Deubel, Schneider, and Findlay (1997) also found dramatic increases in saccade latencies caused by the presentation of a stimulus at fixation simultaneous with the onset of a peripheral saccade target. The slowing of prosaccades in the peripheral onset condition actually resulted in no significant difference in prosaccade latencies for the peripheral and central cue conditions. Although these latencies were the same the direct comparison of these conditions was not warranted because saccades to peripheral onsets and saccades in response to central arrows are mediated by different processes. For example, the distance and direction parameters needed to execute a saccade are programmed differently for peripheral onsets and symbolic cues. For

² Although these two peripheral cue conditions differed slightly (there was no task cue in Exp. 1), the difference is unlikely to account for slower responding in this experiment.

reflexive saccades, like those to peripheral onsets, the parameters are programmed simultaneously whereas these parameters are specified sequentially in response to symbolic cues, like a central arrow (Abrams & Jonides, 1988). In addition, reflexive saccades are programmed in superior colliculus whereas saccades programmed using symbolic cues require cortical involvement (Pierrot-Deseilligny, Rivaud, Gaymard, Muri & Vermersch, 1995).

The presentation of the fixation cross simultaneous with the peripheral cue disrupted reflexive saccade programming. However, fast incorrect antisaccades in the peripheral onset condition and saccade direction accuracy rates of less than 75% suggest that an incorrect reflexive saccade was being programmed in the antisaccade condition and suppressing the reflexive response to the peripheral onsets was still quite difficult.

In fact, comparing the central and peripheral cue condition on saccade direction errors indicated that the central cues might have elicited responses similar to the those generated by peripheral cues. The saccade direction error rates were as high in the central cue condition as they were in the peripheral cue condition. Although it might seem that a central arrow would be easily reinterpreted under opposite looking direction instructions, recent evidence suggests that attentional responses to these symbolic cues are automatic. Central arrow cues elicit attentional shifts even when the direction of the arrow is irrelevant to the current task and when attention is biased to be oriented to a different location (Hommel, Pratt, Colzato, & Godijn, 2001). These automatic attentional shifts seem to have caused saccade direction errors to be as frequent in the central cue condition as in the peripheral cue condition but did not result in as much slowing of the initiation of antisaccades (28 vs. 71 ms in the central and peripheral conditions, respectively). In

addition, the amount of slowing observed varied by age. Older adults were slowed to the same extent as young adults when making antisaccades inconsistent with the direction of a central arrow, but older adults had more difficulty making antisaccades inconsistent with a peripheral onset.

Although there were no differences between the cue types when performance was collapsed across the prosaccade and antisaccade conditions, when prosaccade performance was taken as a baseline, antisaccades were more difficult to make in response to peripheral onsets than central arrows. Older adults had more difficulty making antisaccades than young adults did in both cue conditions, but the effect was larger in the peripheral onset condition. Because the goal structure of the central and peripheral cue procedures was the same, the larger age difference in performance in the antisaccade condition can be attributed to a deficit in the ability to inhibit the prepotent response.

4 General Discussion

4.1 Summary of Experimental Results

In two experiments the sources of difficulty experienced by older adults on tasks that require suppressing a reflexive response were examined. In Experiment 1, the role of goal activation was assessed by using short and long RSIs in the manner reported by De Jong et al. (1999) on both a spatial Stroop and an antisaccade task. As was previously found, the long RSI produced a larger interference effect in the performance of young adults on a spatial Stroop task than the short RSI condition supporting the idea that the goal of the current task is less accessible following a long RSI than a short RSI. This pattern was the same in older adults. The goal neglect hypothesis had predicted that older adults would be more susceptible to goal neglect and, as an extension, under conditions that induced goal neglect in young adults, older adults would show larger interference effects. This was not the case. Older adults were not more susceptible to goal neglect than young adults.

