The Role of Inhibition in Reading for

Young and Older Adults

By

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ABSTRACT

The primary objective of the current research was to examine the impact of aging effects on inhibitory processes. Connelly et al. (1991) found that older adults were more disrupted by distraction in a reading with distraction task. Carlson et al. (1995) replicated and extended Connelly et al.'s findings by showing that older adults were able to use knowledge about distractor location to improve total reading time. In the present study four tasks were used in order to investigate the role of aging on inhibition.

In the reading with distraction task participants read aloud paragraphs that either did not contain distractors, contained distractors in predictable locations, or distractors in unpredictable locations. The results indicated that although older adults were more disrupted by distraction compared to younger adults, they were not differentially affected by distractor predictability. The results also indicated that only one inhibitory measure was able to predict eye-tracking measures, restraint.

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INTRODUCTION

Age differences have been found in cognitive performance with older adults typically performing worse (i.e. poor comprehension of text or slower reaction times) than younger adults in tasks such as reading (e.g. Connelly, Hasher, & Zacks, 1991), negative priming (e.g. Hasher, Stoltzfus, Zacks, & Rypma, 1991), and visual search tasks (e.g. Farkas & Hoyer, 1980). These age differences have been purported to be related to the functioning of attentional processes (Hasher & Zacks, 1988). Attention serves to direct a person's focus toward items that are salient or important to current goals. Once an item has been selected for processing, the initial selection phase is modulated by attentional control processes that involve both excitatory and inhibitory mechanisms. Excitatory mechanisms enhance the activation of relevant information while inhibitory mechanisms suppress the activation of irrelevant information (Hasher, Zacks, & May, 1999). Therefore, inhibitory processes serve to keep information processing focused on relevant information and so are essentially attentional processes that serve a selective function (Hasher & Zacks, 1988). A deficit in these inhibitory processes has been suggested as an explanation for the reason that older adults perform worse on some tasks compared to younger adults (e.g. Cameli & Phillips, 2000; Chiappe, Hasher, and Siegel, 2000; Connelly et al., 1991).

The primary purpose of this dissertation is to report the results from an experiment that investigates aging effects on inhibitory mechanisms in young and older adults. The findings from the present research have both theoretical and methodological implications. In terms of theoretical considerations, the findings will attempt to investigate the inhibition deficit hypothesis through studying the cognitive areas in which inhibitory deficits exist in older adults in general (e.g. selective attention, divided attention, memory). In addition, the current study will attempt to examine the underlying mechanisms and similarities in the tasks that lead to consistent age-related differences (e.g. reading with distraction, reading comprehension, neuropsychological tests). The findings have implications for theories of cognitive aging, as well as for theories regarding inhibitory mechanisms in general. Therefore, the goal is to link general hypotheses concerning inhibitory processes to specific theories about cognitive aging. From a methodological standpoint, the findings can provide further information about the conditions in which older adults are likely to experience inhibitory deficits. Thus, a major goal of the dissertation is to tie together cognitive aging theories of inhibition and task parameters that result in different levels of performance for older adults compared to younger adults.

Before presenting the rationale and results for the experiment, the first section of the paper will discuss the most prolific hypothesis that has been used to explain how inhibition is involved in cognition, inhibition deficit hypothesis. In the second section, an overview of prior work on inhibition will be provided, focusing in particular on previous research methods investigating age-related differences in inhibitory processes. The third section will describe the procedure and results of the current experiment, which is designed to evaluate and replicate the effectiveness of location cues while reading text with distracting information.

CHAPTER 1

Theories of Age-related Changes in Inhibitory Processes

The proposed studies will examine age-related differences in inhibitory processes using a reading with distraction paradigm which will be described in the next section. Not only will the study determine whether age-related differences exist in a reading with distraction paradigm, but also will attempt to determine the underlying causes of such differences if they exist in the study. The inhibition deficit hypothesis has been a central theory in cognitive aging for the last decade. Therefore, the current experiment will focus on the inhibition deficit hypothesis since it is one of the most studied and debated theories of cognitive aging (Hasher & Zacks, 1988). The inhibition deficit hypothesis will be evaluated experimentally to determine its ability to explain differences in performance for young and older adults on various tasks (e.g. fixation durations, reading times, neuropsychological measures) in the proposed study. This section of the paper includes a discussion of how the inhibition deficit hypothesis proposes to explain inhibitory processes. The inhibition deficit hypothesis is also discussed in terms of the relevant cognitive aging theory that could explain age-related differences in inhibition.

Inhibition Deficit Hypothesis

The inhibition deficit hypothesis is based upon the assumption that for the efficient operation of working memory, inhibitory mechanisms must limit entrance into working memory to goal-relevant information and dampen the activation of goal-irrelevant information. The inhibition deficit hypothesis assumes that inhibition is an active process. That is, inhibition is not automatically carried out for irrelevant information, instead it is through the use of conscious control that a person decides which information is irrelevant and need not be attended that then leads to inhibition of the irrelevant information. Therefore, the inhibition deficit hypothesis states that the goal of inhibition is to prevent the processing of irrelevant information. In addition, the inhibition deficit hypothesis states that the efficiency of inhibitory processes is reduced with age, which can have an adverse impact on a variety of cognitive processes such as selective attention, memory, and comprehension. This decrement in inhibition allows more irrelevant information to enter working memory. Once entered, irrelevant information receives sustained attention and interferes with the processing of relevant information. According to Hasher and Zacks (1988), the functional capacity of working memory is reduced with aging because less efficient inhibitory processes fail to prevent irrelevant information from entering or being maintained in working memory. The presence of irrelevant information in working memory results in poorer encoding, retrieval, and comprehension on the part of older adults.

Several studies have shown support for the inhibition deficit hypothesis (e.g. Bertoli & Probst, 2005; Cameli & Phillips, 2000; West & Alain, 2000). Cameli and Phillips (2000) conducted a priming task while measuring event-related potentials (ERPs) to determine whether older adults could benefit from the constraints of a sentence context. In their study, the final word of each sentence varied in the degree of relatedness to the preceding context. One third of the sentences ended with the highest probability word (i.e. best completion), one third ended with a word semantically related to the best completion, and one third ended with a word semantically unrelated to the best completion. The ERP data were recorded while participants read the sentences. Cameli and Phillips were particularly interested in the N400 ERP component because it has been linked to the semantic processing of words. The amplitude of the N400 varies inversely with semantic priming. That is, words that are unprimed elicit large N400s, whereas those that are primed elicit smaller or no N400 activity. Cameli and Philips hypothesized that if older adults have difficulty inhibiting irrelevant information (e.g. unrelated words) during word priming, they may benefit from the constraints provided by a sentence context and show a pattern of priming similar to younger adults. They found that younger adults were able to benefit from the preceding semantic context while older adults did not. In their study, younger adults showed the expected decrease in the N400 with semantic priming while older adults showed no discrimination between the three conditions of relatedness. That is, the preceding context resulted in equal priming of related and unrelated words for the older adults which could be explained by the inhibition deficit hypothesis. According to the inhibition deficit hypothesis, older adults have a deficit in the ability to inhibit unnecessary processing which would allow older adults to process related and unrelated words to the same extent and result in equal priming for related and unrelated words. Thus, Cameli and Phillips concluded that the results supported the inhibition deficit hypothesis since older adults did not exhibit a smaller N400 when presented with related words in comparison to when unrelated words were presented. In comparison, the differences in the N400 were seen with younger adults.

Hasher et al. (1991) used a letter-naming task to assess age differences in inhibition. In their study, two letters, a target in one color (e.g. red) and a distractor in another color (e.g. green) appeared on the screen. There were two conditions: a sequential condition in which the current target letter had been the previous pair's distractor letter, and a control condition in which both the current target letter and distractor letter were different from both letters of the previous pair. In their study, younger adults showed the typical negative priming effect. They had slower responses to name a letter on a current trial that had served as a distractor on the previous trial relative to naming a letter that had not occurred on the previous trial. However, older adults showed no negative priming which Hasher et al. claimed supported the inhibition deficit hypothesis. They stated that older adults were unable to suppress the irrelevant letter on a given trial. As a result, they showed equivalent priming when naming that same letter when it became a target letter on the next trial and when the target letter had not appeared earlier.

Although several studies have supported the inhibition deficit hypothesis, not everyone is convinced of its validity (Burke, 1997; McDowd, 1997). For example, Burke found fault with the notion that inhibitory deficits are distributed across the cognitive system as a whole instead of being more localized. There are several studies that have shown age equivalence (e.g. Connelly & Hasher, 1993; Kramer et al., 1994) which cannot be accounted for if inhibitory deficits are believed to be generally distributed across the cognitive system. Connelly and Hasher (1993) attempted to resolve this concern by investigating the dissociation in identity and location suppression.

Connelly and Hasher found dissociation in the inhibitory function of older adults. They found age deficits in identity suppression (ability to inhibit an item based on characteristics of identity such as letter name); however, age equivalence was found in location suppression (ability to inhibit an item based on its spatial location). Since that time several studies have found age equivalence in identity priming tasks (e.g., Kramer, Humphrey, Larish, Logan, & Strayer, 1994; Sullivan & Faust, 1993) and age differences in location priming tasks (e.g., McDowd & Filion, 1995). As a result, the effect of aging on identity and location mechanisms is more complex than originally assumed and thus, may not be as easily delineated into the two categories of age-equivalence and age-differences.

Although many of the identity negative priming tasks do show age differences (e.g. Connelly & Hasher, 1993; Hasher et al., 1991) and many of the location negative priming tasks do show age equivalence (e.g. Connelly & Hasher, 1993; Kramer et al., 1994) there are the few exceptions as noted above. Originally, Connelly and Hasher (1993) attempted to explain the dissociation in inhibitory function as a result of the different effect that aging had on the two separate visual pathways, dorsal and ventral pathways. They suggested that the ventral pathway (processes identity) is age-sensitive, whereas the dorsal pathway (processes location) is not. However, these conclusions do not explain the recent findings of age equivalence in identity priming tasks and age differences in location priming tasks. Thus, it may be that moderating variables of the task used to assess identity and location priming (e.g. preparatory interval, type of stimuli, and mode of response) are more important than the “type” of inhibition measured in determining whether or not age difference will be found. Burke agreed and went on to state that the inhibition deficit hypothesis had been applied to a narrow range of research (e.g., priming tasks), and support was sparse for other areas of research (e.g., memory). It is possible that the type of task that is used can have an impact on whether differences in task performance will be found between young and older adults.

Another critique of the inhibition deficit hypothesis is that it has failed to produce consensus regarding the role of inhibition in cognitive function (McDowd, 1997). McDowd argued that the theory lacked supporting evidence regarding how inhibition suppresses interfering irrelevant information to help with efficient information processing. Thus, in the inhibition deficit hypothesis, inhibition is an under-specified mechanism leaving the question of how it works unanswered. McDowd also argued that it was not clear if inhibitory function is unitary or comprised of multiple mechanisms. Burke agreed with McDowd (1997) in stating that the mechanism of inhibition was not specified in the inhibition deficit hypothesis.

In response to the criticism of an under-specified inhibitory mechanism, Hasher et al. (1999) attempted to increase the specificity of inhibition by introducing the idea that inhibition has three functions to serve. Hasher et al. (1999) proposed that inhibition has three major functions: access, deletion, and restraint. The access function controls the access to working memory by inhibiting activated irrelevant information from entering working memory. The deletion function is responsible for controlling the deletion of old, no-longer relevant information by preventing it from remaining in working memory. Therefore, the access and deletion functions of inhibition serve to protect and clear working memory of irrelevant information. The role of restraint in inhibition is to control the urge to react with the first and strongest response. Thus, restraint allows other less probable responses to have a chance to be considered. Studies have shown deficits in all three functions of inhibition for older adults (Connelly et al., 1991; Hasher & Zacks, 1988; May & Hasher, 1998). However, the few studies that have investigated the three functions of inhibition do not agree on which function(s) of inhibition exhibits age deficits (e.g. Chiappe et al., 2000; May & Hasher, 1998). The proposed study will attempt to investigate the three functions of inhibition for young and older adults by using different tasks to test each function of inhibition.

A deficit in the access function of inhibition can be seen through the use of an external distraction. An external distraction tends to have a greater impact on older adults than on younger adults. For example, while reading, distracting information disrupts older adults more than younger adults and as a result, older adults have longer reading times when compared to younger adults (Connelly et al., 1991). An exception occurs when there are salient cues to direct attention to target stimuli, such as, location cues (Connelly & Hasher, 1993). In these cases, older adults are as efficient at inhibiting distracting information from entering working memory as younger adults. The proposed reading with distraction study will first attempt to replicate previous findings of benefits for younger and older (Carlson, Hasher, Connelly, & Zacks, 1995). In the current experiment, participants will read paragraphs with distracting material that is either randomly placed or systematically placed within the text. According to the inhibition deficit hypothesis, older adults should have more difficulty reading material when there is distracting information imbedded in the text but should benefit when the distracting information is easier to discriminate such as, when there are location cues for where the distraction will occur within the text. According to the inhibition deficit hypothesis when there is more distraction, older adults incur more processing deficits compared to younger adults due to their inefficiency to inhibit irrelevant information. Thus, the proposed study will be able to address the role of the access function and whether or not the inhibition deficit hypothesis is the appropriate explanation for age differences in reading with distraction tasks. One way in which the current study will investigate the access function is by manipulating distractor predictability. Distractor predictability is hypothesized to affect the amount of information that is allowed access to working memory because more distraction could result in less target text being processed whereas, more distractor text would be processed.

The current study will also expand on the previous research that has investigated the access function of inhibition by adding the use of eye-tracking measures. The addition of eye-tracking measures (e.g. fixation times to target and distractor words) might allow for a more specific explanation for why older adults are more disrupted when distracting information is present. For example, if older adults are found to have longer fixation times to distractor words when compared to younger adults, this finding could provide support for the argument that older adults are allowing more irrelevant information access to working memory. These results would suggest an age deficit in the access function of inhibition.

Another function of inhibition suggested to be susceptible to aging is the deletion function (Hasher et al., 1999). The purpose of the deletion function is to clear the working memory of irrelevant information. The "garden path" sentence processing task demonstrates the deletion function of inhibition. The purpose in this task is to apply the deletion function to switch from a highly probable ending of a sentence to a less probable one that participants are instructed to remember. If the deletion is successful then an individual should have access to the to-be-remembered information but not to the initial highly probable information because this should have been deleted from working memory. Older and younger adults have been shown to differ on the deletion function of inhibition when given both implicit and explicit directions to forget information (Hasher & Zacks, 1988). Younger adults do in fact delete the initial highly probable ending while older adults do not. Older adults recall fewer to-be-remembered items than younger adults but just as many to-be-forgotten items. Thus, it seems that the inhibitory mechanism that deletes irrelevant information and prevents it from being active in working memory becomes impaired with age. These findings suggest that older adults have less control over the contents of working memory than do younger adults when it comes to the use of deletion. The deletion function of inhibition will be assessed in the proposed study of reading with distraction. In the reading with distraction task, after participants read the paragraphs they will complete a test designed to assess their recall of target text and distracting text. If older adults do have more problems with the deletion function of inhibition then they should recall more of the distracting text in the recognition test than younger adults.

The restraining function of inhibition prevents powerful responses from being produced before they can be evaluated and before less likely, yet appropriate, responses can be considered. Inhibitory control over practiced actions diminishes with age, as age tends to affect the ability to stop an undesired, but strong action (May & Hasher, 1998). May and Hasher conducted a study to look at the inhibitory control of prepotent but unwanted motor responses by using a stop signal paradigm that occasionally required the withholding of a well practiced response. Participants were trained on a categorization task in which they indicated whether an object (e.g., chair) was a member of a specific category (e.g., furniture). Participants were then informed that on some trials a tone would sound indicating that they were to withhold making a categorization response. Control over the restraint function of inhibition was hypothesized to be the ability to prevent a categorization response when the tone sounded. May and Hasher found that younger adults had greater inhibitory control than older adults. Younger adults were better at preventing an unwanted response than older adults. Therefore, May and Hasher suggested that one cause of cognitive decline in older adults could be a result of a loss of control over the restraint function of inhibition. The proposed study will look at the restraint function of inhibition through the use of four different tasks: the Stroop Task, Hayling Test, errors on the Reading Span task, and the reading with distraction task. If age-related differences are due in part to deficits in the restraint function of inhibition then it is expected that older adults will have more problems when naming the word color than younger adults during the Stroop Task, which would result in longer response times.

