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An Examination of Inhibitory Effects in Word Recognition in Younger and Older Adults

by

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies for acceptance, a thesis entitled "An Investigation of Inhibitory Effects in Word Recognition in Younger and Older Adults" submitted by Alisa D. McArthur in partial fulfillment of the requirements for the degree of Doctor of Philosophy.

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ABSTRACT

Three experiments were conducted in order to examine the inhibitory deficit hypothesis (Hasher & Zacks, 1988) of age-related cognitive decline in the area of hypothesis testing during visual word recognition. Specifically, the effect of forming incorrect hypotheses (see Lindfield, Wingfield, & Bowles, 1994) when attempting to identify a visually degraded word was investigated. In Experiment 1, the inhibitory neighborhood frequency effect was investigated using the progressive demasking task. Older adults demonstrated an inhibitory effect (slower reaction time) for words with just one higher frequency neighbor (HFN) relative to words without HFNs. Younger adults, demonstrated an inhibitory effect which only appeared for words with four HFNs.

In Experiment 2, a task similar to that used by Lindfield et al. (1994) in picture identification was used to further investigate hypothesis testing in identifying degraded word stimuli. Fragmented words were presented either in an ascending or fixed presentation. In both cases, the entire word was never presented. Both younger and older participants were significantly more accurate in the fixed presentation relative to the ascending presentation, a perceptual interference effect (Bruner & Potter, 1964). However, there was no significant age-interaction. Number of HFNs was also manipulated, as in Experiment 1. However, no significant effects were observed with this variable.

In Experiment 3 the progressive demasking procedure was preceded by a prime. The prime was either unrelated (PAPER-MILK), associatively related (LEMON-LIME) or a foil (associatively related to a HFN of the target; BOY-GILL). Older adults demonstrated a significantly larger facilitory priming effect compared to younger adults (unrelated reaction time - related reaction time). Younger adults demonstrated a small, but significant, interference effect (foil - unrelated), however, the effect was not significant for older adults. The older adults, however, were more likely to make HFN errors in the foil condition (e.g., mistaking EAST for EASE when the prime was WEST).

Results from all three experiments are discussed in terms of the inhibitory deficit hypothesis. As well, implications for hypotheses (Grainger & Jacobs, 1996; Sears, Lupker & Hino, 1999) regarding the inhibitory neighborhood frequency effect will be discussed.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Consider the following situation. After completing a strenuous hike in the mountains you see a sign posted in the distance. As you approach the sign and squint to read it, much to your delight you realize that it reads "BEERS AHEAD!". You begin to walk more briskly in anticipation of your reward when you round the bend and come face to face with a grizzly bear. Once the bear moves away you take a closer look at the sign and realize your mistake; the sign reads BEARS AHEAD! This is the potential problem when we form hypotheses about the identity of incomplete stimuli. In situations such as this, our ability to inhibit (abandon) initial hypotheses to make the correct identification is essential. How younger and older adults deal with these types of situations is explored in the present study.

Introduction

During the past several years researchers have illustrated age-related differences on a number of different measures of cognitive functioning. These have included a reduced working memory span (e.g., Chiappe, Hasher, & Siegel, 2000; Wingfield, Stine, Lahar, & Aberdeen, 1988), decreased speed of information processing (e.g., Salthouse & Meinze, 1995), problems in selective attention (e.g., Earles, Tabor Connor, Frieske, Park, Smith & Zwahr, 1997; Plude & Hoyer, 1986), increased costs in task-switching (Mayr, 2001) and episodic memory deficits (e.g., Craik & Jennings, 1992). Researchers have since attempted to integrate these findings into a general theory of cognitive aging, one capable of explaining a number, if not all, of these observed age-related cognitive deficits. Some candidates have been decreased processing speed (Salthouse, 1996), and working memory deficits (Hedden & Park, 2001). Another alternative explanation, which is the focus of the present study, is the inhibitory deficit hypothesis (Hasher & Zacks, 1988; Zacks & Hasher, 1994).

According to the inhibitory deficit hypothesis, as people age, the ability to stay 'focused' on the task at hand and ignore irrelevant information deteriorates (Hasher & Zacks, 1988). Hasher and Zacks (1988) proposed that a deficit in the ability to inhibit, or ignore, irrelevant information could explain the working memory deficit observed in older adults (i.e., decreased working memory span; Chiappe et al., 2000; Wingfield, et al., 1988). A deficit in inhibitory functioning would result in an increase in irrelevant information entering working memory, thereby creating interference for the processing of relevant information, as well as decreasing the available working memory capacity for relevant information. This would lead to the appearance of decreased working memory capacity.