In the antisaccade task, the RSI manipulation did not affect the performance of older or younger adults in a way that was consistent with a goal neglect explanation. Performance was more error prone in the long RSI condition, as the goal neglect hypothesis predicted, but it was also faster, suggesting that the differences in accuracy rates and latencies between the two conditions were due to a speed/accuracy trade-off rather than an increase in goal neglect. The speed/accuracy trade-off in the antisaccade task in Experiment 1 precludes any consideration of how goal neglect plays a role in antisaccade task performance in both older and younger adults. It is unknown why the RSI manipulation increased interference in the spatial Stroop task, but had no net effect

on performance in the antisaccade task. Possible explanations for this difference are considered below.

In Experiment 2, a different manipulation, task switching, was employed to vary the difficulty of goal maintenance, and thus, the likelihood of goal neglect. Participants performed the prosaccade and antisaccade conditions in single task and mixed task blocks. Although under some conditions mixing costs are not observed with task switching (e.g., when the different tasks are distinguished by different stimuli (Jersild, 1927; Spector & Biederman, 1976)), typically, mixing costs are significant, particularly when the response stimuli do not indicate the task to be performed as was the case with the eye movement tasks used here (Mayr, 2001; for a review see Pashler, 2000). In addition, large age differences in mixing costs are found when the response sets for the two tasks are exactly the same, another condition present in Experiment 2. Although an initial reading of the literature predicted large mixing costs, particularly for older adults, they were not obtained. The failure to find a large effect of task switching may have been due to task similarity reducing switch costs, although the size of reductions that have been reported do not come close to eliminating the switch costs (Arrington et al., 2001). Alternately, the different component operations that were required on each trial may have reduced the effect of task switching (Jersild, 1927). It seems counterintuitive to predict that making the task to be performed on each trial more complex should reduced the effect of having to switch between the different tasks. As with the RSI manipulation the task switching manipulation created a speed/accuracy trade-off. Saccade direction accuracy was reduced for both the antisaccade and prosaccade conditions in the mixed task blocks, but saccade latencies were also faster indicating no net effect of the task

switching manipulation. In addition, residual switch costs were also not observed. As in Experiment 1, no evidence of goal neglect was found on the eye movement tasks using a manipulation thought to make goal activation more difficult.

Experiment 2 also varied the difficulty of the inhibitory task while maintaining a consistent goal structure by using different types of direction cues, a peripheral onset and a central arrow. Because the task to be performed was the same in the different cue conditions, goal neglect was equally likely in both. Although the goal structure was the same for the peripheral onset and central arrow cue conditions performance in the antisaccade condition was different for the two cue conditions. The difference between antisaccade and prosaccade latencies was greater in the peripheral onset condition and this effect was larger for older adults than for younger adults. When the inhibitory demands were high, in the peripheral onset condition, older adults had more difficulty than young adults, but when the role of inhibition was reduced, in the central arrow cue condition, age-related changes in the difference between antisaccade and prosaccade performance were reduced as well. Age differences in performance on the antisaccade task are related to an inhibitory deficit.

4.2 Implications for Theories of Cognitive Aging

4.2.1 Inhibitory Deficit Hypothesis

The results of Experiment 2 provided support for the inhibitory deficit hypothesis of aging (Hasher & Zacks, 1988; Zacks & Hasher, 1994; Hasher et al., 1999). Older adults had more difficulty performing antisaccades as measured by the slower responding when the cue elicited a prepotent response in the wrong direction that needed to be suppressed, than when the response was associated with a cue that was not prepotent. The

additional difficulty in performance with peripheral onsets can not be attributed to more difficulty maintaining the current task goal, however, because the goal structure of the two tasks was the same.

Older adults also had more difficulty than young adults performing antisaccades in the central cue condition. In this condition, it can be assumed that attention was automatically moved to a location consistent with the direction of the central arrow cue (Hommel et al., 2001), the direction inconsistent with the required response. The premotor theory of attention asserts that patterns of performance that indicate attentional shifts are actually caused by the programming of a motor response to a particular location (Rizzolatti et al., 1994, but see Klein & Pontefract, 1994). In this view, in order to have a movement of attention in the central arrow condition, a saccade to that location must be programmed. Older adults appear to have more difficulty recovering from the inconsistent attentional shift than young adults do.