Chiappe et al. (2000) conducted a series of studies to determine which functions of inhibition are impacted by aging. Chiappe et al. found age differences only in the access function of inhibition. In their experiments, younger and older adults participated in a sentence span task in which the final word of a series of sentences was to be recalled at the end of the series. They looked at three types of intrusion errors (incorrect recall of a target word) to determine whether deficits were associated with the access, deletion, or restraint function of inhibition. One type of error, current nonfinal intrusions (CNF), was an error in which the response was a word from the current trial but was not one of the target words (associated with access function). Another type of error, previous intrusions, was an error in which target words or nonfinal words from earlier trials were recalled (associated with deletion function). Finally, extraneous intrusions were errors in which the response was a word that had not been presented in the current or previous trials (associated with restraint function). Previous intrusions and extraneous intrusions occurred at the same rate for older and younger adults. Therefore, no differences between younger and older adults were observed with regard to the deletion or restraint functions of inhibition.

In this study, older adults experienced more current nonfinal intrusions which lend support for the hypothesis that older adults experience more problems with the access function of inhibition. The same analysis will be done in the proposed study by looking at the same types of errors used by Chiappe et al. (2000) for participants' performance on the Daneman and Carpenter Reading Task (1980).

The breakdown of inhibition into three functions could be a useful manner in which to explain some age-related differences in cognitive performance. However, few studies have focused on the three functions of inhibition explicitly to test their role and impact on the performance of younger and older adults. The addition of the three functions of inhibition to the original inhibition deficit hypothesis does provide a more specific account of how inhibition deals with irrelevant information. In preliminary studies there is some support for the idea that different tasks tap into three different functions of inhibition and these functions may differ between younger and older adults (Connelly et al., 1991; Hasher & Zacks, 1988; May & Hasher, 1998). However, the tasks used thus far to assess the three functions of inhibition have been primarily reading tasks (e.g. reading paragraphs with distracting text embedded and garden-path sentences). Thus, it would be beneficial to use different tasks to assess the three functions of inhibition to determine if the distinction of access, deletion, and restraint is a reliable manner in which to explain age-related differences in cognitive performance. Therefore, one of the goals of the proposed study is to use both neuropsychological tests and the reading with distraction paradigm to examine the three different functions of inhibition.

There have been two studies that have examined the relationship between different inhibitory measures (Persad, Abeles, Zacks, & Denburg, 2002; Rush, Barch, & Braver, 2006). Rush et al. (2006) did not find a correlation between their measures of inhibition. In comparison, Persad et al. (2002) found a correlation between three measures of inhibition. Persad et al. investigated the role of inhibition and cognitive slowing in age-related performance decrements on memory (e.g. PASAT and CVLT) and attention (e.g. TMT) tasks. In their study, reading speed was used as a measure of processing speed. They found that three measures (Trails B- A, verbal fluency score, and perseverative response score) loaded onto a single factor which they interpreted as reflecting inhibitory processes. They also found age to be significantly correlated with the inhibition measures, suggesting that inhibitory functioning changes with age. They also found that age accounted for a significant proportion of the variance on the CVLT and PASAT. They wanted to examine the role of inhibition in performance on the CVLT and PASAT so they partialled out the inhibition measures. When the inhibition measures were partialled out, the age-related variance on both the CVLT and the PASAT were substantially reduced. They also examined the role of processing speed by partialing out reading speed. Compared to the inhibition measures, reading speed did not account for as much of the age-related variance on the CVLT and PASAT. Moreover, even after speed was accounted for, the inhibition measures still explained a significant proportion of the age-related variance in performance on the memory tasks. They suggested that depending on the nature of the task, and the role of inhibition to successful performance, age deficits would be expected to different degrees. Therefore, they stated that future studies needed to go beyond simple comparisons of inhibition between young and older adults, and examine more fully the relationship of inhibitory processes and cognition.

The inhibition deficit hypothesis, even with recent changes, is not able to encompass all of the relevant findings in the area of cognitive aging. For example, the inhibition deficit hypothesis can not explain why age deficits are not consistently found in identity and location suppression. It may be unreasonable to have an all-encompassing theory of inhibition in cognitive aging. However, it is possible that the limitations of the theory are due to the fact that it has been narrowly applied to the tasks that have been used to investigate inhibition. Research that has claimed to support the inhibition deficit hypothesis (e.g., Carlson et al., 1995; Hartman & Hasher, 1991; Hasher, Quig, & May, 1997) tend to rely on three experimental paradigms: (a) sentence completion tasks, (b) garden path sentences, and more recently (c) reading paragraphs with distracting information. Therefore, it is possible that age differences may be related to episodic memory deficits rather than inhibitory deficits because all three paradigms rely on the use of memory for comprehension in the task (Burke, 1997). Consequently, explanations for age deficits in cognition with relation to how inhibition is expressed may depend on the task used. The next chapter will focus on the methodological manipulations used in reading studies to investigate the inhibition deficit hypothesis. Moreover, the chapter will provide an overview of the manipulations that have led to comparable and conflicting results in the literature and how the current study will improve upon these methods to investigate age-related differences in inhibition.

CHAPTER 2

Methods for Investigating Inhibition

Reading Studies

Studies using the reading with distraction paradigm are commonly used to investigate differences in reading times and comprehension accuracy for younger and older adults. Older adults show an increase in reading time and a decline in comprehension accuracy when reading paragraphs with distracting information (Connelly et al., 1991). One of the first studies to use reading with distraction to investigate inhibitory processes in younger and older adults was Connelly and colleagues study (1991).

Age differences have been found when participants read paragraphs with distracting information embedded in the text. Connelly et al. (1991) looked at comprehension accuracy by having participants read a passage that either did or did not contain distracting text interspersed amid the target text about every fourth or fifth word. The distracting words were meaningfully related to the text of the story. They found that although both older and younger adults were impeded when distracting text was present, the disruption to reading time from distraction was substantially greater for older than for younger adults. Older adults also selected fewer correct answers on multiple choice questions that followed each passage. However, the interaction between age and passage type was not significant which indicates that although distracting material reduces older adult’s comprehension accuracy there is not a larger disruption for older adults compared to younger adults between passages with distracting information and passages without distracting text.

Several studies have been able to find ways to manipulate the reading task so that age equivalence could be found (Carlson et al., 1995; Connelly et al., 1991). The manipulations that have shown age equivalence have provided insight as to what areas of cognition might be less prone to age deficits. Connelly et al. conducted a second experiment to determine if the presence of distracting information was enough to account for the slowing of reading times in older adults. In their second experiment, several conditions were added. In one of the conditions, distracting words were replaced with strings of Xs. In another condition, meaningful distractor words were used, however, these words were not relevant to the target text. Another condition included meaningful distractor words that were related to the target text. Connelly et al. found that older adults were slowed more than younger adults by text-related distracting material than by text-unrelated distractors. Older adults were also more slowed by passages with text as the distractor than when the passages contained strings of Xs as distractors. Their second experiment demonstrated that the degree of disruption in reading time was influenced by the nature of the relation between the target text and distractors. Thus, age equivalence could be found when the distracting information within a paragraph was unrelated to the text.

Carlson et al. (1995) were able to replicate the findings of Connelly et al. (1991) and extend their findings by adding location as a task parameter. Carlson et al. (1995) also used reading with distraction to look at the impact on reading time for younger and older adults in the absence or presence of distraction in either fixed predictable locations or unpredictable locations. Participants were to read passages with target text that was interrupted with distraction in either predictable and fixed locations, or in random locations. The distracting information could either be a string of Xs, unrelated distractor text, or related distractor text. The three experiments confirmed earlier findings that spatially unpredictable distraction has a markedly disruptive effect on reading, with a greater effect for older adults (Connelly et al., 1991). The results also confirmed that spatially fixed and predictable distraction can substantially reduce the negative impact of distraction on older adults and allow older adults to perform at a level comparable to younger adults. The findings suggested that spatial information cuing the location of relevant material provides a powerful aid to older adults whose performance would otherwise be greatly disrupted by semantically meaningful distraction when compared to younger adults (Connelly et al., 1991). Thus, Carlson et al. were able to bypass the effect of text relatedness on older adults by making the location of distracting information predictable. The proposed reading with distraction task will attempt to replicate the previously mentioned findings of benefits for older adults when distracting information is placed in fixed locations. Manipulation of distractor location will be conducted to determine if there are age-related differences in performance on reading time, comprehension accuracy, and eye-tracking data (e.g., first pass fixation durations to target and distractor words which could provide information on how text is processed or allowed access into working memory).

Specific adjustments in task parameters for reading studies have resulted in age equivalence or age differences. When studies are compared, it appears that stimulus characteristics (e.g., text relatedness and location predictability) are better than response characteristics (e.g., type of memory test and pacing of experiment) at discriminating between studies that find age equivalence versus studies that find age differences. Both age differences and age equivalences have been found in self-paced studies (Carlson et al., 1995; Connelly et al., 1991) and experimenter-paced studies (Hasher et al., 1991). The type of memory test (indirect or explicit) also does not impact the findings of age differences (Connelly et al., 1991) or age equivalence (Carlson et al., 1995). Testing the recall or recognition of items would require the execution of the deletion function of inhibition. The inconsistencies in the literature do not aid in discovering if older adults experience deficits in the deletion function. Thus, the current study will use several tasks (e.g. distractor word recognition) to investigate the deletion function and to discover if the deletion function is impaired only under specific testing situations (e.g. explicit memory tests).

There have been two task parameters that result in equivalent reading times in younger and older adults: the use of unrelated text as distracting information within a paragraph (Carlson et al., 1995; Connelly et al., 1991), and the placement of distracting information in predictable locations (Carlson et al., 1995; Connelly et al., 1991). Age differences have been found when distracting information within a paragraph is meaningfully related to the text in the paragraph with older adults having slower reading times and worse comprehension accuracy than younger adults

(Connelly et al., 1991). There is also some evidence that placing distracting information in unpredictable locations can lead to age differences with longer reading times for older adults compared to younger adults (Carlson et al., 1995; Connelly et al., 1991). Thus, with regard to reading in younger and older adults, there appear to be particular methodologies that result in age differences while others lead to findings of age equivalence. These variables appear to be tapping into the access function of inhibition. Therefore, it is possible that one source of age differences is a result of a deficit for older adults in the ability to control the information that is allowed access to working memory. If there are age deficits in the access function it is expected in the current study to find age differences when the access function may be more strained such as in the unpredictable location in the reading task.

There are several weaknesses in the methodologies that are used in reading tasks. There are several variables that when manipulated between studies cannot differentiate between studies that will find differences in performance for younger and older adults versus those that find equivalent performance for younger and older adults. For example, moderating variables such as the pacing of the experiment or the type of memory test are unable to account for differences in reading times between younger and older adults when reading with distraction. Both age differences and age equivalences have been found in self-paced studies (Carlson et al., 1995; Connelly et al., 1991) and experimenter-paced studies (Hasher et al., 1991). The type of memory test (indirect or explicit) also does not impact the findings of age differences (Connelly et al., 1991) or age equivalence (Carlson et al., 1995). In addition, more recent studies that have manipulated the relatedness of distractors to the target text using the reading with distraction paradigm have not been able to find differences in how distracting information impacts the reading performance of younger and older adults (Kemper & McDowd, 2006).

In previous studies (e.g., Connelly et al., 1991) it has been assumed that longer reading times when distractors are present for older adults compared to younger adults provides support for the inhibition deficit hypothesis. Kemper and McDowd (2006) tested this idea by adding eye tracking to the typical reading with distraction paradigm. They stated that if the inhibition deficit hypothesis was correct then older adults should spend more time fixating the distracting material. However, in their study they did not find age differences in fixation duration, fixation probability, or regressions to distracting information. Thus, Kemper and McDowd stated that the duration of reading time may not be the most effective way to evaluate age differences when reading text with distracting information. Therefore, in addition to using the duration of reading time the proposed study will also use comprehension accuracy and eye-tracking data to investigate age differences.

Through the use of the reading with distraction paradigm several task parameters have been discovered that when manipulated can lead to findings of age equivalence or age differences. Thus, one of the strengths of readings tasks is the discovery of parameters, such as predictable location, that can be manipulated to lead to either a finding of age differences or age equivalence. As discussed earlier, one strength of reading tasks is that the earlier studies (e.g., Connelly et al., 1991) have been adapted and improved upon to extend the original findings (e.g., Carlson et al., 1995). Although these strengths help to maintain the use of reading tasks as an effective manner in which to investigate inhibition there are also a few weaknesses with the methods. As mentioned earlier, there are several task parameters that alone cannot account for findings of age equivalence or age differences. Thus, one of the goals of the current study is to look at the effect of location cues on performance for younger and older adults in a reading with distraction task as has been done in previous studies. The current study has expanded on previous studies' reliance on overall reading times by adding eye-tracking measures to provide more variables for investigating age differences. This additional information may provide an insight as to whether older adults are processing more irrelevant information which would suggest that there are age deficits in the access function of inhibition.

A strength for research investigating the inhibition deficit hypothesis is that the manipulation of several task parameters leads to consistent findings of either age equivalence or age differences. However, does this lead to any theoretical contribution or aid in advancing knowledge? Numerous studies simply attempt to replicate previous findings or manipulate several different variables in a new study to provide support for a theory (e.g., Connelly et al., 1991) but manipulations should be carried out more systematically. That is, variables of interest (e.g., distractor location) in a particular paradigm (e.g., reading with distraction tasks) should be controlled and manipulated one at a time without making large changes to the experimental design to be able to make comparisons from one study to the next.

Thus, for reading studies, there are improvements that could be made to the methods used within the task. The proposed study will attempt to replicate previous findings of benefits obtained for older and younger adults when distracting information is placed in predictable locations within a paragraph (e.g. Carlson et al., 1995). The proposed study will improve upon previous reading with distraction studies by adding the use of eye-tracking to allow more variables to be measured and compared for younger and older adults. The addition of variables such as, fixation durations to target and distractor words will provide more information about how young and older adults process text. The first pass fixations to words will provide insight as to what information is allowed access to working memory for both young and older adults and how much of that information is allowed access. This knowledge will provide a manner in which to investigate the access function of inhibition. The total fixation duration times to target and distractor words will provide information about the deletion function of inhibition. Presumably if previous distractor information is not deleted from working memory it will cause interference in text processing, this interference would necessitate rereading text to comprehend the paragraph and longer total fixations to words.

CHAPTER 3

Methods

Introduction

The current dissertation had three primary purposes: (1) to further investigate the effects of target location on selective attention during a reading task using eye-tracking, (2) to test Hasher et al.'s (1999) three component model of inhibitory function, and (3) to assess whether the three inhibitory function components are related to selective attention performance in the reading task for young and older adults. Inhibitory processes were investigated in young and older adults through the use of cognitive neuropsychological measures, a reading with distraction task, a comprehension test, and a recognition task. The three component model of inhibitory function was investigated by conducting an exploratory factor analysis to determine if the various neuropsychological measures loaded onto three separate factors.

Reading with distraction task

Participants

Younger and older adults read aloud and then answered multiple –choice questions about stories that were presented in three different conditions. There were three distractor conditions: no distractors, distractors presented in predictable locations, and distractors presented in unpredictable locations. The resulting design was a 2 (age) X 3 (distractor location condition) mixed factorial design, with distractor location conditions tested within-subjects. Comprehension accuracy, total reading time, and fixation duration for target and distractor text were compared for younger and older adults across the three conditions. Sixty younger (mean age = 23.13, SD = 4.02) and sixty older adults (mean age = 68.67, SD = 6.66) participated in this experiment.

The young adults were recruited from the University of Kansas subject pool and participated in exchange for course credit. The older adults were recruited from the Grayhawk Lab database of community-dwelling adults over the age of 60 years, and received monetary compensation for their participation. All participants had normal or corrected-to-normal vision and no color blindness.

Design and materials

Participants read and answered questions about 1 practice and 9 experimental stories. Eight of the paragraphs were those used by Connelly et al. (1991).[1] The other paragraph was adapted from McCall and Crabbs Schroeder (1979). The nine paragraphs were compared on several measures to ensure that there were no significant differences among any of the paragraphs using Coh-Metrix (McNamara, Louwerse, Cai, & Graesser, 2005; see Table 1). Thus, nine critical stories plus one practice story were used. The paragraphs were edited slightly from the originals to fit on the computer screen when presented in 14 point Arial font. Each story was approximately 125 words and all stories spanned 10 lines. All materials were presented in the same font, Arial 14 pt., with target text presented in italic font type and distracting text presented in roman font type. The stimulus items were presented in white on a black background to maximize pupil size. The display was arranged by dividing a landscape-formatted page into five columns. The distracting words or phrases were placed in the second and fourth column for every paragraph and the target text occupied the first, third, and fifth columns (predictable location condition) or, distractor and target text were randomly placed throughout the columns (unpredictable location condition). The distractor words were unrelated to the target text. Twelve distractor words were selected using the Nelson, McEvoy, & Schreiber (1998) norms such that none were associated with other words of the paragraph. In the two distractor present conditions, the twelve distractor words were repeated such that there were about 60 distractor words per story with the provision that no word ever repeat itself successively. Care was taken to ensure that the distractor words were matched for part of speech, word length, and word frequency and that they were not appropriate continuations of the sentence and could be detected by noticing that they violated semantic and morphosyntactic rules.