Hasher and Zacks (1988) proposed that inhibitory processes have two different functions that aid in the efficiency of working memory. The first function is to hinder the access of goal-irrelevant information into working memory. This goal-irrelevant information may have been activated initially in parallel with goal-relevant information, and may be internally or externally derived. For example, the irrelevant information could be irrelevant environmental information, personal memories or concerns, or misguided interpretations. The second function is to suppress irrelevant information that does gain access into working memory, as well as to suppress information that may have initially been relevant, but is no longer. Inhibitory processes are also thought to prevent attention from returning to previously rejected information (Zacks & Hasher, 1994).

This hypothesized deficit in the ability to inhibit irrelevant information is thought to manifest itself in situations where there is competition between target and non-target information. That is, to successfully process target information, one must inhibit competing items to reduce the amount of interference created during target identification. This hypothesis has received much attention and has gained considerable support in a number of different areas of study, including visual attention (e.g., Lahar, Isaak, & McArthur, 2001; McDowd & Oseas-Kreger, 1991; Verhaeghen & De Meersman, 1998), language processes (e.g., Hamm & Hasher, 1992; Hartman & Hasher, 1991; Hasher, Quig, & May, 1997) and memory processes (e.g., Chiappe et al., 2000; Hasher & Zacks, 1988; Oberauer, 2001). There has also been some neuroanatomical evidence, linking inhibitory control with the prefrontal cortex (Nielson, Langenecker, & Garavan, 2002).

Inhibition in Selective Attention

Initially, much of the support for the inhibitory deficit hypothesis stemmed from the negative priming paradigm (e.g., McDowd & Oseas-Kreger, 1991; Stoltzfus, Hasher, Zacks, Ulivi, & Goldstein, 1993). These tasks require participants to respond to one item (the target) while ignoring another item (the distractor). When the distractor on one trial becomes the target on the very next trial, response times are slowed relative to a control condition where there is no relationship between target and distractor items on successive trials. This phenomenon is referred to as the negative priming effect, and is suggested to be a measure of the strength of inhibition (McDowd, 1997). That is, it is suggested that this response slowing is due to the active inhibition of the distractor item on each trial. As a result, when a target on one trial is identical to the previous trial's distractor, it takes longer to reach a activation level necessary to make a response. According to this view, the more strongly something is inhibited the longer it should take to access it (McDowd, Oseas-Kreger, & Filion, 1995).

Several investigators have reported that older adults do not exhibit a negative priming effect (e.g., Kane, Hasher, Stoltzfus, Zacks, & Connelly, 1994; Kane, May, Hasher, & Rahhal, 1997; McDowd & Oseas-Kreger, 1991). However, there have also been reports of equivalent negative priming effects in younger and older adults (e.g., Kramer, Humphrey, Larish, Logan & Strayer, 1994; Sullivan & Faust, 1993). Some researchers have begun to question the validity of the negative priming paradigm as a measure of inhibitory processes (e.g., Milliken, Joordens, Merikle, & Seiffert, 1998; Neill & Valdes, 1992; Pesta & Sanders, 2000), so the interpretation of this literature may not be straightforward.

Inhibitory deficits in other attentional paradigms have also been explored (e.g., the attentional blink, Lahar et al., 2001; the modified Sternberg recognition task, Oberauer, 2001). In the attentional cueing paradigm the inhibition of return effect (Posner & Cohen, 1984) has been used to gauge the degree of inhibition previously attended locations are subjected to. Inhibition of return occurs when attention is drawn to a cued location and is then drawn away. Subsequent shifts of attention to the same location are delayed, producing delayed responding to items presented in the previously cued location (Posner & Cohen, 1984). One postulated function of inhibition of return is to increase the efficiency of visual search by avoiding locations that have already been examined (Klein & MacInnes, 1999). The initial reports using this paradigm were of age equivalent inhibition of return (Faust & Balota, 1997; Hartley & Kieley, 1995). However, more recently, McCrae and Abrams (2001) reported age differences in object-based inhibition of return but not in location-based inhibition of return. For older adults, attention was inhibited from returning to previously attended locations, but not to previously attended objects.