If both peripheral and central arrow cues lead to automatic attentional shifts and, according to premotor theory, to the programming of a saccade that is incorrect, then why would the requirements for suppression be higher in the peripheral condition than in the central arrow condition? As was described above, both types of cues may automatically elicit an incorrect saccade program, but the types of saccades would be different. Saccades consistent with the direction of an arrow, a symbolic cue, would still require the involvement of cortical structures and would be considered intentionally generated, whereas saccades toward a peripheral onset could be programmed in superior colliculus (Pierrot-Deseilligny et al., 1995). In addition, suppression of a program for an intentional saccade appears to be easier than the suppression of a program for a reflexive saccade

(Logan & Irwin, 2000). The inhibitory deficit of older adults has more of an impact when a reflexive saccade program must be suppressed.

Older adults had more difficulty suppressing incorrect responses in an eye movement task, but they did not show a larger interference effect in the spatial Stroop task for either RSI condition. Why would older adults show a pattern consistent with an inhibitory deficit in one task, but not the other? This finding adds to a growing literature indicating that the inhibitory deficits of older adults are task specific (Burke, 1997; Kramer et al., 1994; MacCrae & Abrams, 2001; McDowd, 1997). For example, Connelly and Hasher (1993) found that different inhibitory tasks show different patterns of age decrements. In a negative priming experiment they found that both young and older adults demonstrated negative priming for a previously ignored location, but that only young participants showed negative priming for the identity of a previously ignored letter.

Many of the tasks that demonstrate equivalent inhibitory function for older and younger adults require the inhibition of information at a particular spatial location (Zacks & Hasher, 1997). When the spatial location of distracting information is predictable, age-differences in the impact of the distracting information can be eliminated (e. g., Connelly & Hasher, 1993; Carlson, Hasher, Connelly, & Zacks, 1995). It may be that older adults were as able as young adults to ignore the meaning of the word while making the spatial location information because it always appeared in the same position, above or below the asterisks. However, this task analysis is tenuous because it would seem that in order to make the location judgement the location of the word would have to be attended allowing the meaning of the word to be automatically extracted. If the meaning of the word is

processed, then it would be this meaning that would have to be suppressed. Whether the failure to find a larger interference effect for the older adults in the spatial Stroop task supports the idea that older adults are spared in their ability to suppress information at a particular location hinges on whether this Stroop task is a test of the ability to suppress information at a particular location or the meaning of a word. This is a direction for future research.

4.2.2 Goal Neglect

The experiments reported do not provide support for the idea that older adults have more difficulty maintaining the current task goal and, in situations where the stimulus may be associated with an alternative response, may show larger interference effects. On the one task that did elicit a pattern of performance consistent with goal neglect, the spatial Stroop task, the performance of older adults was not more disrupted than the performance of young adults when the likelihood of goal neglect was increased. Although the goal neglect hypothesis predicted a larger age difference in performance when the likelihood of goal neglect was higher, the failure to find this result provides evidence against the goal neglect hypothesis. Admittedly, this evidence is weak because it argues from a null statistical finding from one experiment and the power of the manipulation to detect a moderate size interaction was low (power = .55). For example, one could argue, as has been done for the inhibitory deficit hypothesis, that older adults are spared increased susceptibility to goal neglect on some tasks, and the spatial Stroop task is one of them.

More troubling for the goal neglect hypothesis of interference effects was the failure of manipulations that should have affected the likelihood of goal neglect. Both the

RSI and task switching manipulation had no overall effect on antisaccade performance when speed/accuracy trade-offs in performance were considered. Although the manipulation of RSI in the Stroop task led to a pattern of data that supports a goal neglect account of interference effects, this same manipulation did not affect performance in the antisaccade task in a consistent manner. The different patterns of results for the two tasks may indicate that the two tasks differed in a critical characteristic that obscured the impact of goal neglect on antisaccade performance. Alternately, given that the task switching manipulation also did not have the predicted impact on performance in the antisaccade task, it may be that the processes involved in antisaccade performance are not explained well by the goal neglect model. Both of these suggestions have some merit.