Paragraphs were assigned to three blocks such that each block contained three paragraphs. The format was varied across blocks: (1) paragraphs without distractors, (2) paragraphs with distractors placed in predictable locations, and (3) paragraphs with distractors placed in unpredictable locations (see Table 2). The order was counterbalanced across participants as was the assignment of paragraph to condition. Each paragraph was followed by four multiple choice questions and one open-ended question (see Table 3). Each question contained six choices: the correct answer, a distractor word or phrase taken from the distractor condition, and four other plausible answers. If participants were uncertain about the correct answer, they were encouraged to guess. At the conclusion of the reading experiment, participants were administered a word recognition test. The words included 18 distractors originally cued by a change in font, 18 targets, and 36 foils (content words that did not appear in any of the experimental paragraphs). The words were randomly ordered for each participant.

Eye movement parameters were analyzed for 8 (or 16) critical words in each paragraph: (1) 8 target words and (2) 8 distractor words, if present. A target and distractor word was randomly chosen from lines 2 -9 such that all distractor words either immediately preceded or followed the target word. Two measures were computed for each critical word: the duration of the first pass fixation to the word, and the total duration of all fixations to a word. First pass fixation duration was the sum of all fixations to a region beginning with the initial fixation to a word and ending with either the first fixation leftward to a previous word or rightward to a successive word. Total fixation duration included all first-pass fixations as well as any fixations resulting from regressions to the word or after a leftward or rightward fixation to another word. Fixations were defined as a minimum of two successive eye positions occurring with a fixation diameter of 30 pixels.

In addition to the eye-movement data there were three other measures obtained from the reading with distraction task: the total reading time for each condition, a comprehension accuracy score, and a word recognition accuracy score. Comprehension accuracy for the multiple-choice and open-ended questions for each paragraph was compared for younger and older adults across the three conditions.

Word recognition for targets, distractors, and foils were also compared for young and older adults.

Apparatus

An Applied Sciences Laboratories eye tracker (Model 6000) with head-mounted optics was used to record eye movements. The participants wore head-mounted optics (HMO). The sensor on the HMO was interfaced with a head tracker to monitor head movements. The head tracker noted displacements of the sensor attached to the readers' visor relative to a base unit and corrected the record of eye movements for head movements. Head movements were sampled 100 times per second and eye movements were sampled 60 times per second. For the reading with distraction task, stimuli were presented using GazeTracker software (Lankford, 2000) which was also used to analyze the eye movement data. One microcomputer controlled the eye tracker; it was interfaced with a second computer running the GazeTracker software for presentation and analysis. The paragraphs were presented on a 20 in. flat panel computer screen at a viewing distance of 36 in.

The recognition task was programmed using E-prime v1.1 (Psychology Software Tools, Inc., PST) and was executed on the same 20 in. flat panel computer screen used for the reading task. Responses were recorded in E-prime by pressing the appropriate keyboard button for each response.

Testing the three component model of inhibition

The neuropsychological tests, reading with distraction task, and recognition task were assumed to measure single components of inhibition. The functions of inhibition linked to each cognitive neuropsychological test and reading with distraction measure are listed in Table 4. A factor analysis was conducted to test the functions of inhibition that each neuropsychological measure was hypothesized to be measuring. The following cognitive neuropsychological tests were administered to each participant:

1. Daneman and Carpenter Reading Span test - The Daneman and Carpenter Reading Test (1980) was comprised of three sets each of two, three, four, five, and six sentences. Participants were instructed to remember the last word of each sentence. At the end of each series, participants were to recall the words. Participants were presented with increasingly longer sets of sentences until they failed to recall the final words of all three sets at a particular level. As in Chiappe et al. (2000), three types of errors were analyzed in the current study to investigate the three functions of inhibition.

   a. current nonfinal intrusions – errors in which the response was a word from the current trial but was not one of the target words to-be-recalled. These errors reflect problems in the access function of inhibition.

   b. previous intrusions – errors in which the response was a target word or nonfinal word from earlier trials. These errors reflect problems in the deletion function of inhibition.

c. extraneous intrusions – errors in which the response was a word that had not been presented in the current or previous trials. These errors reflect problems in the restraint function of inhibition.

2. D-KEFS (Delis-Kaplan Executive Function System) Trails test - There are five parts to the test. The comparison of the different parts of the Trail Making Test (TMT) to one another allows the measure of different types of attention: visual scanning, letter inhibition, number inhibition, and attentional switching.

a. Visual scanning: In part one of the TMT, participants cancelled out all of the "3" on the page as quickly as possible.

b. Letter inhibition: In part two, participants drew lines to connect consecutively numbered, but unordered circles on a worksheet while ignoring letters.

c. Number inhibition: In part three, participants drew lines to connect letters in alphabetical order on a worksheet while ignoring numbered circles.

d. Switching: In part four, participants connected the same number of consecutively numbered and lettered circles by alternating between numbers and letters (e.g., 1 – A, 2 – B, etc.).

e. Motor speed: In part five, participants followed a dotted line around the worksheet as quickly as possible.

3. Hayling Test – (Burgess, P., & Shallice, T., 1996). Participants were first given a set of 15 sentences that were missing the final word. Participants were to generate an ending that completed the sentence. Participants were then given another set of 15 sentences that were missing the final word. However, this time participants were to generate an ending that did not complete the sentence. The response time was recorded for both sets of sentences. The Hayling test was evaluated in terms of the difference in the time to generate an ending that did not complete each sentence compared to the time to generate an ending that did complete each sentence.

4. Stroop Color and Word Test (Stroop, 1935). Participants first were asked to name the color of a series of x's printed in colored ink. Next, they were asked to name the color of the ink in which the color words were printed (i.e., red, blue, green). The color words and the ink in which they were printed were incompatible (e.g., the word "red" is printed in green ink). The Stroop test was evaluated in terms of the difference in the time to name the color-words as compared to the time to name the colored x's.

5. Cognitive Failures Questionnaire – (Broadbent, D., Cooper, P., FitzGerald, P., & Parkes, K., 1982). There were 25 questions that measure how distractible participants were based on a five level scale (never, very rarely, occasionally, quite often, or very often).

Investigating the relationship between the three components of inhibition and selective attention

Hierarchical regression was used to investigate whether age differences in total reading time during the reading with distraction study were attributable to inhibition or selective attention. That is, hierarchical regression was used to determine which cognitive neuropsychological measures could account for the variances in reading times between young and older adults. Hierarchical regression was also used to investigate whether the inhibitory or selective attention variables accounted for fixation duration to distractors.

The three functions of inhibition were expected to differentially affect the total reading times and fixation duration to distractors. The conceptual formulas for the two dependent variables are provided below. The components of inhibition that are predicted to account for the most variability within each formula are underlined. Conceptual formulas for the hierarchical regressions were:

reading time difference score = <u>access</u> + <u>deletion</u> + <u>restraint</u>

fixation duration to distractors = <u>access</u> + deletion + restraint

Procedure

After participants were greeted and consent was solicited, participants completed the demographic form, which asks for information about age, gender, race, education, and health. Each of the cognitive measures was then administered. Then participants completed the computerized portion of the experiment, and appropriate credit or payment was given. Participants sat in an adjustable chair. The chair could be raised or lowered to accommodate to bi- or tri-focal lenses. Participants wore reading glasses if they normally require glasses to read.

All participants were told before testing that they would be reading a series of stories for comprehension and that a set of four multiple-choice questions would follow each story. Participants were also instructed to ignore any distracting material presented in roman font type and instructed to read at a pace that ensured comprehension. Each story was presented on the computer screen one at a time until the participant stated that they had finished reading the story at which time the experimenter advanced to the next screen. The four multiple choice questions then followed each story one at a time and participants verbally answered each question at their own pace. Once the multiple-choice questions had been answered then the next story was presented. The eye-tracker was calibrated at the start of each session and between blocks for each participant.

At the conclusion of the reading experiment, participants were administered a word recognition test. Participants were first instructed to decide if they recognized the word from any of the paragraphs that they read by either pressing the "Y" key for "yes" or the "N" key for "no". Participants then gave a confidence rating for their yes/no decision using a 3-point scale with 1 = very confident, 2 = somewhat confident, and 3 = guessing.

Chapter 4

Results

Neuropsychological Measures

The means for each neuropsychological test are presented in Table 5. A one-way ANOVA was conducted for each of the neuropsychological tests.

Cognitive Failures Questionnaire

Participants were provided with a questionnaire that contained 25 questions related to perceived distractibility. For each question, participants placed an “X” below one of five possible choices: never, very rarely, occasionally, quite often, or very often. Young (M = 34.4, SD = 11.2) and old adults (M = 32.8, SD = 9.2) did not differ significantly on the Cognitive Failures Questionnaire, $F(1,119) = .719$, $p = .398$.

Stroop Task

A normalized score was calculated for performance on the Stroop task and was used for all analyses. The normalized score was created by subtracting the number of correct responses on the “color word” condition from the number of correct responses on the “color XXX” condition and then dividing by the number of correct responses on the “color XXX” condition. Younger adults had significantly smaller costs (M = 24 % slowing, SD = .1) than older adults (M = 43%slowing, SD = .1), $F(1,120) = 92.6$, $p<.001$.

Trails Making Test

A normalized score was calculated for each of the first four Trail Making Tests (TMT) and was used for all analyses. A normalized score was created by subtracting movement time performance on TMT 5 from each of the other TMT and then dividing by performance on TMT 5 to eliminate the motor component of each task [e.g. (TMT 1 – TMT 5)/TMT 5]. The normalized score for TMT 1 examines visual scanning. Younger adults had significantly smaller costs (M = 2.5 % slowing, SD = .3) than older adults (M = 13.8 % slowing, SD = .2) on visual scanning, $F(1,120) = 11.672$, $p <.001$. However, young and older adults did not exhibit significant differences on letter inhibition (young M = 45.8% slowing, SD =.5; old M = 54% slowing, SD = .6; $p = .444$), number inhibition (young M = 40% slowing, SD =.4; old M = 49.2% slowing, SD = .6; $p = .318$), or switching (young M = 208% slowing, SD =1.2; old M = 236% slowing, SD = .1.3; $p = .211$).

Hayling Test

A normalized score was calculated for the Hayling Test and used for all analyses. The mean response time for the sentence completion condition was subtracted from the mean response time for the nonsensical ending condition for each participant and then divided by the mean response time for the sentence completion condition. Young adults (M = 302% slowing, SD = 2.4) had significantly smaller costs than older adults (M = 793% slowing, SD = 5.6), $F(1,120) = 39.019$, $p < .001$.

Reading Span

Younger adults had a significantly larger reading span (M = 3.8, SD = .60) than older adults (M = 3.2, SD = .7), $F(1,120) = 27.532$, $p < .001$. The reading span was about one set of sentences larger for young adults than older adults. On the reading span task, younger adults had significantly fewer previous intrusions (M = .2, SD = .4) than older adults (M = .7, SD = .8), $F(1,120) = 17.759$, $p < .001$. However, young and older adults did not differ on the amount of current nonfinal intrusions and extraneous intrusion errors during the reading span task.

Reading with distraction task

Eye tracking parameters were calculated for two types of words: target words and distracter words. Fixations to lines 1 – 9 were analyzed since eye tracking accuracy was best for this region. Eight target words and eight distractor words from each paragraph were selected for eye-tracking analyses. Targets were defined as the word appearing immediately before or after the distractor word. Two parameters were calculated for each of these words: the duration of the first pass fixation to the word and, the total duration of all fixations to a word.

Target words: Fixations to targets were analyzed to determine if the presence of distractors disrupts processing of the text. A series of 2 (age) x 3 (condition: distractor absent, distractor predictable location, distractor unpredictable location) analyses of variance were carried out on the target data.

First pass fixation duration to target words. First pass fixation data for target words are show in Figure 1. Neither the main effect of condition ($F(2,238) = .844$, p

=.431) *or* age ($F(1,119) = 2.55$, p =.113), nor the interaction ($F(2,238) = .786$, p =.457) were significant. Thus, older and younger adults had equivalent initial fixations durations to target words for all three conditions.

Total fixation duration to target words. Total fixation data for target words are shown in Figure 2. There was a main effect of condition [$F(2, 238) = 33.095$, p <.001], with longer fixation durations in the unpredictable location condition (M = 522 ms, SD = .0) than in the predictable location (M = 427 ms, SD = .0), and fixations were longer for the predictable location than durations in the distractor absent condition (M = 379, SD = .0). The main effect of age was also significant [$F(1, 119)$ = $p < .001$] with younger adults having shorter total fixation durations (M = 364 ms, SD = .0) than older adults (M = 522 ms, SD = .0). The age x condition interaction was also significant [$F(2,238) = 7.987$, $p < .001$]; total fixation durations to targets for older adults consistently increased across conditions whereas for young adults total fixation durations only increased in the unpredictable condition.

Distractor words: Fixations to distractor words were analyzed to determine if readers would ignore them. A series of two 2 (age) X 2 (condition: predictable location and unpredictable location) ANOVAs examining age effects in distractor processing were carried out for the distractor data.

First pass fixation duration to distractor words. First pass fixation data for distractor words are shown in Figure 3. There was a main effect of condition with longer fixations to unpredictably placed distractors (M = 184 ms, SD = .0) compared to distractors placed in predictable locations (M = 156 ms, SD = .0), $F(1,119)$ =

26.091, *p*<.001. The main effect of age was also significant with older adults having longer fixations (M = 200 ms, SD = .0) than younger adults (M = 141 ms, SD = .0), *F*(1,119) = 39.183, *p*<.001. Although the mean data suggest that predictability affects older adults differently compared to young adults, the age X condition interaction was not significant, *p*=.086 even with a moderate level of power (P = .404).

Total fixation duration to distractor words. Total fixation data for distractor words are shown in Figure 4. The total fixation durations to distractors were significantly longer in the unpredictable condition (M = 318 ms, SD = .0) than in the predictable condition (M = 220 ms, SD = .0), *F*(1,119) = 71.844, *p* <.001). Total fixation durations were significantly longer for older adults (M = 334 ms, SD = .0) than younger adults (M = 204 ms, SD = .0), *F*(1,119) = 42.594, *p* < .001. However, the age X condition interaction was not significant, *p* = .101. Therefore, distractor predictability did not differentially affect older and younger adults' total fixation durations.

Line by Line analysis: Average fixation time was calculated for each line of text (lines 1 – 9) and subjected to a 2 (age) x 3 (condition: distractor absent, distractor predictable location, distractor unpredictable location) x 9 (line) analyses of variance.

Total fixation durations for lines of text. Total fixation data for lines of text are shown in Figures 5 - 7. The total fixation durations to each line in all three conditions were converted into a normalized score since there is less material to read in the distractor absent condition. The normalized score was created by dividing the total fixation duration per line by the number of characters per line. This was done so that line fixation durations could be compared across all three conditions. There was a significant main effect of condition, $F(2, 238)=44.261$, $p<.001$. Post-hoc comparisons using Bonferroni found that the total fixation durations were significantly shorter in the distractor absent condition compared to both the unpredictable condition (mean difference = .013, SE = .002, p = .000) and the predictable condition (mean difference = .005, SE = .002, p = .019). Total fixations were also significantly shorter in the predictable condition compared to the unpredictable condition (mean difference = .018, SE = .002, p = .000). There was a significant main effect of line with fixation times generally declining across lines, ($F(8, 952)=7.357$, $p<.001$). There was a significant main effect of age, $F(1,119)=46.813$, $p<.001$. Older adults had significantly longer fixation durations (M = .074 sec/characters, SD = .0) than younger adults (M = .048 sec/characters, SD = .0). There was a significant age X condition interaction paralleling the fixation durations to target words, $F(2, 238)= 5.876$, p=.003. Older adults were more affected by distraction than younger adults. Younger adults were able to benefit more from distractor predictability than older adults. There was also a significant age X line interaction, $F(8, 952)= 8.692$, $p<.001$. Young adults total fixation durations were consistent across all nine lines whereas, older adults had a steady decline in total fixation duration as they read through the paragraph. There was also a significant condition X line interaction, $F(16, 1904)=2.479$, p=.001. Total fixation durations steadily declined throughout paragraphs in both the distractor absent and unpredictable distractor conditions whereas fixation durations declined for the first half of paragraphs in the distractor predictable condition and then leveled off. However, the three-way interaction of condition X line X age group was not significant, $p = .305$.