Considered together, these results suggest that it is very unlikely that there is one inhibitory mechanism that declines with age. It is much more likely that there are different forms of inhibitory processes. McDowd et al. (1995) point out that it is important to delineate the various types of inhibitory processes and to determine which of these are affected by aging and which are not. One of the major goals of this study was to address this concern. The present study investigated inhibitory processes in hypothesis testing taking place while trying to identify a visually degraded word.

Inhibition in Language Processing

A common theme in studies that have investigated inhibitory processes in older adults is that they have a difficulty with 'pruning'. That is, following an initial stage of widespread activation, whether it be ideas, interpretations of an ambiguous word, or inferences, older adults have more difficulty inhibiting items that are no longer relevant, leading to increased interference (competition) for the target (e.g., Hamm & Hasher, 1992; Lindfield, Wingfield & Bowles, 1994).

For example, Hamm and Hasher (1992) suggest that older adults have a deficit in inhibiting inferences that are drawn during discourse processes, inferences that are later shown to be incorrect. The idea is that older adults 'get stuck on' an initial idea and have a difficult time 'letting it go'. Hamm and Hasher used garden path sentences in which participants were presented with paragraphs, which initially lead to one interpretation of events. However, by the end of the paragraph it became clear that the original interpretation was false and a new interpretation was formed. Hamm and Hasher found that older adults were more likely to 'hold onto' the original interpretation, compared to younger adults (for a similar finding, using the directed forgetting paradigm, see Zacks, Radvansky & Hasher, 1996).

Duchek, Balota, and Thessing (1998) investigated the effects of distracting information on reading times and text comprehension in younger and older adults. The distracting information was embedded in the text (in italics) and was either orthographic (xxxx), lexical (unrelated material), or semantic (related material). Reading times and comprehension in these conditions were compared to a control condition in which there was no distracting information. Duchek et al. reported that older adults required more time with increasing distraction difficulty (with orthographic information being the least distracting and semantic information being the most distracting) and that, correspondingly, they made more comprehension errors. They concluded that these results were due to "the decreased efficiency of an inhibitory system" (p. 178), and therefore, supported an inhibitory deficit in older adults.

It has also been suggested that older adults increased off-target verbosity (e.g., Arbuckle & Gold, 1993; Gold, Andres, Arbuckle, & Schwartzman, 1988) when speaking may be explained by an inhibitory deficit. Specifically, it is suggested that older adults are more likely to stray off-topic or lack focus during conversation due to an inability to inhibit irrelevant thoughts that are activated during discourse (Burke, 1997). Furthermore, off-target verbosity has been linked to other neuropsychological measures of inhibition (e.g., verbal fluency; Arbuckle, Nohara-LeClair, & Pushkar, 2000).

Note that in some language processing studies there is no evidence of an age-related inhibitory processing deficit. For example, Rouleau and Belleville's (1996) results suggest that older adults may experience an inhibitory deficit at the lexico-semantic level, but that the phonological system may be spared of such a decline. They used the irrelevant speech effect paradigm to test inhibitory processes in younger and older adults. Participants were asked to recall short sequences of visually presented digits while attempting to ignore irrelevant background noises. Inhibitory processes are thought to affect performance on the working memory task (i.e., recalling the digits), in that the better one is able to inhibit irrelevant noise the better one should be recalling digits. The typical finding is that participant's performance on the working memory task is affected when the irrelevant noise is unfamiliar or familiar speech, but is unaffected when the irrelevant stimuli is white noise. This effect is termed the irrelevant speech effect. Rouleau and Belleville found that both younger and older adults exhibited the irrelevant speech effect, and, more importantly, that older adults did not exhibit a larger effect. The inhibitory deficit hypothesis would predict that if older adults were less able to inhibit irrelevant information then they should be more affected by the presentation of irrelevant verbal material relative to younger adults. Instead of completely rejecting the inhibitory deficit hypothesis, Rouleau and Belleville suggested that this task measures inhibition at a phonological stage of processing rather than a lexico-semantic stage, and that this phonological system is spared from an inhibitory deficit in normal aging.