Although the spatial Stroop performance was affected by the RSI manipulation such that interference was more pronounced in the long RSI condition than in the short RSI condition, this pattern of results was not obtained in the antisaccade task. It might be argued that the manipulation of RSI used in the antisaccade task was not sufficient to induce goal neglect. In the spatial Stroop task RSIs of 218 and 2028 ms were used, whereas in the antisaccade task the RSIs were 1200 and 3200 ms. The longer values were chosen for the eye movement tasks because the RSI was based on the button press to the target stimulus, but at this point in task performance the eyes were usually still fixating the target stimulus in one of the peripheral boxes. Before the next trial began the eyes had to be back at fixation, however. The longer intervals allowed participants enough time to return their eyes to the center of the screen before the next trial began. In essence, the response on each trial was not completed until the eyes returned to fixation and so the difference between the RSIs used in the two conditions was not as great as it might have

seemed. Even at slightly longer intervals, the discrepancy between the lengths of the RSIs on the two tasks probably does not account for the failure to find goal neglect in the antisaccade task. If the RSI is affecting goal activation in a similar way for the two tasks, then the cumulative response distribution for the 1200 ms RSI condition in the eye movement task and the 2000 ms RSI condition in the spatial Stroop task should be comparable, but they are not. The different RSIs used in the eye movement and spatial Stroop tasks does not account for the failure to find an effect of RSI in the eye movement task.

Another feature of the antisaccade task that may have distinguished it from the spatial Stroop task and eliminated the effect of goal neglect was the warning signal that unconfounded RSI from foreperiod. In both the short and the long RSI conditions of the antisaccade task the fixation cross disappeared 200 ms before the peripheral onset was presented. In the spatial Stroop task the RSI was not interrupted by any events for either the short or the long RSI condition. As was discussed previously, warning signals aid in nonspecific preparation processes, and it may be assumed that part of nonspecific preparation is to increase the activation of the current task goal. If these assumptions are correct, the warning signal in the antisaccade task may have boosted goal activation 200 ms before stimulus presentation for both RSI conditions eliminating differences in goal activation that would have been apparent before the warning signal was presented. Although the preparedness argument is compelling, the failure to find evidence of goal neglect in the antisaccade task with the task switching manipulation as well suggests that the goal neglect account may not adequately explain antisaccade performance.

In applying the goal neglect hypothesis to performance in the antisaccade task it was assumed that the goal of the task is to make a correct saccade, toward the cue in the prosaccade condition and away from the cue in the antisaccade condition (see also De Jong, 2001). In this view, competing task sets only lead to interference if the current task goal is not sufficiently activated. Once the task goal reaches an activation threshold the correct task set is selected and other related task sets are inhibited through lateral inhibition (De Jong et al. 1999, De Jong 2001). This view implies that in the antisaccade condition, correct antisaccade performance is executed independently of the prosaccade task set.

Overlap between the processes required for correct antisaccade performance and the processes required for correct prosaccade performance may prevent the task sets from being represented as separate schemas, however. Lateral inhibition following antisaccade schema selection may be insufficient for correct antisaccade performance because, at the very least, the initial stages of prosaccade response programming are essential in the antisaccade condition. In order to correctly perform an antisaccade the location of the peripheral onset must be explicitly attended, as it is in the prosaccade condition. This explicit attention to the location of a peripheral onset may allow the prosaccade task set access to response generation and on all trials the response programming must be explicitly suppressed. This may, in part, account for the failure to find an effect of the task switching manipulation on antisaccade performance. Perhaps even under single task conditions, the prosaccade task set is activated to some extent making it difficult to maintain the antisaccade task goal. Unfortunately, this idea does not account for why the task switching manipulation did not affect prosaccade performance. There would be no

reason for a different task set to be active during single task prosaccade blocks particularly when that task was introduced before the antisaccade task.