Total fixation durations for columns in predictable location condition. Average total fixation durations for columns of target text and distractor text were calculated and subjected to a 2 (age) x 2 (column: target words vs. distractor words) analysis of variance. Total fixation data for columns are shown in Figure 8. There were three columns that contained target words (1, 3, and 5) and two columns that contained distractor words (2 and 4). Total fixation durations were averaged across the three target columns to create a target column variable and fixation durations were averaged across the two distractor columns to create a distractor column variable. There was a significant main effect of column [$F(1,119) = 578.02$, $p < .001$]. Total fixation durations were longer in target columns (M = 3.0 sec, SD = .1) than in distractor columns (M = 489 ms, SD = .0), $F(1, 119)=578.017$, $p<.001$. There was also a main effect of age [F $(1,119) = 35.688$, $p <.001$] with older adults (M = 2.2 sec, SD = .1) having longer fixation durations than younger adults (M = 1.3, SD = .1). The age X column interaction was also significant [$F(1,119) = 32.897$, $p <.001$], indicating the effect of age was greater for fixations to columns of target text compared to columns of distractor text. Independent t-tests were conducted to determine if young and older adults differed in total fixation durations to columns of target text and distractor text. Older adults had significantly longer fixation durations to both columns of target text (M = 3.8 sec, SD = 1.8) [$t(119) = -5.914$, $p < .001$] and columns of distractor text (M = .6, SD = .3)[$t(119) = -5.282$ $p < .001$] compared to young adults (target columns: M = 2.3 sec, SD = .7; distractor columns: M = .4, SD = .2).

Total reading time. Total reading time data are presented in Figures 9 - 11. Average total reading time per paragraph was calculated for the 9 paragraphs and subjected to a 2 (age) X 3 (paragraph) X 3 (condition: distractor absent, distractor predictable location, distractor unpredictable location) analysis of variance. This analysis revealed a main effect of age [$F(1,119)=73.507$, $p< .000$] indicating that older adults (M = 84 sec, SD = 2.6) read more slowly than young adults (M = 51.8, SD = 2.7), and a main effect of condition [$F(2,238)=275.67$, $p<.001$] indicating that the distractors in unpredictable locations (M = 91.2, SD = 2.8) slowed reading times more than distractors in predictable locations (M = 66.6, SD = 2.3), and distractors in predictable locations slowed reading times more than target text in the distractor absent condition (M = 45.9, SD = 1.1). There was a significant main effect of paragraph [$F(2,238) = 98.419$, $p<.001$] with significantly longer reading times in the first paragraph (M = 75.1, SD = 2.4) followed by the second (M = 66.3, SD = 1.8) and third paragraph (M = 62.4, SD = 1.6). The age X condition interaction was also significant [$F(2,238)=25.227$, $p < .001$], indicating that the difference between young and older adults in total reading time increased when comparing the distractor absent condition to both distractor present conditions versus comparing the distractor predictable and unpredictable conditions. There was also a significant paragraph X age interaction [$F(2,238)=23.830$, $p <.001$] with older adults having a larger decline in total reading times than young adults from the first to the second paragraph. However, the condition X paragraph interaction was not significant, *p* = .083. In addition, the three-way interaction of age X paragraph X condition was not significant, *p* = .378.

A second analysis was performed on the total reading time data. Relative costs were calculated for the predictable distractor condition and the unpredictable distractor condition. Relative costs were calculated by subtracting total reading time in the distractor absent condition from the total reading time in the predictable (or unpredictable condition) and then dividing this number by the total reading time in the distractor absent condition. There was a significant main effect of condition with longer reading times in the unpredictable distractor condition (M = 98% slowing, SD = .0) than in the predictable distractor condition (M = 43% slowing, SD = .0), $F(1,119) = 350.528$, $p < .001$. That is, the costs were larger for the unpredictable condition than for the predictable condition. There was a significant main effect of age, $F(1,119) = 517.27$, $p <.001$. Older adults had larger costs (M = 83%, SD = .0) than younger adults (M = 57%; SD = .0). However, the condition X age interaction was not significant, $p = .831$ which suggests that the presence of distractors slowed older adults to the same extent as young adults in both distractor conditions.

Recognition Accuracy. Recognition accuracy data are presented in Figure 12. A 2 (age) x 3 (item type: target, distracter, foil) analysis was carried out on recognition accuracy. There was a main effect of item type [$F(2,238)= 37.06$, $p <$ .001] but, there was not a main effect of age, $F(1,119) = .593$, $p =.593$. Participants were more accurate in recognizing foils, followed by targets, and distractors. Post-hoc comparisons using Bonferroni found that accuracy rates were significantly higher for foils compared to both targets (mean difference = .122, SE = .0, *p* = .000) and distractors (mean difference = .134, SE = .0, *p* = .000). However, accuracy rates did not significantly differ between target and distractor words (mean difference = .013, SE = .0, *p* = 1.000). The item type X age interaction was not significant, *p* = .207.

Recognition Confidence Rating. Confidence rating data for the recognition task are presented in Figure 13. An age x item type ANOVA was also carried out on confidence ratings, with similar findings. The main effect of item type was significant [$F(2,238) = 32.794$, $p < .001$], as was the main effect of age [$F(1,119) = 4.409$, $p = .038$], and the age x item type interaction [$F(2,238) = 8.021$, $p = .001$]. Post-hoc comparisons using Bonferroni found that participants were more confident in their responses for distractors compared to both targets (mean difference = .182, SE = .0, *p* = .000) and foils (mean difference = .177, SE = .0, *p* = .000). However, there were not significant differences in level of confidence for targets and foils (mean difference = .005, SE = .0, *p* =1.000). Older adults were more confident in their responses (M = 1.5, SD = .0) than younger adults (M = 1.623; SD = .0). The interaction indicates that young and older readers were equally confident in rejecting distractors, but younger adults were less confident about targets and foils than older adults.

Comprehension task. A separate one-way ANOVA was carried out on the comprehension accuracy for both the multiple-choice and open-ended questions.

Young and older adults did not differ on the multiple-choice task (M = 34.6 and 34.6 correct out of 36 for young and older adults, respectively), indicating that young and older adults' comprehension for details was not differentially affected by the presence of distracting text. However, there was a significant difference between young and older adults' accuracy on the open-ended questions, $F(1,120) = 5.994$, $p=.016$. Young adults were more accurate in answering the open-ended questions (M = 8.7 out of 9, SD = .6) than older adults (M = 8.4, SD = .8) indicating that young and older adults' overall comprehension was differentially affected by the presence of distracting text.

Factor Analysis. An exploratory factor analysis was used to examine the underlying dimensions of the neuropsychological tests. The factor solution was obtained using principle-components extraction and Varimax rotation methods. The criteria for determining the numbers of the factors included a scree test, eigenvalue greater than 1.0, and a factor loading cutoff of .50. Results from the factor analysis are summarized in Table 6. Principle-component analysis of the neuropsychological test scores yielded the same four factors for young and older adults. Therefore, an overall principle-component analysis of the neuropsychological measures yielded four factors that accounted for 28.4% of the variance in neuropsychological test scores. The factor loading scores were saved as a variable for each of the four factors to be used later in the regression analyses. The first factor, speed/executive attention, included four tests that are hypothesized to measure attention and executive processes. It is important to note that the tests with coefficient loadings at or above .5

on this factor were all timed: the normalized difference scores from the Trails Making Tests 1, 2, 3, and 4.

The second factor, interpreted as access, consisted of two tests that measured the amount of information from the current task allowed access to working memory. Tests with coefficient loading at or above .5 included current nonfinal intrusions (CNF) on the reading span test and the Cognitive Failures Questionnaire. The loading coefficients of the neuropsychological tests on the access factor point to the directionality of relationship between scores on the individual tests and the factor scores. The negative loading of the Cognitive Failures Questionnaire indicate that higher factor scores are associated with the report of fewer distractions. The positive factor loading for CNF indicates that higher factor scores were associated with more intrusions on the reading span test.

The third factor, interpreted as deletion, consisted of two tests that measured the ability to inhibit distraction from outside sources unrelated to the current task. The tests with coefficient loading at or above .5 on this factor included previous intrusion errors (PI) and extraneous intrusion errors (EI) on the reading span task. The pattern of factor loadings indicates that higher factor scores were associated with more intrusions of both types on the reading span test.

And finally, the restraint factor was defined by two tests that measured the ability to suppress a response from a previous trial or condition. Tests with coefficient loading at or above .5 on this factor included the normalized difference scores from the Stroop and Hayling tests. The pattern of factor loading indicates that higher factor scores were associated with more interference from the color words while naming colors on the Stroop task and longer response times to complete sentences with a nonsensical word on the Hayling test.

Regression. To examine the role of inhibition on reading with distraction performance, hierarchical regression analyses were performed examining the amount of variance accounted for by speed/executive attention, access, deletion, restraint, age, and education. The factor loading scores for each of the four factors from the factor analysis were used as the inhibitory predictor variables. Regressions were carried out for first pass fixation durations to distractor words, total fixation durations to distractor words, and total reading times. All regression analyses used a common approach: in step 1, measures of inhibition were entered to investigate whether speed/executive attention, access, deletion, or restraint accounted for residual variance in fixations to distractor words or total reading times. In step 2, baseline differences in reading during the no distractor condition were entered to account for overall individual differences in reading ability and its ability to account for additional variance in fixations and reading times beyond that attributable to speed/executive attention, access, deletion, or restraint. In step 3, age and education were entered to determine if they accounted for any residual variance in fixation and reading times. Separate analyses were conducted for the following dependent variables: first pass fixation in the predictable condition, first pass fixation duration in the unpredictable condition, total fixation duration in the predictable condition, total fixation duration in the unpredictable condition, total reading time in the predictable condition, and total reading time in the unpredictable condition. Results from the hierarchical regression analyses are presented in Tables 7 - 9. Age was only a significant predictor for total reading times in the unpredictable condition, thus, the third step of the regression will be discussed only for total reading times in the unpredictable condition.

First pass fixation durations to distractor words

Only the restraint factor and total reading time significantly predicted first pass fixation duration during the DP condition [restraint, $\Delta r^2 = .209$, Fch(1,119) = 31.377, and total reading time in the ND condition, $\Delta r^2 = .111$, Fch(1,118) = 19.299], together they accounted for 32% of the variance in first pass fixation durations to distractor words in the DP condition. Similarly for first pass fixation durations in the DU condition, both the restraint factor and total reading time in the ND condition [restraint, $\Delta r^2 = .125$, Fch(1,119) = 16.947, and total reading time, $\Delta r^2 = .067$, Fch(1,118) = 9.72] were significant predictors. Together they accounted for 19% of the variance in first pass fixation duration to distractor words in the DU condition. Therefore, only one of the inhibition factors, the restraint function, accounted for a significant proportion of variance in first pass fixations in both the predictable and unpredictable conditions.

Total fixation durations to distractor words

The significant predictors for total fixation duration during the DP condition were the restraint factor, $\Delta r^2 = .215$, Fch(1,119) = 32.637 , and total reading time in the ND condition, $\Delta r^2 = .121$, Fch(1,118) = 21.462. Together these predictors accounted for 34% of the variance in total fixation durations to distractor words in the DP condition. The significant predictors of total fixation durations in the DU condition were the restraint factor, , $\Delta r^2 = .16$, Fch(1,119) = 22.685, and total reading time in the ND condition, $\Delta r^2 = .168$, Fch(1,118) = 29.572. Together they accounted for 33% of the variance in total fixation durations to distractor words in the DU condition. A proportion of variance in total fixation durations was accounted for by one of the inhibition factors, restraint factor, in both the predictable and unpredictable conditions.

Total reading times

The significant predictors for total reading times during the DP condition were the restraint factor, $\Delta r^2 = .226$, Fch(1,119) = 34.839, and total reading time in the ND condition, $\Delta r^2 = .387$, Fch(1,118) = 118.438. Together these predictors accounted for 61 % of the variance in total reading time for the DP condition. The significant predictors of total reading times in the DU condition were the restraint factor, $\Delta r^2 = .242$, Fch(1,119) = 38.003, total reading time for the ND condition, $\Delta r^2 = .328$, Fch(1,118) = 90.12, and age, $\Delta r^2 = .014$, Fch(1,117) = 4.041. Together these predictors accounted for 59% of the variance in total reading time for the DU condition. A proportion of variance in total reading time was accounted for by one of the inhibition factors, restraint factor, in both the predictable and unpredictable conditions. In addition, even when inhibition and reading ability were partialled out for the unpredictable condition, age was still able to account for a significant proportion of variance in total reading time.

Chapter 5

Discussion and Conclusions

The central focus of the current research was to investigate the utilization of knowledge about target and distractor location on selective attention through the use of eye-tracking in a reading with distraction task. Connelly et al. (1991) investigated the effect of disruption caused by distractors that were either related or unrelated to target text. They found that although both young and older adults were impeded by distraction, older adults experienced more disruption from distraction. The current study replicated these findings for total reading time. In the current study, older adults had significantly longer total reading times than younger adults. Moreover, location predictability differentially affected old and younger adults. Young adults were better able to take advantage of distractor predictability and reduce reading time whereas older adults were not able to benefit from distractor predictability information. However, relative costs were also calculated for total reading time to take into account the fact that the distractor absent condition contained fewer words. When relative costs were compared for young and older adults, although older adults had significantly higher costs in reading time, older and younger adults were slowed to the same extent in both distractor conditions. Therefore, these findings do not support the findings of Connelly et al. One reason for the differences between the current study and Connelly et al. is that in their study they were manipulating distractor relatedness to target text. Thus, when distractors were meaningfully related to target text older adults experienced significantly more interference than young adults. Older adults may have experienced more interference since Connelly et al.'s task was more difficult than the current study not only because the distractors occurred in unpredictable locations but the distractors were also meaningfully related to the target text.

The relative costs found for young and older adults do provide support for the findings of Carlson et al (1995). Carlson et al. found that the placement of distraction in predictable locations reduced disruption, especially for older adults. That is, older adults were able to use spatial information as efficiently as young adults to aid in inhibiting distracting information. These findings were replicated in the current study in finding that young and older adults total reading times were slowed to the same extent in both the distractor predictable and unpredictable location conditions.

Connelly et al. (1991) also compared correct responses for young and older adults on a multiple-choice comprehension task. They found that older adults had significantly fewer correct responses than young adults. In comparison, in the current study, comprehension by young and older adults was not differentially affected by the presence of distracting text. One reason that the current study did not find age differences in comprehension accuracy on the multiple-choice questions might have been due to target and distractor relatedness. Although the choices provided on the comprehension task were reasonable completions to the question, the distractors were not related to the target text. This may have made it easier to select an answer in the current study compared to Connelly et al. This explanation seems plausible since age differences were found for the open-ended questions. Thus, when the comprehension task was more difficult (i.e. open-ended) small age differences were found.

Previous studies investigating inhibition in reading tasks (e.g. Carlson et al., 1995; Connelly et al., 1991) have focused primarily on reading times and accuracy on comprehension tests. Kemper and McDowd (2006) suggested that total reading time may not be the best measure on which to compare young and older adults. Therefore, age-related differences in the role of knowledge of distractor location was also assessed in the current study by comparing first pass fixation durations to target/distractor words, total fixation durations to target/distractor words, total fixation durations to columns of target/distractor text, and total fixation durations to lines of text.

Similar to Kemper and McDowd (2006), in the current study young and older adults did not differ on first pass fixation durations to target words. Thus, young and older adults initially fixated on target words for equivalent amounts of time for all three conditions. However, age differences were found for other eye-tracking measures. For first pass fixation durations to distractor words older adults spent more time fixating distractors in all three conditions.

Older adults had significantly longer total fixation durations to target words than young adults. Parallel to the total fixation durations to targets, total fixation durations to distractors were greater overall for older adults compared to young adults. Distractor predictability did not differentially affect older and younger adults' total fixation durations to distractor words. In comparison, distractor predictability did differentially affect young and older adults' total fixation durations to target words. Young adults were able to take advantage of the location cues in the distractor predictable condition, whereas, older adults were not able to use this information to direct their attention in space. This suggests that older adults required longer fixations to target words because they were more disrupted by distractor words. That is, it is possible that older adults required longer fixation times to process and make sense out of the target words due to the disruption of reading caused by the distractor words.

In contrast to Kemper and McDowd (2006), the current study found age differences in first pass fixation durations and total fixation durations. A reason that the current study found age differences, whereas Kemper and McDowd did not find age differences may have been related to the reading with distraction task employed in each study. One difference between the current study and the study conducted by Kemper and McDowd is that in their study participants read single sentences with a singular distractor. Thus, their reading task may not have caused enough distraction to require older adults to rely on the use of inhibitory processes. In contrast, the current study required participants to read paragraphs with numerous distractors (about 60 distractor words per paragraph) placed randomly throughout the paragraph (unpredictable condition) which may have led to more disruption than just having to suppress the response to read a single distractor. Therefore, the current study may have created more disruption to text processing that necessitated inhibitory processes to complete the task efficiently. If there are inhibitory deficits associated with the aging process then tasks that are more difficult will be more likely to find age differences in measures such as first pass fixation durations and total fixation durations.