This result could help explain Stine and Wingfield's (1994) report of no age differences in the ability to inhibit high-probability competitors in discourse comprehension. They used a gating paradigm to test the prediction (based on the inhibitory deficit hypothesis) that older adults would have increased difficulties recognizing a partially presented unexpected word (i.e., one that would not be the most likely word given the context of a sentence) relative to younger adults. Stine and Wingfield investigated how much of a target word needed to be presented to make a correct identification under a number of different conditions. Participants listened to sentences that were either 'high' or 'low' contextually constraining before making a decision on the identity of the final (target) word of the sentence. For the low contextually constraining sentences participants simply heard "The next word you will hear is...". This was then followed by the onset of the target word. The high contextually constraining sentences varied. For example, "All the guests had a very good ...". Additionally, sentences either ended with a word that was the most predictable word in the high contextually constraining sentence (low probability competitor condition), or the second most predictable word (high probability competitor condition). For the above example, "All the guests had a very good ...", the most probable word (i.e., the low probability competitor condition) would be TIME, and the second most probable word (i.e., the high probability competitor condition) would be DINNER. (These probabilities were established in previous research; Bloom & Fischler, 1980). Initially, participants heard the entire sentence without the final word. Next they would hear the sentence with just the very beginning of the final word presented. After each presentation the participants were to make a guess at what that final word was. Progressively more of the final word was presented until the participant could correctly identify the word. Stine and Wingfield recorded the amount of information (i.e., how much of the final word) required in order for a correct identification to be made.

Stine and Wingfield (1994) hypothesized that if older adults did have a deficit in the ability to 'prune' following broad spread activation then they would need to hear more of the target word to correctly identify it. They predicted that, according to the inhibitory deficit hypothesis, relative to younger adults, older adults would need to hear even more of the word when it had a high probability competitor because it would be more difficult for them to inhibit this competitor. For the sentence "All the guests had a very good ...", older adults would be predicted to require to hear more of the target word when it was SUPPER than when it was TIME, relative to younger adults. Although Stine and Wingfield found that older participants required more of the target word to be presented to make a correct identification, they did not find the interaction that the inhibitory deficit hypothesis predicted. Instead, they found that both younger and older adults required longer presentation times of the target word when there was a high probability competitor compared to the low probability competitor condition, and that this increase in presentation time was no greater for older adults than for younger adults. This finding suggests that older adults do not perform any differently than younger adults when they may be required to alter an original interpretation.

The Perceptual Interference Effect.

In a similar study, Lindfield et al. (1994) investigated inhibitory processes in younger and older adults via the perceptual interference effect (Bruner & Potter, 1964). As with the gating paradigm used by Stine and Wingfield (1994), the perceptual interference effect occurs when participants are asked to respond to a partially presented stimulus. In Bruner and Potter's (1964) study, participants were presented with blurred photographs of common objects. During the course of a trial, the photographs were gradually focused to a predetermined focus level (but still not fully focused), at which point the participant attempted to identify the object. There were three different initial blur levels so that some pictures began much more blurred than others. However, all pictures ended at the same level of focus. Bruner and Potter reported that identification accuracy was worse the more blurred the initial presentation was (even though all photographs ended at the same level of focus). Bruner and Potter (1964) suggested that participants form incorrect hypotheses as to the identity of the object as the object is being brought into focus, and that these incorrect hypotheses interfere with the correct identification. This finding has been termed the perceptual interference effect and has been replicated in younger adults by a number of researchers (e.g., Luo & Snodgrass, 1994; Snodgrass & Hirshman, 1991).

Luo and Snodgrass (1994) explain the perceptual interference effect with their competitive activation model. They suggest that the initial presentations lead to the activation of competing hypotheses as to the identity of the target, and that these hypotheses compete with the correct identification and produce interference. It is apparent, then, that inhibitory processes could play a role in inhibiting hypotheses that are initially generated based on partial stimulus information, but are later rejected as more information becomes available. It should be noted that participants do not have the contextual support driving their hypotheses as they do in the task used by Stine and Wingfield (1994).

This type of explanation (Luo & Snodgrass, 1994) is what sparked Lindfield et al. (1994) to use the perceptual interference effect to test the inhibitory deficit hypothesis of cognitive aging. They used drawings of familiar objects and compared the identification response latencies and errors of younger and older adults in two presentation conditions. In the fixed presentation condition, participants were presented with a line drawing at a predetermined level of fragmentation (described below). In the ascending presentation condition, participants were presented with a line drawing that gradually decreased in the level of fragmentation (making the object more identifiable) up to the level of fragmentation in the fixed presentation condition. Fragmentation was achieved by removing blocks (16 X 16 pixel squares) from the computer picture (see Figure 1 for an example). These levels of fragmentation were predetermined for each participant. That is, participants were initially presented with pictures of objects in the ascending condition and the level of fragmentation chosen for the main experiment was that level at which they correctly identified 40 to 60 percent of the pictures.