Other research has suggested that older adults have more difficulty on tasks that require the explicit inhibition of an inappropriate response than young adults, but when the task includes a inhibitory component that is not conscious older and young adults are equally able to inhibit irrelevant task sets (Kramer, Hahn, Irwin, & Theeuwes, 2000; Nieuwenhuis et al., 2000). Kramer and colleagues have found that older and younger adults were equally likely to incorrectly look toward an irrelevant peripheral onset when their goal was to look toward a target defined by its color, but only when they were unaware that the peripheral onset was occurring (Kramer, Hahn, Irwin, & Theeuwes, 1999). When the onset of the nontarget stimulus was made more salient, older adults were more likely and young adults were less likely to look toward it suggesting that older adults have more difficulty suppressing responses when the need to suppress is made explicit, but they perform like younger adults when the suppression goal is not explicit (Kramer et al., 2000).

4.3 Implications for Theories of Cognitive Control

A goal neglect account of cognitive aging was not supported by this research and the unexpected findings from the manipulations thought to affect goal neglect may call into question some of the assumptions of the hypothesis. A recent article also questioned whether the goal neglect theory was specified adequately to make predictions about how older adults performance may be affected in a particular situation (De Jong, 2001).

Indeed, concepts such as goal selection, goal maintenance, internal control, and environmental support are presently so poorly defined that it is on one hand often

difficult to derive precise predictions from the goal-neglect hypothesis of cognitive ageing, while on the other hand it is often relatively easy to provide some reasonable post hoc account for findings that would at first sight seem to fit uncomfortably with the hypothesis. (pp.87)

Despite these misgivings about a goal neglect hypothesis of cognitive aging, there may still be merit in the idea that the current task goal must be actively maintained and interference in task performance will occur if the goal activation is not sufficient. The theory is supported by the increase in the interference effect with long RSIs compared to short RSIs found by De Jong et al. (1999) and replicated here with young and older adults.

The results from Experiment 2 can be captured by a model of cognitive control that allows the strength of the competing response to influence task performance. For example, consider Kimberg and Farah's production system (Kimberg et al., 1997; Kimberg & Farah, 1993; 2000). In this view, the strengthening of associations between stimuli and responses (or goals and tasks) can carry out the work of internal control. It is the strength of connections that a stimulus shares with different responses that determines what task is executed. This model can capture the difference between antisaccade performance in the peripheral cue and central arrow conditions of Experiment 2. A peripheral onset would have a strong connection to the response of looking toward that onset, the peripheral-prosaccade strength. A central arrow cue would also have a strong association with the response of looking in the direction that the arrow is pointing, the central-prosaccade strength, although the strength of this association should be less than the peripheral-prosaccade strength because of less experience responding to arrows than

responding to changes in our peripheral vision. The two antisaccade association strengths should be equivalent because the instructions of the experiment would set up these associations and participants would be expected to have little experience responding in the opposite direction from these cues. Performing the antisaccade in the peripheral onset condition would be more difficult because the strength of the association to the prosaccade response is greater than in the central arrow condition.

This theory can explain the age difference in performance in the antisaccade condition with central arrow cues as well. Age decrements in performance are thought to result from weakened associations between stimuli and responses. Because the association strength of the antisaccade response to peripheral onsets and central arrow cues should be equivalent, then the weakening of those associations caused by age should be equivalent. The weakened antisaccade response associations would not lead to equivalent impairments in antisaccade performance because the competing prosaccade response associations have different strengths. Weaker central-antisaccade strength in older adults compared to younger adults should result in age differences in performance in the central arrow condition, a pattern consistent with the finding of Experiment 2. Further research is required to determine whether cognitive control in the face of a competing response requires an inhibitory mechanism. One way to examine this question would be to look at whether inhibiting a response on one trial makes performing that response more difficult on the next trial.

4.4 Conclusions

The results of this research support the inhibitory deficit hypothesis of aging, but not the goal neglect hypothesis. Older adults' performance was slowed to a greater degree

when the inhibitory demands of the task were increased, but the goal structure of the tasks was the same. In addition, an increase in the likelihood of goal neglect was not sufficient to cause greater interference in older adults. In fact, what appeared to be straightforward predictions on how goal neglect would affect performance were not supported.

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