Consistent with the first pass and total fixation durations, total fixation duration to lines of text were significantly longer for older adults than younger adults. In addition, older adults fixated on lines of text for longer periods of time than young adults when distractors were in unpredictable locations. Moreover, older adults exhibited a larger learning effect through each paragraph compared to young adults. That is, young adults maintained constant fixation durations for each line of text within a paragraph whereas older adults had a steady decline in fixation durations from the beginning of the paragraph to the end. These results suggest that young adults are able to perform the task with relative ease and did not need practice whereas older adults required more time to become efficient in reading with distraction. Moreover, older adults may require a period of time to learn how to be more efficient at reading due to the added disruption caused by distractors as they move through the paragraph. This may provide support for the inhibition deficit hypothesis as the additional time required to perform the reading task may be a result of a deficit in inhibitory processes.

Older adults appear to be learning across the lines of text for both the distractor absent and distractor unpredictable location conditions with fixation durations decreasing across the lines of text. In contrast, in the predictable distractor location condition fixation durations for both young and older adults decline across the first half of the paragraph. Therefore, both older and young adults are able to take advantage of distractor predictability by the middle of the paragraph and perform at their peak performance level. The distractor absent and unpredictable distractor locations condition may have been demanding enough to make the task more difficult for older adults and they required more practice to read efficiently. Similar to the current study, Connelly et al. (1991) performed an analysis to investigate practice effects by looking at the age X passage order (1st -6th passages) interaction. They found that for young adults reading times were consistent across the passages for all conditions. However, older adults showed an improvement in total reading time from the first paragraph to the third paragraph and then a leveling off of reading times after the third paragraph. Therefore, the current findings are consistent with Connelly et al. in showing a learning effect over time for older adults whereas young adults do not require this additional time to perform the task efficiently. A possible explanation for older adults requiring more time before they are able to benefit from location predictability would be that an inhibition deficit affected their ability to learn distractor location. If aging results in a decrement in inhibition then it would be more difficult to inhibit distracting information and one would have to find a way to compensate for this decrement. The learning effect that was seen in the current study across lines of text may be an example of how older adults are able to compensate for inhibitory deficits. Even though older adults have more difficulty in inhibiting distracting information, with some practice they are eventually able to become more efficient at reading with distraction.

The current study also compared recognition accuracy and confidence level rates for young and older adults for target and distractor words. On the recognition task, young and older adults were equally accurate when identifying foils, targets, and distractors. The recognition of distractors in the current study may have been easier due to the distractors repeating several times in each paragraph. Even though young and older adults did not have long fixations to distractor words this repetition may have led to the words being more easily recognizable. Although young and older adults were equally good at the recognition task, older adults were more confident in their responses. Older and young adults were equally confident about recognizing distractors but younger adults were less confident about targets and foils. One reason that young and older adults differed on their confidence level for targets and foils could have been related to the amount of time that each participant spent on making their decision. The recognition task was not timed but, in general, older adults spent more time on the recognition task than young adults. Therefore, young adults may have been more apt to select the "somewhat confident" response each time whereas, older adults were more prone to think about their response until they were confident about their answer. In the future, it may be beneficial to measure the amount of time that individuals require to complete the recognition task.

The current study also investigated Hasher et al.'s (1999) three component model of inhibition. According to the three component model of inhibition the functions of inhibition include: access, deletion, and restraint. However, in the current study, a factor analysis investigating the relationship between the neuropsychological measures revealed four factors: a speed factor, an access factor, a restraint factor, and a deletion factor. Each function is discussed below.

The Hasher et al. model (1999) proposes three functions of inhibition: access, deletion, and restraint. In the current study, the access function of inhibition was initially measured by comparing performance for the following variables: current nonfinal errors on the Daneman & Carpenter reading span test, Visual scanning (Trails 1), Letter inhibition (Trails 2), Number inhibition (Trails 3), and the Cognitive Failures Questionnaire. The factor analysis revealed that performance on only two of these neuropsychological measures loaded onto the access function of inhibition: the Cognitive Failures Questionnaire and the number of current nonfinal errors on the Daneman and Carpenter Reading span test. Significant age differences were not found for either measure. The lack of age differences on these measures suggests that the access function of inhibition is age-invariant. In addition, the access function was not related to performance in the current reading with distraction task. The access function of inhibition did not account for variance in either fixation durations or total reading times for both young and older adults. Therefore, based on results from both the factor analysis and regression, age differences in the reading with the distraction task cannot be attributed to an age-related deficit in the access function of inhibition.

In contrast, Chiappe et al. (2000) found a deficit in the access function of inhibition using the number of current nonfinal errors on the reading span task. A possible explanation for the contradictory findings between the Chiappe et al. study and the current study could be whether or not participants were encouraged to guess if they were not able to recall all of the target words. In the current study, participants were not encouraged to guess but they may have been encouraged to guess in Chiappe et al.'s study. Thus, in the Chiappe et al study, current nonfinal errors may reflect guessing strategies rather than the access function of inhibition.

The deletion function of inhibition was initially measured by comparing performance for the following variables: previous intrusion errors on the Daneman & Carpenter reading span test and Trails 4. The factor analysis found two neuropsychological measures that loaded on the same factor: previous intrusion errors and extraneous intrusion errors on the Daneman and Carpenter Reading Span test. Of these two measures, age differences were only found for one, the number of previous intrusion errors. Therefore, the status of an age deficit in deletion is equivocal. While both types of errors on the reading span task can be plausibly related to deletion (or the failure to delete information from working memory), only one, previous intrusion errors, seems vulnerable to aging. One possible explanation for the inconsistency could be that older adults are efficient at deleting information from working memory that is not related to the task but, they have a deficit in deleting information that was once relevant and is no longer relevant for the current goals or information that is related to the current task. The inability to delete previously processed information from working memory would cause interference with new task demands. For example, if previously read text (e.g. distractor words) was not cleared from working memory then it would interfere with the integration of newly acquired information resulting in longer total fixation durations to target words. However, the deletion function was not a significant predictor of performance on the reading with distraction task. That is, inhibitory deletion did not account for significant variance in fixation durations or total reading times for either young or older adults even though age differences were found for previous intrusion errors. These findings suggest that inhibitory deletion is not imperative for efficient reading performance in the current study. Therefore, based on results from both the factor analysis and regression, age differences in the reading with distraction task were not due to an age-related deficit in the deletion function of inhibition.

The restraint function of inhibition was initially measured by comparing performance on the following variables: the normalized Stroop difference score, the normalized Hayling difference score, and extraneous intrusion errors on the Daneman & Carpenter reading span test. The factor analysis revealed that two of the initially hypothesized measures of restraint loaded on this factor: the Hayling and Stroop measures. Significant age differences were found for both. These findings suggest that in the reading with distraction task, older adults had difficulty with restraint. Reading is a well practiced and automated response for adults. The function of restraint in the current study was to suppress this automatic response to read every word of text. Therefore, when the restraint function is working properly it aids participants' ability to read text with distraction by suppressing the automatic response to read all words (i.e. distractor words) and only read words that are necessary for the task (i.e. target words). The ability to suppress the processing of distractor words would lead to faster overall total reading times and better comprehension for each paragraph. Restraint is critical in the reading with distraction task since it role is to aid in ignoring distractor words. Distractor words, once accessed and not deleted from working memory, cannot be integrated with the remaining text. Thus, a breakdown in the restraint function of inhibition would make it more difficult for older adults to ignore distractor words and force them to attempt to integrate distractor words, disrupting the reading of the text and leading to longer total reading times. These findings support the hypothesis that older adults have a deficit in the restraint function of inhibition. These results are also consistent with May and Hasher (1998) who also found age differences in the restraint function of inhibition.

In the current study, there was at least one measure for all three functions of inhibition that did not load onto the predicted factor. Further, for each factor, there was at least one measure that did not show significant age differences. Thus, the decomposition of inhibition into component factors and the mapping of neuropsychological tests onto these component factors are questionable. The lack of agreement on these issues hinders evaluation of models like that of Hasher et al. that hypothesize age-differences in the components of inhibition and which rely on single-indicators of these hypothesized components. A more extensive investigation of the component structure of inhibition, using a broad range of neuropsychological and experimental measures of inhibition is necessary in order to resolve these disputes.

The current study was designed to investigate how well the three component model of inhibition could account for performance on a reading with distraction task. A factor analysis revealed that the neuropsychological tests loaded onto four factors. The four factors were interpreted as corresponding to speeded attention, inhibitory access, inhibitory deletion, and inhibitory restraint. The four factors were used to investigate performance on the reading with distraction task; eye-tracking was used to obtain first pass fixation durations to distractor words, total fixation durations to distractor words as well as a total reading time measure. Only one of the four factors was able to account for a significant proportion of variance for the eye-tracking measures and total reading time, the restraint factor. This suggests that part of being able to perform the reading with distraction task involves restraining or suppressing a prepotent response. In the reading with distraction task individuals must learn to NOT read every word and to NOT integrate every word. Age differences in performance on the reading with distraction task appear to be related to an age deficit in the restraint function of inhibition, suggesting that older adults are not able to suppress the reading and processing of distractor words. Since older adults had more difficulty in ignoring distractor words then these words caused more interference when older adults were trying to integrate the text into a coherent message which lead to longer total reading times, more regressions to reread text, and poorer comprehension.

The current study also found that total reading time in the no distractor condition accounted for significant variance in the eye-tracking measures even when individual differences in inhibition were controlled. In fact, the best predictor of fixations to distractor words and total reading times in both distractor conditions was total reading times in the distractor absent condition. Therefore, good readers (i.e. faster reading times in the no distractor condition) are more efficient in ignoring distractor words and reading paragraphs with distracting information compared to poor readers (i.e. slower reading times in the no distractor condition). While this provides some information about the reading process it does not provide knowledge about how inhibition affects reading with distraction. If age-differences in fixation durations and total reading time were due to age-related inhibitory deficits, as suggested by Hasher and colleagues (e.g. Hasher et al., 1999), then the inhibition factors should have accounted for the most variance in the fixation durations and reading times instead of reading time in the no distractor condition. This suggests that processes other than inhibition may be necessary for efficiency in the reading with distraction task.

Conclusions

In the inhibition deficit hypothesis it is assumed that the act of inhibition is active in that inhibition does not take place automatically. Moreover, the inhibition deficit hypothesis assumes that the goal of inhibition is to prevent interference from distractors. Hasher and Zacks (1988) first attempted to explain age differences in performance on various tasks (e.g. negative priming and reading with distraction) by stating that the aging process leads to deficits in these inhibitory processes. The current study did find results that support the inhibition deficit hypothesis.

Conditions in which the reading with distraction task was made more difficult by the presence of distraction lead to age differences in total reading time, first pass fixation durations, and total fixation durations. However, the presence of distraction did not lead to a consistent differentiation between young and older adults on the various eye-tracking variables, recognition task, comprehension task, and neuropsychological measures of inhibition. Thus, more research is necessary to investigate the role of inhibition in different tasks.

Almost ten years ago McDowd (1997) made several suggestions for future research directions such as, specifying the role of inhibition in cognition. Since that time, theorists investigating inhibitory processes have made some progress. Although there are numerous uncertainties associated with inhibition in the area of cognitive aging, there is one idea that has been agreed upon among researchers: The function of inhibition is to help guide efficient information processing through its suppressing effects on irrelevant information. Many researchers also agree that a theory of inhibition must include multiple inhibitory mechanisms to be successful in explaining recent research (e.g. Connelly & Hasher, 1993; McDowd, 1997). The inhibition deficit hypothesis has progressed from its original assumptions (Hasher & Zacks, 1988) with the addition of the three functions of inhibition (Hasher et al., 1999) by specifying the role of inhibition in cognition. However, there is still a lot of work to be done to understand how inhibition is impacted by aging. For example, there is still a debate as to how inhibition works. Research needs to be conducted to answer this question in a way that will help decipher the exact way in which inhibition works.

One way in which research could do so would be to investigate the individual differences and task components that lead to differences in inhibitory functioning (McDowd, 1997). Another way in which the study of inhibition could proceed is to use alternative tasks (e.g. vigilance tasks and divided attention tasks) rather than relying on priming tasks to study inhibition (McDowd, 1997). It is possible that tasks that are assumed to test inhibitory processes are in fact measuring other variables (e.g., reading comprehension tasks). Thus, a reliable measure of inhibition needs to be developed in order to understand how aging affects inhibitory processes (McDowd, 1997). As more research is conducted to define the function of inhibition further, it brings the area of cognitive aging closer to being able to pinpoint what variables lead to differences in younger and older adults and which variables lead to age equivalence.

Future Directions

Even though the reading with distraction paradigm has become more prevalent in the cognitive aging literature there are still areas in need of further research. For example, although Hasher et al. (1999) improved upon their initial definition of inhibition by adding three functions of inhibition there is still need for further clarification about how inhibition functions. The few studies that have attempted to investigate whether the functions of inhibition are able to account for age differences in performance have not obtained consistent results (Chiappe et al., 2000; May & Hasher, 1998). One reason for the inconsistency in the literature investigating the functions of inhibition could be due to similar criticisms raised about the initial definition of inhibition. Although the definition of each of the three functions of inhibition help to explain how inhibitory processes function the definitions are still too general. That is, there are general definitions of how the access, deletion, and restraint functions are assumed to operate in cognitive processing, but there is a lack of specific means by which to measure each function of inhibition. Therefore, future research should focus on providing a more specific account of how the three functions of inhibition operate and what specific tests can be used to measure each function. In addition, it is still uncertain whether the three functions of inhibition are the best manner in which to describe how inhibition operates. The current study was able to find age differences on several tasks assumed to be testing each of the three functions of inhibition. Further research should be conducted to better understand what tests should be used to measure each function. If access, deletion, and restraint are found to be the best manner to explain inhibitory function then future research could use this knowledge to predict performance on different outcome measures such as eye-fixation parameters.

There have also been some inconsistencies in recognition performance for young and older adults. The current study used an explicit memory task to test recognition, and age differences were not found for the recognition of target and distractor words. In contrast, Kim, Hasher, and Zacks (2007) have been able to find age differences in recognition of distractor and target items through the use of an implicit memory task. Therefore, future studies could investigate whether age differences in a similar task would be found if an implicit memory task was used rather than an explicit memory task.

Finally, future studies should also investigate the benefit of providing multiple cues to direct attention to target text within a paragraph. Although young adults were able to benefit from spatial predictability of distractor location in the current study, older adults were not able to benefit to the same extent. Thus, future studies could provide older adults with an additional cue (e.g. identity cue – target text presented in color) to investigate whether older adults are able to use this information to become more efficient readers. Moreover, the use of an additional cue could be used to investigate if spatial and identity cues are independent processes or if they rely on the same mechanisms and if these are the same for young versus older adults.

Footnotes

[1] The stimuli were provided by Dr. Gabriel Radvansky.

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Appendix A

DEMOGRAPHIC QUESTIONNAIRE

Name: ____

Age: ____________________________ Gender: __________________

Ethnicity: ____________________________

Highest *Level* of Education - may not correspond with actual number of years: (please circle)

Grade School:	5	6	7	8		
High School:	9	10	11	12		
College:	13	14	15	16 (Bachelor degree)		
Graduate:	17	18 (Master's degree)	19	20	21 (Ph.D.)	
Other:	_______________________					

I would rate my overall health as: (please circle)

1	2	3	4	5
(excellent)		(good)		(poor)

Please list any specific health problems:

Appendix B
Cognitive Failures Questionnaire

Question	Never	Very Rarely	Occassionally	Quite often	Very often
1. Do you read something and find you haven't been thinking about it and must read it again?					
2. Do you find you forgot why you went from one part of the house to the other?					
3. Do you fail to notice sign posts on the road?					
4. Do you find you confuse left and right when giving directions?					
5. Do you bump into people?					
6. Do you find that you forget that you've turned off a lightor the stove or locked the door?					
7. Do you fail to listen to people's names when you are meeting them?					
8. Do you say something and realize afterwards that it might be taken as insulting?					
9. Do you fail to hear people speaking to you when you are doing something else?					
10. Do you lose your temper and regret it?					
11. Do you leave important letters unanswered for days?					
12. Do you find you forget which way to turn on a road you know well but rarely use?					
13. Do you fail to see what you want in a supermarket (although it's there)?					
14. Do you find yourself suddenly wondering whether you've used a word correctly?					
15. Do you have trouble making up your mind?					
16. Do you find you forget appointments?					
17. Do you forget where you put something like a newspaper or book?					
18. Do you find you accidentally throw away the thing you want and keep what you meant to throw away - as in the example of throwing the matchbook and putting the used match in your pocket?					
19. Do you daydream when you ought to be listening to something?					
20. Do you find you forget people's names?					
21. Do you start doing one thing at home and get distracted into doing something else (unintentionally)?					
22. Do you find you can't quite remember some-thing although it's on "the tip of your tongue"?					
23. Do you find you forget what you came to the shops to buy?					
24. Do you drop things?					
25. Do you find you can't think of anything to say?					