In the ascending condition, the picture was presented at the most fragmented level (2% of the blocks of pixels presented) and remained on the screen until the participant attempted to identify the picture (or reported that they could not identify the picture). The picture was then presented at the next level of fragmentation (making it more visible), and again the participant was to make an attempt at identification. This procedure continued to the final, predetermined, level of fragmentation. In the fixed condition, the picture was presented only once (at the final fragmentation level for the ascending condition) and stayed on the screen until a response was made. Participant's accuracy, and reaction time for their correct identifications (from the onset of final presentation until a response was made) were recorded. Lindfield et al. predicted that participants would perform better (i.e., more accurate and faster) in the fixed condition relative to the ascending condition, in accordance with the perceptual interference effect. They also predicted that older adults would exhibit a greater perceptual interference effect relative to younger adults. They reasoned that, assuming older adults do have an inhibitory deficit, it would be more difficult for older adults to eliminate erroneous hypotheses formed in the ascending condition. This in turn would lead to an even larger decrease in accuracy and increase in reaction time for the ascending condition (relative to the fixed condition), compared to younger adults.

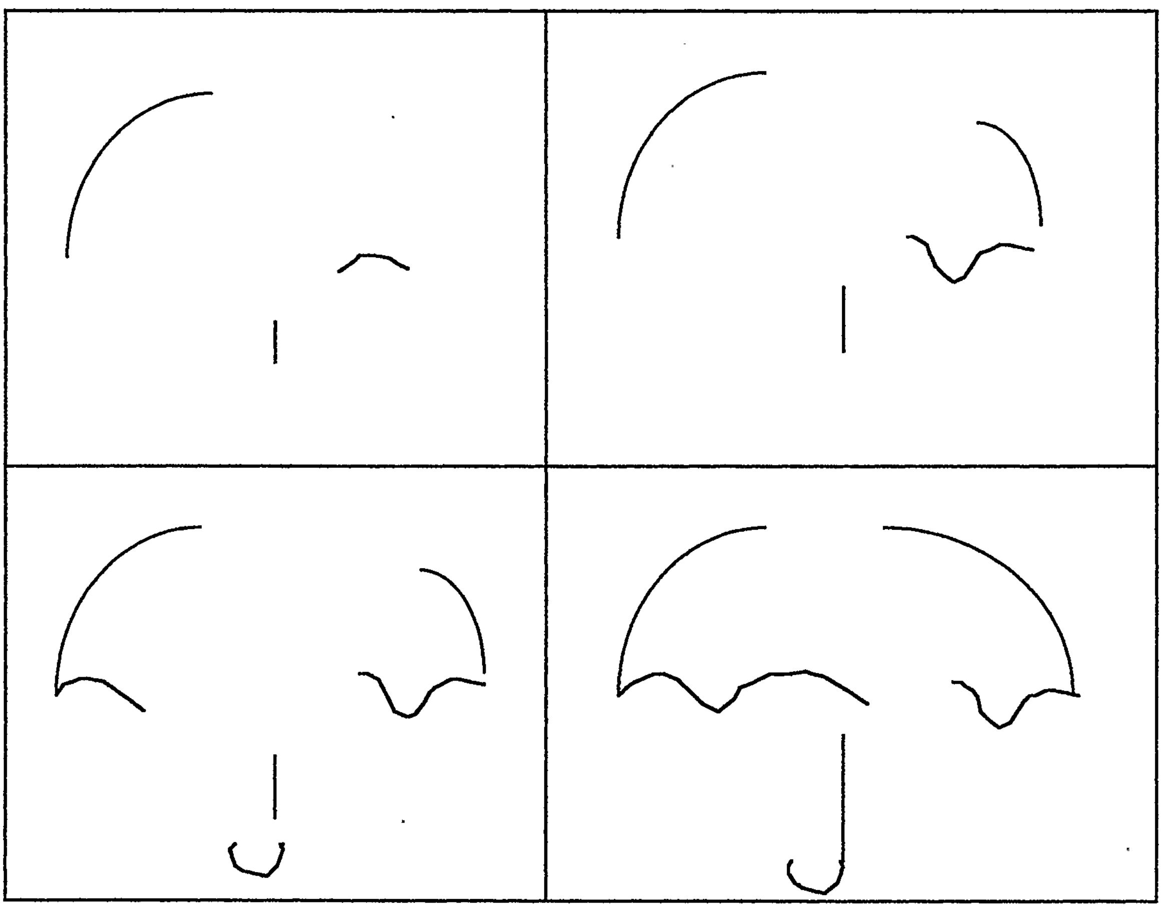

Figure 1. Example of stimuli used by Lindfield et al. (1994).