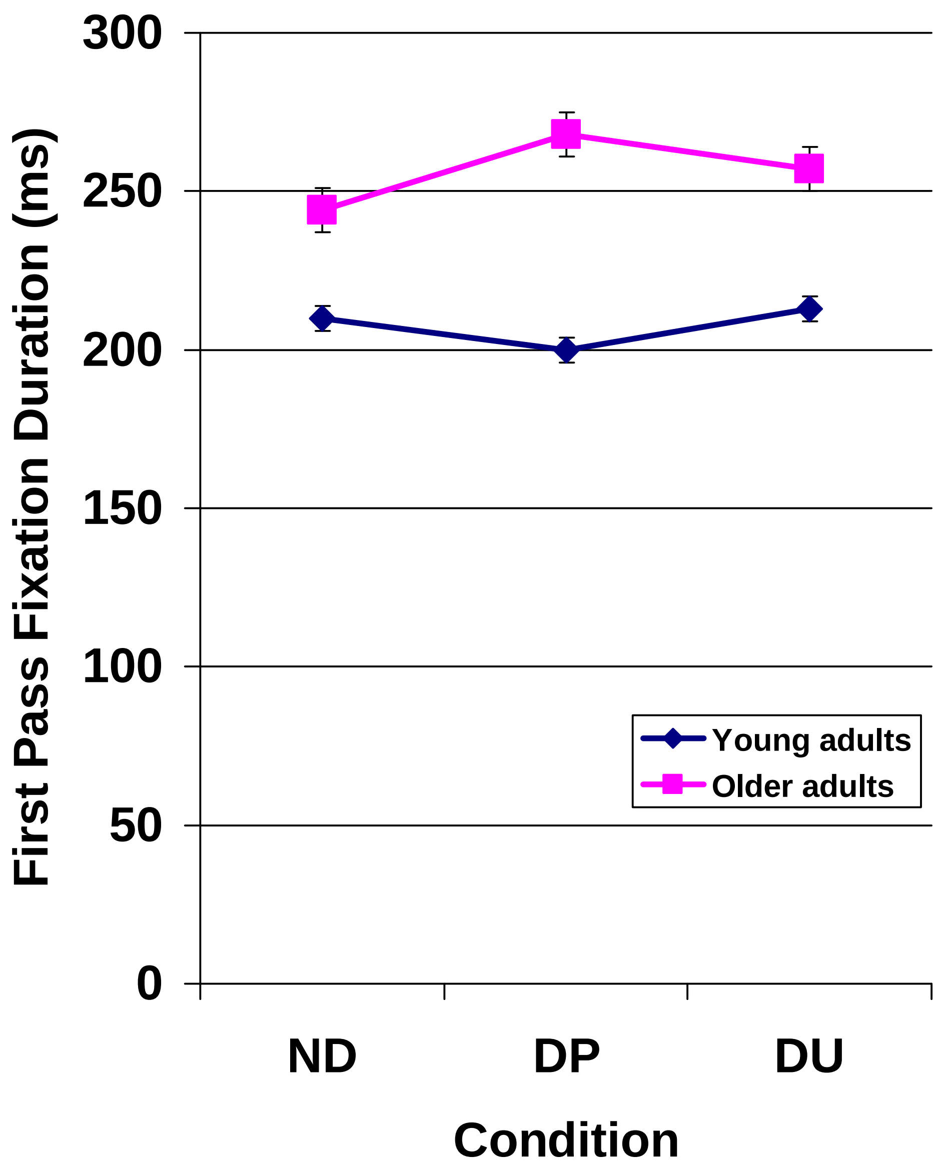

Figure 1. Mean first pass fixation durations to target words across condition by age (ND = distractor absent, DP = predictable distractor location, DU = unpredictable distractor location).

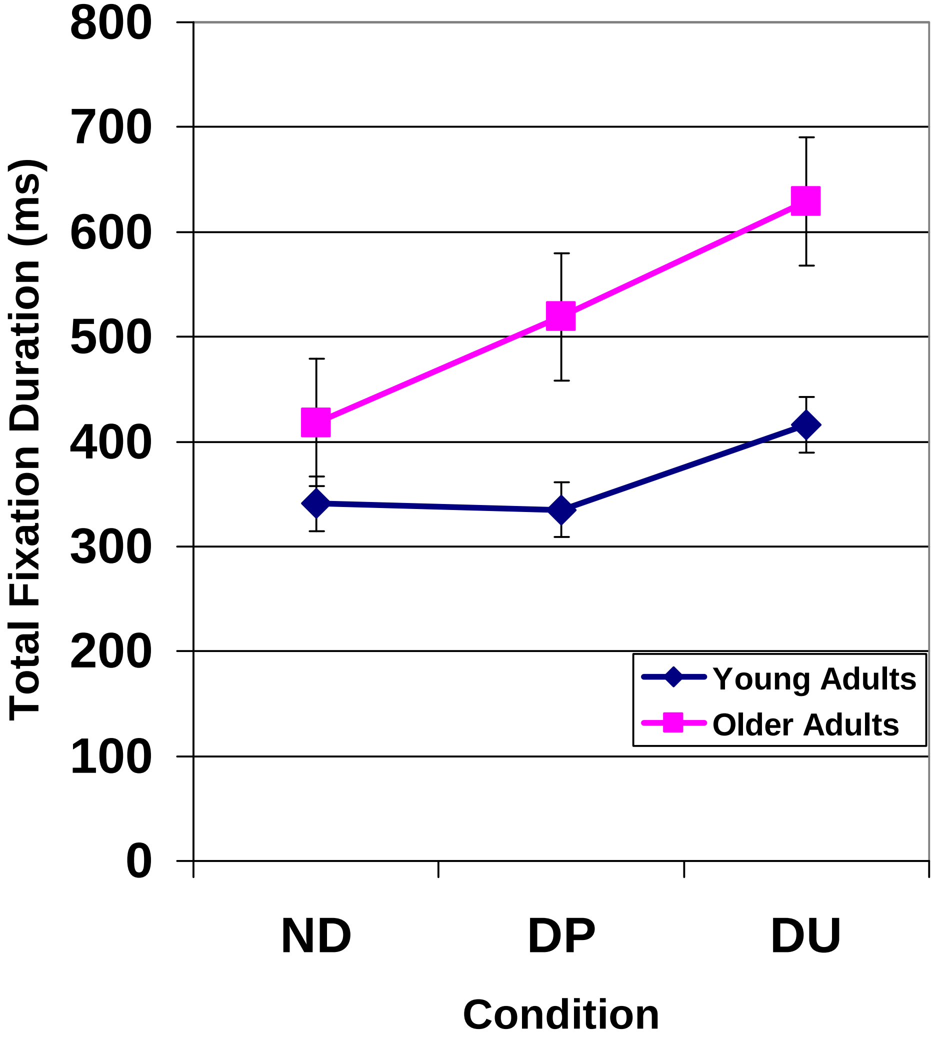

Figure 2. Mean total fixation durations to target words across condition by age (ND = distractor absent, DP = predictable distractor location, DU = unpredictable distractor location).

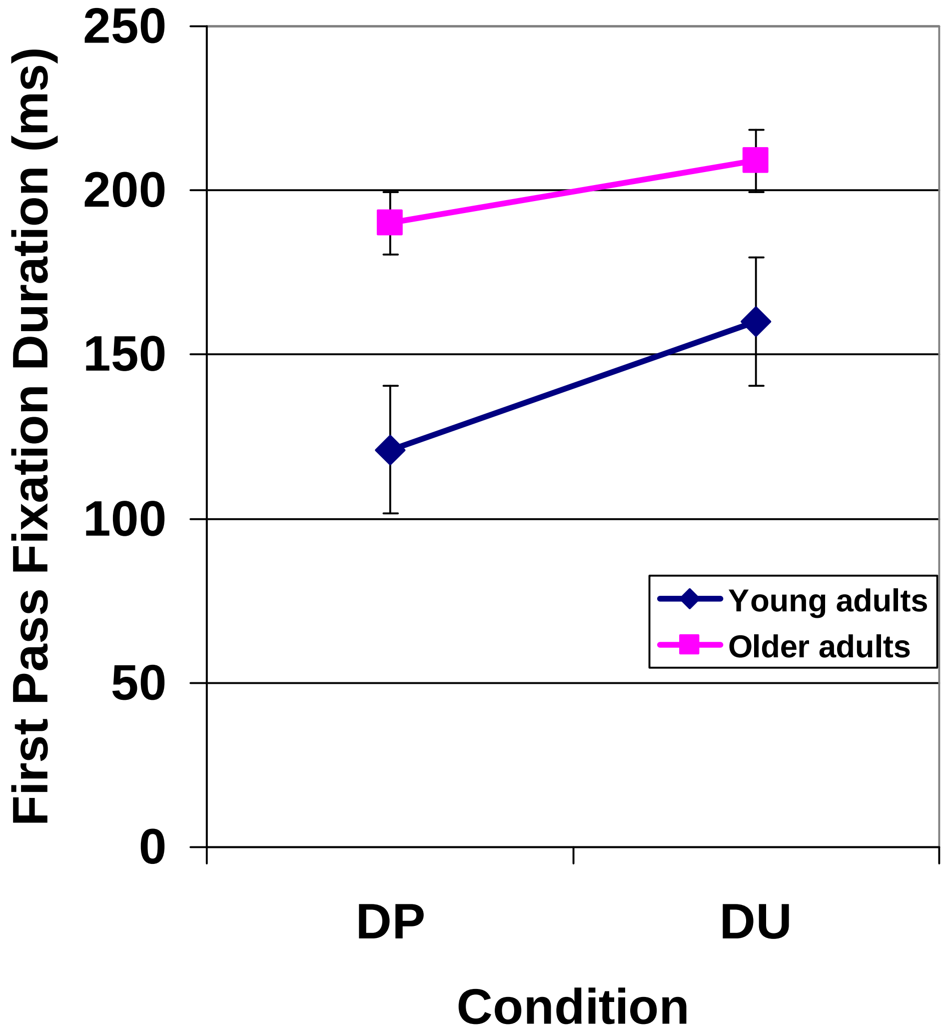

Figure 3. Mean first pass fixation durations to distractor words across conditions by age (DP = predictable distractor location, DU = unpredictable distractor location).

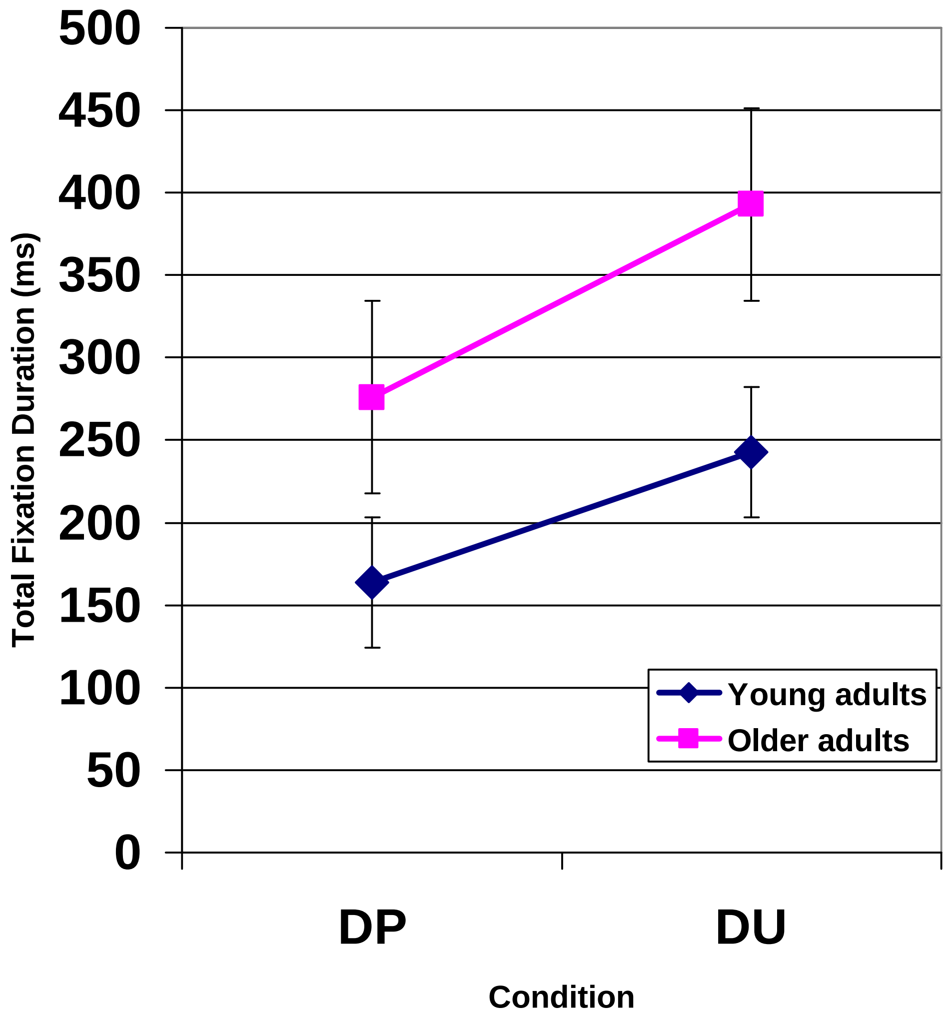

Figure 4. Mean total fixation durations to distractor words across condition by age (DP = predictable distractor location, DU = unpredictable distractor location).

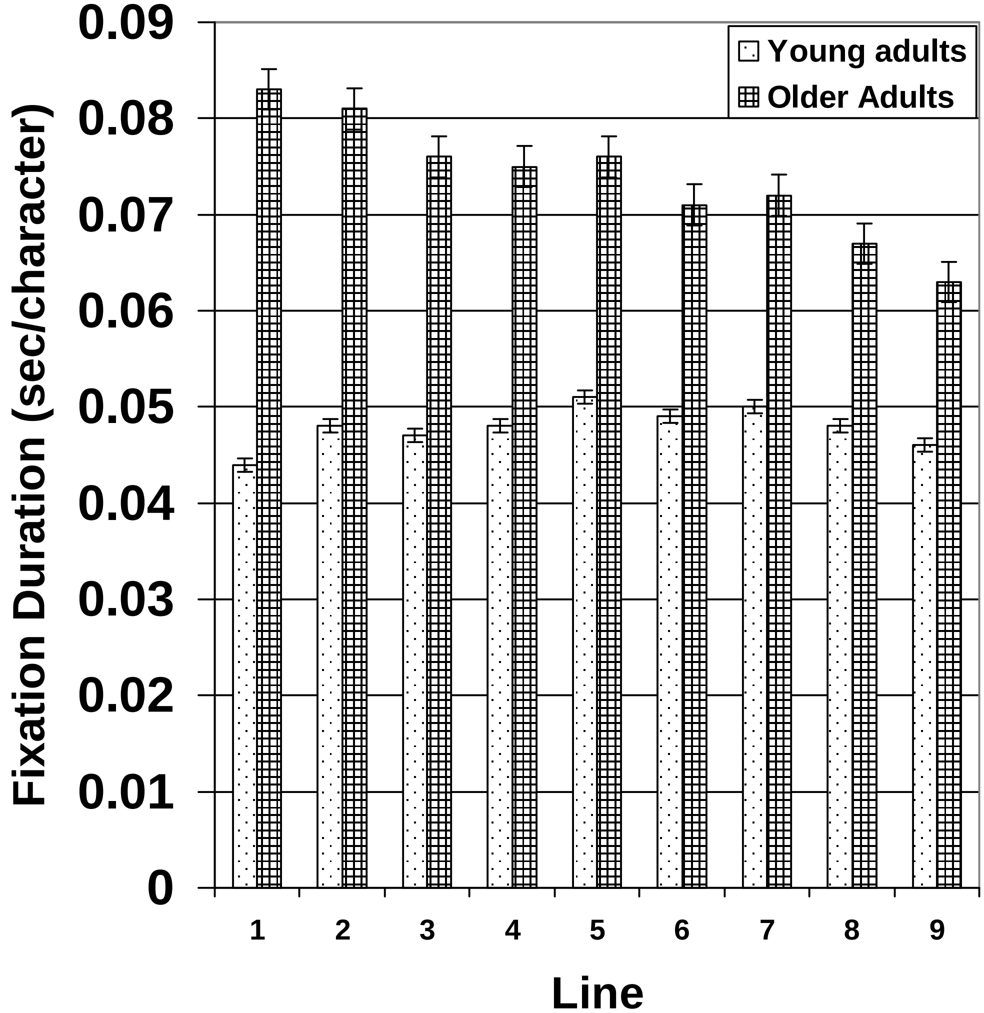

Figure 5. Mean total fixation durations to lines 1-9 across line by age.

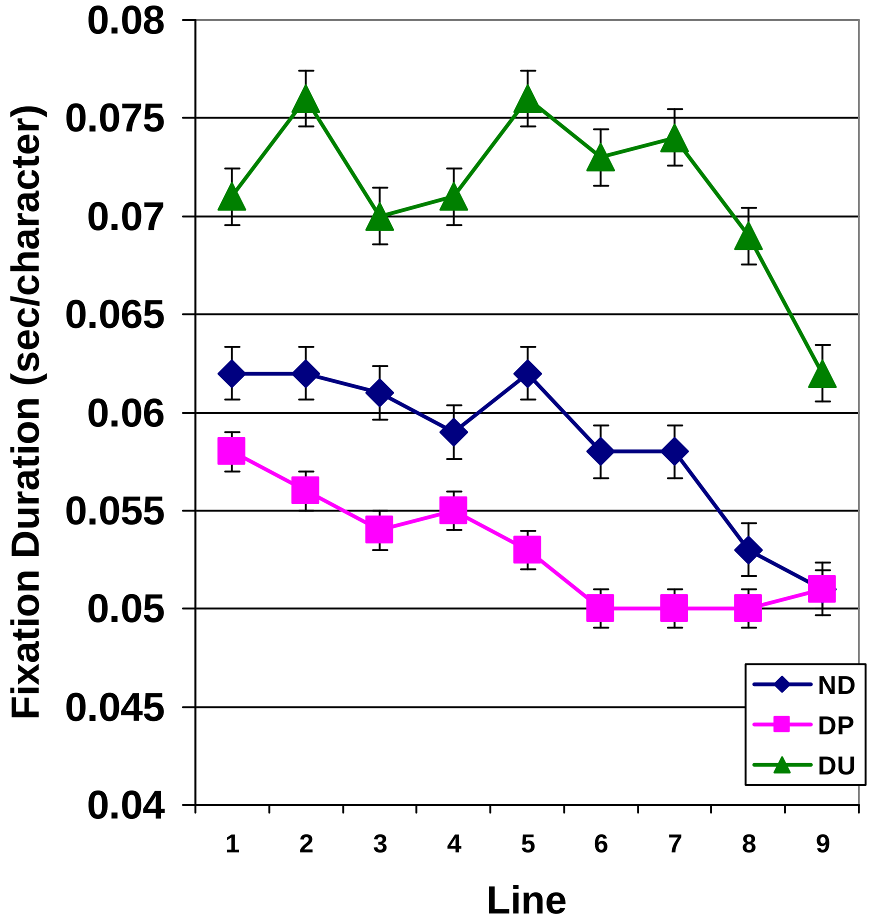

Figure 6. Mean total fixation duration to lines 1-9 across line by condition (ND = distractor absent, DP = predictable distractor location, DU = unpredictable distractor location).

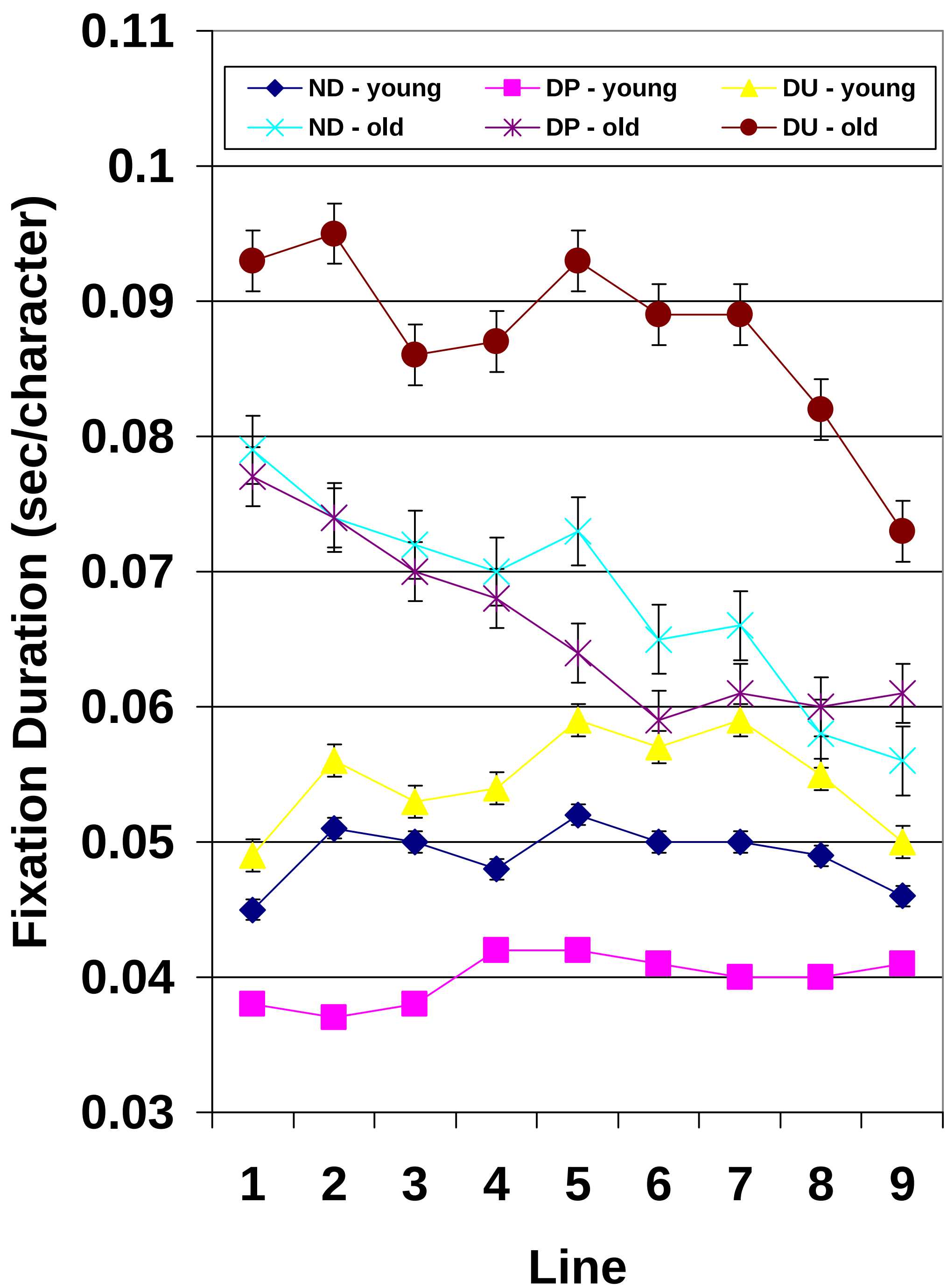

Figure 7. Mean total fixation duration to lines 1-9 across line by condition and age (ND = distractor absent, DP = predictable distractor location, DU = unpredictable distractor location).

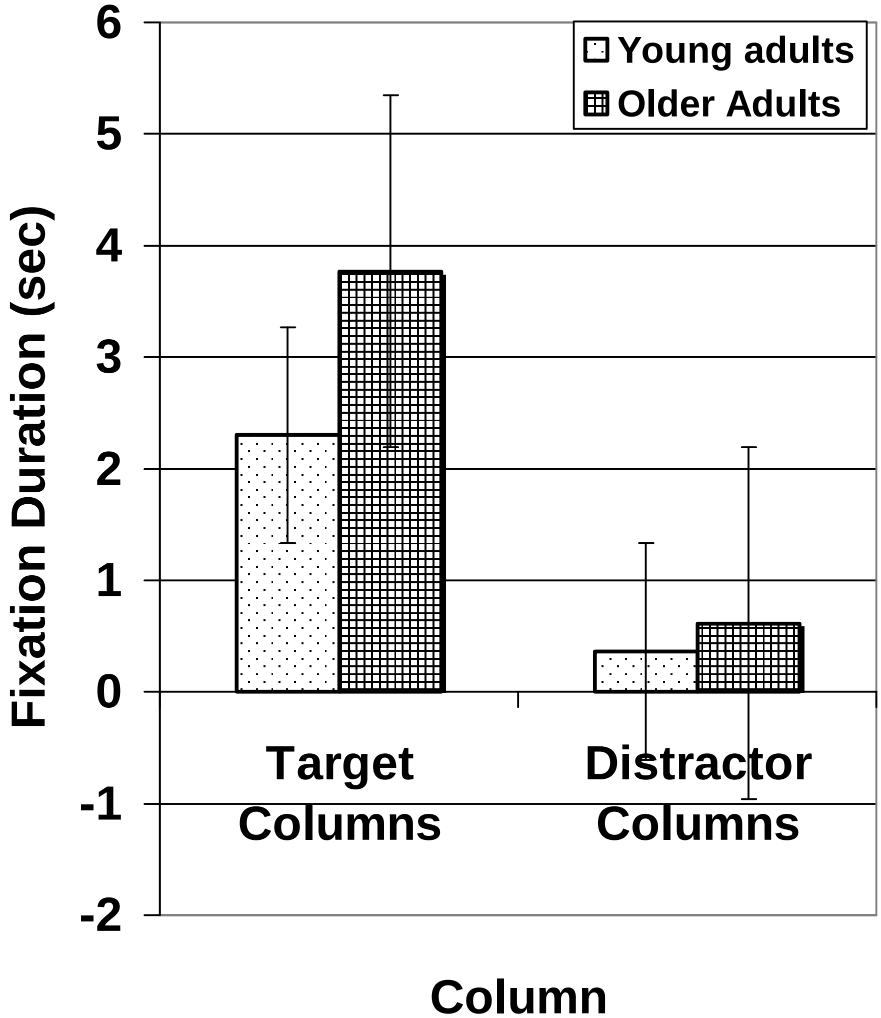

Figure 8. Mean total fixation duration to target and distractor columns by age.

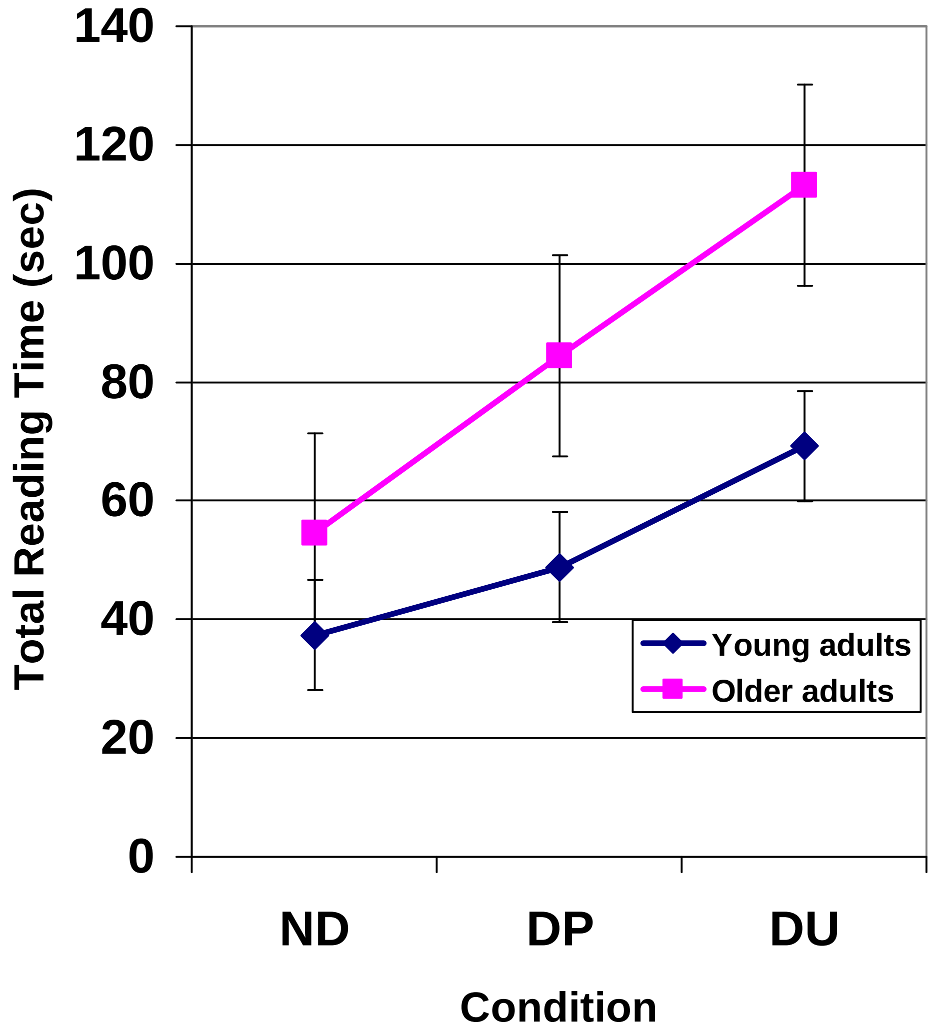

Figure 9. Mean total reading time across condition by age (ND = distractor absent, DP = predictable distractor location, DU = unpredictable distractor location).

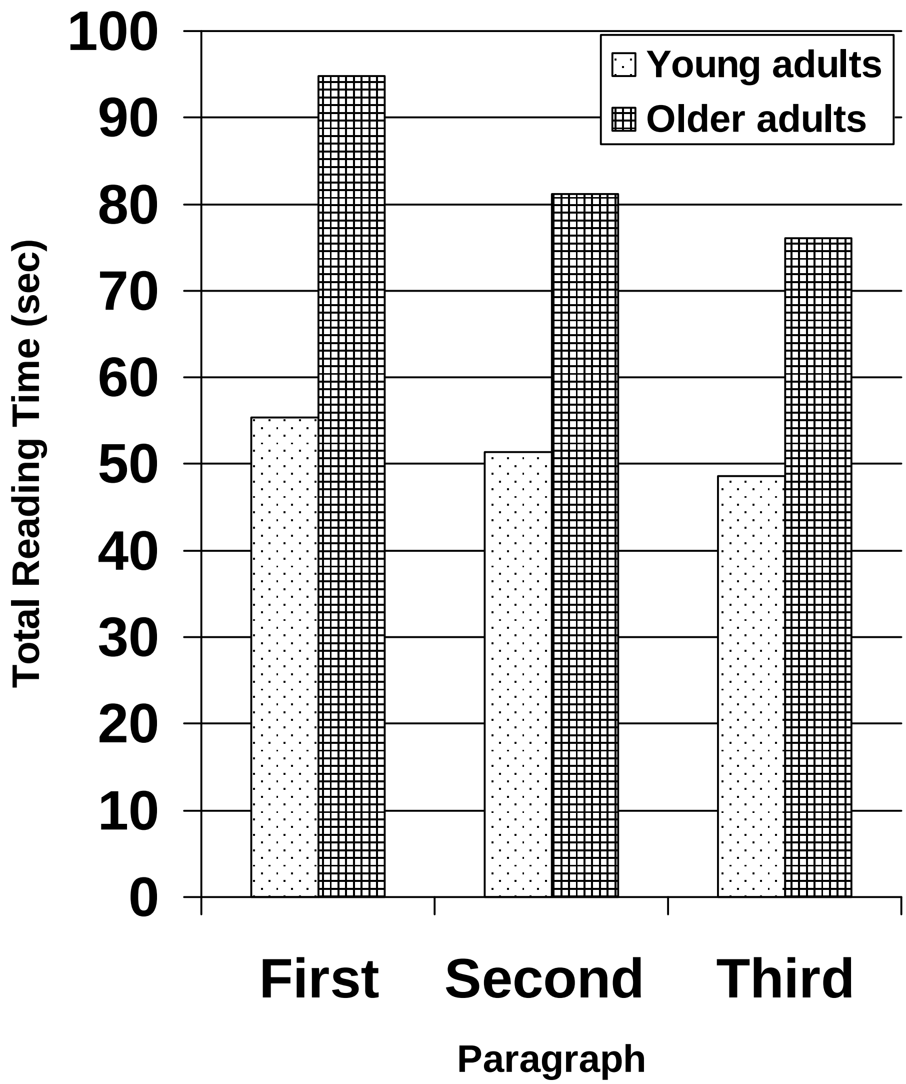

Figure 10. Mean total reading time across paragraph by age.

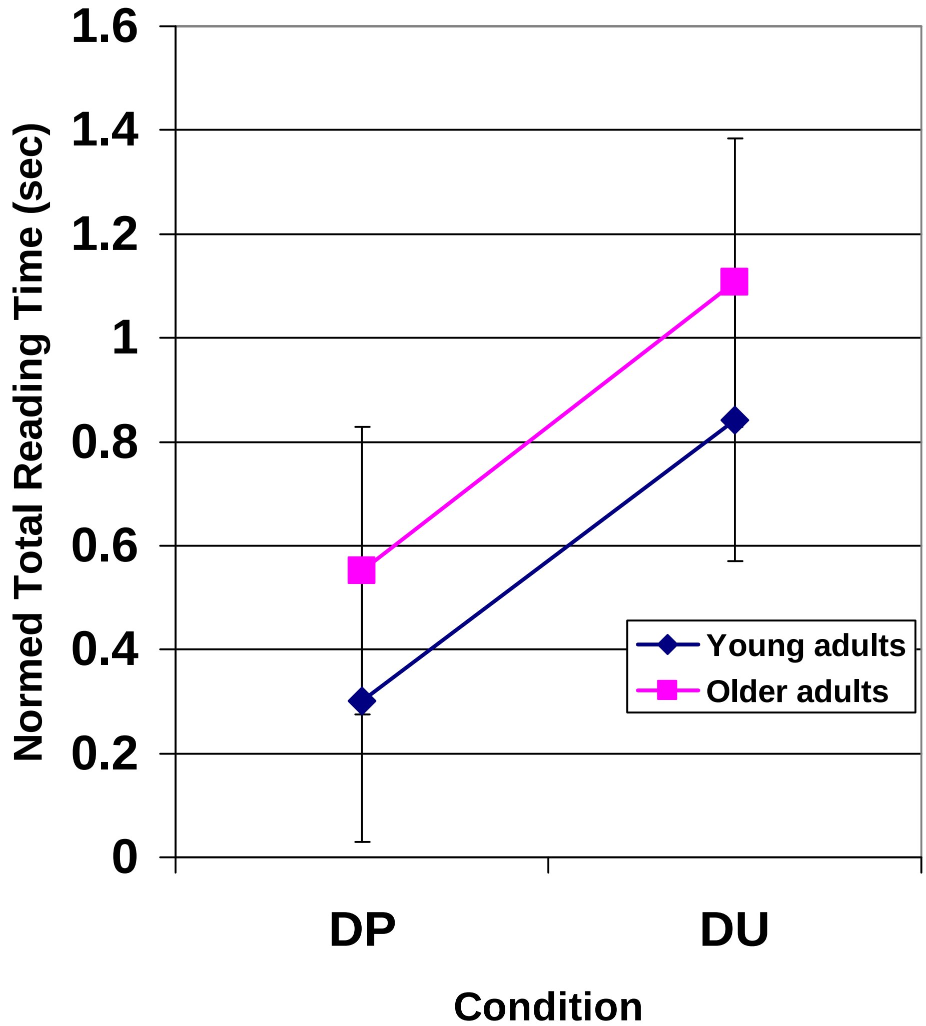

Figure 11. Mean normalized total reading time across condition by age (DP = predictable distractor location, DU = unpredictable distractor location).

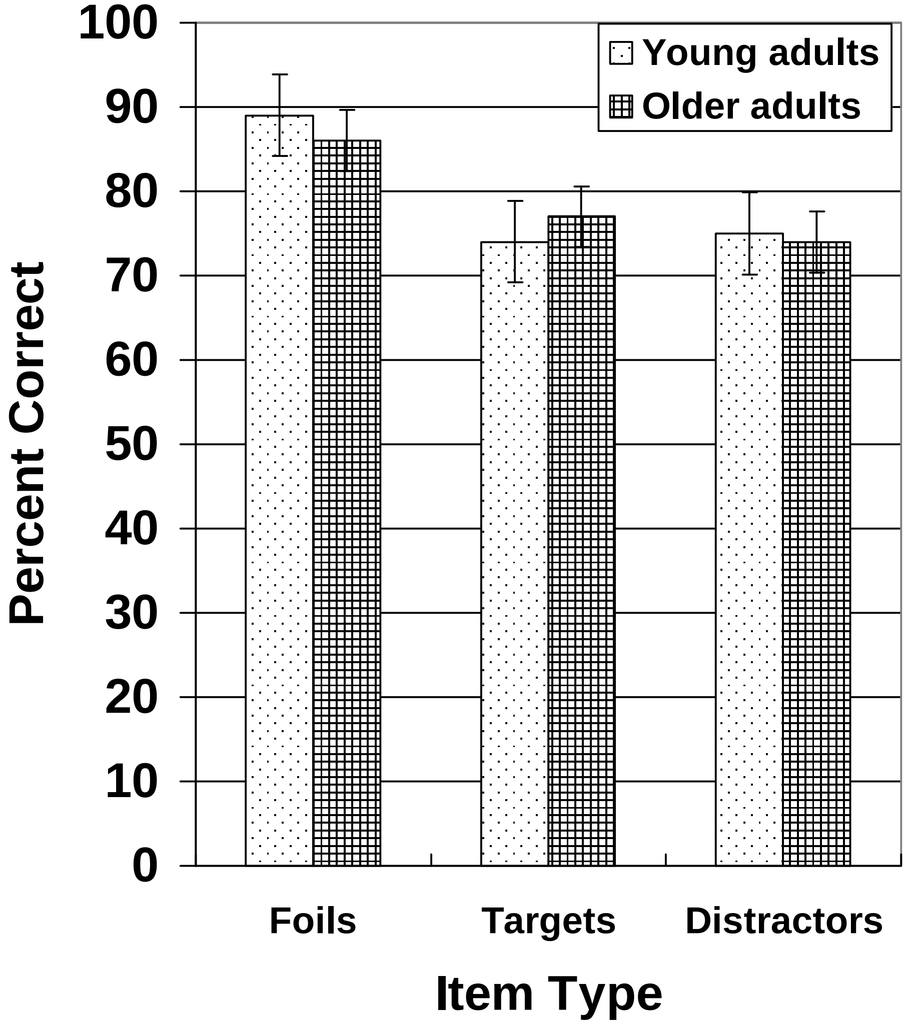

Figure 12. Mean accuracy rates for recognition test by age.

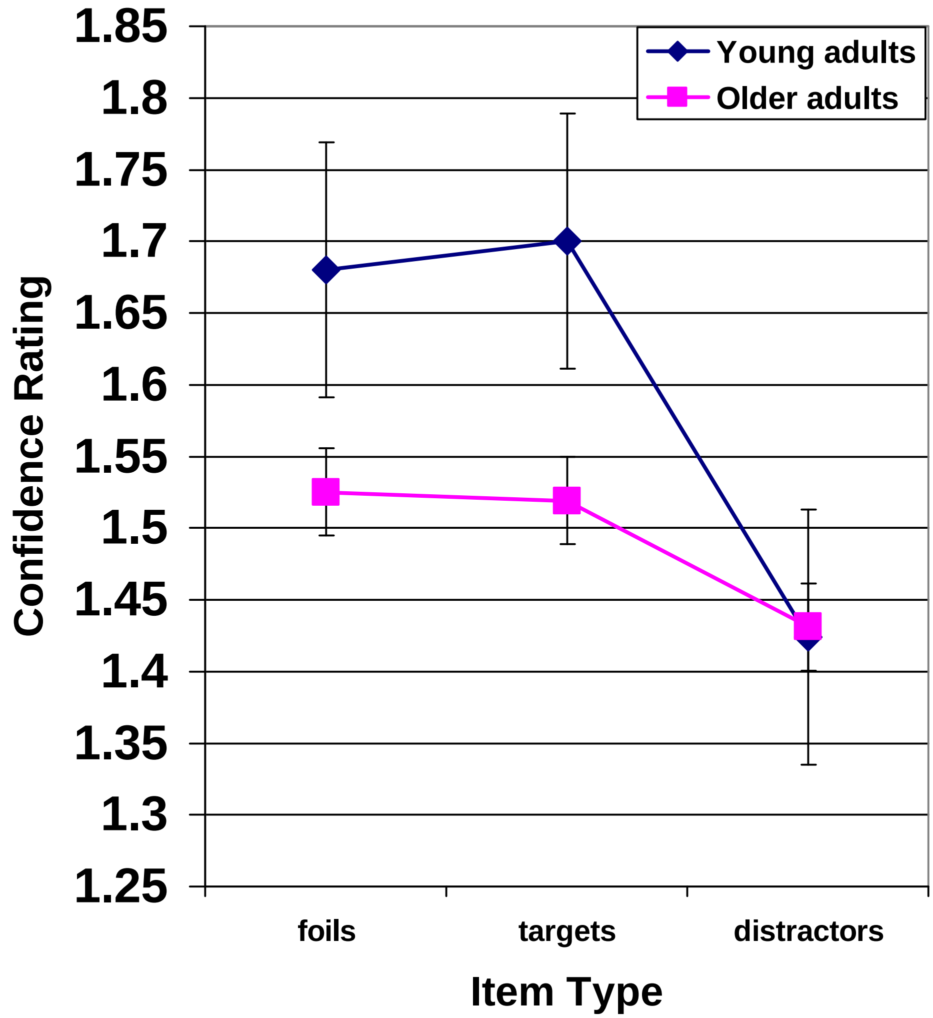

Figure 13. Mean confidence ratings across item type by age (1=very confident, 2 = somewhat confident, 3 = guessing).

Table 1. Coh-Metrix Variables for the nine experimental paragraphs.

Measures	# of Words	# of Sentences	Avg. Syllables per word	Concreten-ess	Freq. of content words	Flesch Reading Ease	Flesch-Kincaid Grade Level
Paragraph 1	127	9	1.21	413	2093	97.05	1.48
Paragraph 2	99	8	1.46	439	1316	74.61	5.09
Paragraph 3	101	8	1.40	376	1882	81.9	3.51
Paragraph 4	118	6	1.3	341	2926	89.12	2.78
Paragraph 5	112	8	1.38	407	2516	83.06	3.31
Paragraph 6	114	7	1.34	386	3263	86.07	3.02
Paragraph 7	122	10	1.27	358	4857	92.88	1.9
Paragraph 8	121	7	1.22	381	2494	96.37	1.7
Paragraph 9	113	9	1.35	376	4630	86.29	2.87

Table 2. Example paragraph materials. The paragraphs were presented in Arial italic font. Distractors were presented in Arial regular font.

Paragraph without distractors

Dr. Baker needed	*some vodka for a*	*party so he went to*
the liquor store.	*Just outside the*	*store he was*
approached by a	*girl who was his*	*brother's age,*
about 17 or 18.	*The girl asked him*	*if he would get her*
a fifth of rum while	*in the store. "I*	*don't know,"*
Dr. Baker said as	*he thought it over.*	*"Oh please sir," she*
said batting her	*eyelashes. He*	*thought that he*
might as well since	*she was being so*	*nice. He paid for*
the items and	*walked out to the*	*girl. As he was*
giving her the	*bottle, men came*	*around the corner*
flashing badges	*and not seeming*	*too happy.*
Dr. Baker felt a	*lump in his throat.*	

Paragraph with distractors in predictable locations

Dr. Baker needed	estate plane rifle	*some vodka for a*	calves estate novel	*party so he went to*
the liquor store.	novel winter calves	*Just outside the*	film daily murder	*store he was*
approached by a	murder film editor	*girl who was his*	winter plane thin	*brother's age,*
about 17 or 18.	thin editor daily	*The girl asked him*	daily motor calves	*if he would get her*
a fifth of rum while	motor calves winter	*in the store. "I*	rifle winter editor	*don't know,"*
Dr. Baker said as	plane estate novel	*he thought it over.*	editor thin motor	*"Oh please sir," she*
said batting her	editor rifle motor	*eyelashes. He*	estate film daily	*thought that he*
might as well since	daily novel thin	*she was being so*	plane murder rifle	*nice. He paid for*
the items and	film murder estate	*walked out to the*	murder editor novel	*girl. As he was*
giving her the	calves thin plane	*bottle, men came*	thin estate film	*around the corner*
flashing badges	winter motor film	*and not seeming*	motor calves winter	*too happy.*
Dr. Baker felt a	rifle daily murder	*lump in his throat.*		

Paragraph with distractors in unpredictable locations

Dr. Baker needed	*some vodka for a*	estate thin murder	*party so he went*	*to* editor daily film
the liquor store.	novel winter calves	*Just outside the*	film daily murder	*store he was*
motor estate thin	*approached by a*	*girl who was his*	winter plane thin	*brother's age,*
about 17 or 18.	thin editor daily	*The girl asked him*	*if he would get her*	plane calves rifle
a fifth of rum while	*in the store. "I*	motor estate film	*don't know,"*	winter novel daily
Dr. Baker said as	plane estate novel	*he thought it over.*	editor thin motor	*"Oh please sir," she*
editor rifle motor	*said batting her*	*eyelashes. He*	estate film daily	*thought that he*
might as well since	daily novel thin	*she was being so*	*nice. He paid for*	murder rifle calves
the items and	*walked out to the*	film murder estate	*girl. As he was*	*giving her the*
murder editor novel	*bottle, men came*	calves thin plane	*around the corner*	thin estate film
flashing badges	winter motor film	*and not seeming*	motor calves winter	*too* motor *happy.*
rifle daily murder	*Dr. Baker felt a*	*lump in his throat.*		

Table 3. Example multiple-choice question and open-ended question for “Dr. Baker” paragraph.

<u>Multiple-choice question</u>

1. Where did Dr. Baker feel a lump?
    a. Leg
    b. Calves
    c. Arm
    d. Throat
    e. Back
    f. Head

<u>Open-ended question</u>

1. Why was Dr. Baker in trouble?

Table 4. Hypothesized categorization of tasks by inhibitory function.

	Access	Deletion	Restraint
Reading w/ distraction	First Pass Fixation	Total Fixation Duration Distractor Word Recog.	Total Reading Time
Reading Span Errors	current nonfinal	previous intrusions	extraneous intrusions
Cog. Measures	Trails 1 Trails 2 Trails 3 CFQ	Trails 4	Stroop Test Hayling Test

Table 5. Means and Standard Deviations for each neuropsychological test.

Neuropsychological Measures	Young Adults		Older Adults	
	Mean	St.Dev.	Mean	St. Dev.
Cognitive Failures Questionnaire	34.35	11.19	32.77	9.23
Stroop**	.24	.09	.43	.12
Visual Scanning (Trails 1)**	16.52	4.52	22.15	4.94
Letter Inhibition (Trails 2)	.46	.52	.54	.63
Number Inhibition (Trails 3)	.40	.44	.49	.57
Switching (Trails 4)	2.08	1.16	2.36	1.31
Hayling**	3.02	2.41	7.93	5.60
Daneman and Carpenter Reading Span**	3.8	0.6	3.18	0.71
Current Nonfinal Errors	0.433	0.81	0.672	0.85
Previous Intrusions**	0.183	0.39	0.672	0.81
Extraneous Intrusions	0.15	0.44	0.148	0.36

*age effect p <.05
** age effect p = .001

Table 6. Results of the Principle-Components Factor Analysis

Variable	Speed/Executive Attention	Access	Deletion	Restraint
% of variance	28.39	11.04	11.73	17.08
Eigenvalue tests	2.839	1.104	1.172	1.708
Visual Scanning (Trails 1)	**0.724**	-0.106	0.212	-0.299
Letter Inhibition (Trails 2)	**0.82**	0.11	-0.028	0.137
Number Inhibition (Trails 3)	**0.857**	-0.05	0.092	0.127
Switching (Trails 4)	**0.88**	-0.006	-0.047	0.105
Current nonfinal errors	0.101	**0.806**	-0.15	-0.034
Cognitive Failures Questionnaire	0.145	**-0.595**	-0.257	-0.176
Extraneous intrusion errors	0.16	0.171	**0.769**	-0.183
Previous intrusion errors	-0.033	-0.245	**0.672**	0.457
Hayling	0	0.16	0.098	**0.796**
Stroop	0.159	-0.018	-0.094	**0.8**

Bold print indicates coefficients loading on each factor. Shaded squares indicate predicted loading coefficients.

Table 7. Regression results for first pass fixation durations to distractor words.

Dependent Variable: First Pass Fixation to DISTRACTORS

Experimental Condition	**Predictor Variables**	R^2	R^2 increase
	1		
Predictable Location	Restraint factor	0.209	
	Total reading time_No Distractor	0.32	0.111
	1		
Unpredictable Location	Restraint factor	0.125	
	Total reading time_No Distractor	0.191	0.067

p<.01

Table 8. Regression results for total fixation durations to distractor words.

Dependent Variable: Total Fixation Durations to DISTRACTORS

Experimental Condition	**Predictor Variables**	R^2	R^2 increase
	1		
Predictable	Restraint factor	0.215	
Location	Total reading time_No Distractor	0.336	0.121
	1		
Unpredictable	Restraint factor	0.16	
Location	Total reading time_No Distractor	0.328	0.168

p<.01

Table 9. Regression results for total reading time.

Dependent Variable: Total Reading Time

Experimental Condition	**Predictor Variables**	R^2	R^2 increase
Predictable Location	1		
	Restraint factor	0.226	
	Total reading time_No Distractor	0.614	0.387
Unpredictable Location	1		
	Restraint factor	0.242	
	Total reading time_No Distractor	0.57	0.328
	Age	0.585	0.014

$p<.01$