Lindfield et al. found that both younger and older adult's accuracy was lower in the ascending condition relative to the fixed condition, thus replicating the perceptual interference effect. However, this effect was no larger for the older adults than for the younger adults. It should be noted, however, that the interaction between Age and Condition was in the predicted direction. That is, the difference in accuracy between the ascending and fixed conditions was larger for older adults relative to younger adults (though not statistically significant). For the response latency data, older and younger adults performed similarly in the fixed condition, but in the ascending condition older adults required more time to respond than the younger participants. Lindfield et al. (1994) noted that the response latency data were consistent with the non-significant trend in the accuracy data.

Lindfield et al. (1994) interpreted these results as support for the hypothesis that older adults have increased difficulties inhibiting distracting thoughts or ideas. They suggested that the increased response time for older adults in the ascending condition was due to the older adults' increased difficulty inhibiting competing hypotheses as to the identity of the objects (even though in the end they made the correct identification). Lindfield et al. believed that in the fixed condition, competing hypotheses would not be generated, and therefore no differences between older and younger participants would be expected, as was observed. Although the accuracy data did not yield a significant interaction, as was predicted by the inhibitory deficit hypothesis, Lindfield et al. still suggested that the results, in combination with the reaction time data, did support such a deficit as it was in the predicted direction and was close to statistical significance ($p < .08$).

This brief review of some of the literature on inhibitory abilities of younger and older adults once again points to the importance of investigating different instances in which inhibitory processes have been implicated. It is clear that some tasks show age equivalence in inhibitory processes while others show age decrements.

The Progressive Demasking Task

A task similar to that used by Lindfield et al. (1994) in the word recognition literature is the progressive demasking task (Grainger & Segui, 1990). In this task, a trial consists of a number of word/mask cycles. That is, each cycle consists of the presentation of a word followed by the presentation of a mask. While the length of presentation for the entire cycle remains constant, initially, the mask is presented for the bulk of the cycle, while the target word is presented only very briefly. On each successive cycle, during a trial, the presentation of the mask decreases and the presentation of the target word increases. For example, given a cycle time of 336 ms, the mask may initially be presented for 320 ms and the target presented for 16 ms, and on each successive cycle the mask decreases in presentation time by 16 ms, and the target increases in presentation time by 16 ms (Grainger & Segui, 1990).

The participants' task during a trial is to identify the word as quickly as possible.

With this method of presentation, the word becomes progressively more identifiable and creates a similar situation to the tasks discussed above (Lindfield et al., 1994; Stine & Wingfield, 1994). In the ascending condition, used by Lindfield et al., the object to be identified is initially very unclear and more information is gradually added. As mentioned previously, this creates a situation in which participants develop hypotheses based on that initial information, and these hypotheses are gradually altered and eliminated as more and more information is presented. Although in the progressive demasking task all information (i.e., the entire word) is presented right from the first cycle of a trial, because the stimulus presentation time is so short, it is initially very difficult to see the entire word. As the trial progresses and the stimulus is presented for longer periods of time it becomes easier to see the word. Therefore, one could argue that this situation may also lead to the forming of hypotheses based on the initial perceptual information available. These hypotheses would also be altered and eliminated as more perceptual information is available.

Grainger and Segui (1990) used the progressive demasking task to investigate the effect of neighborhood frequency on word identification. A neighbor is defined as any word of the same length that can be created by changing one letter of the word while maintaining letter positions. The stimuli were words without higher frequency neighbors and words with one or more higher frequency neighbors. For example, the word SKIP has the neighbors SHIP, SKID, SKIM, SKIN, SKIS, SKIT, SLIP, and SNIP. One can then determine, for any given word, how many neighbors are of higher frequency than the target word. Frequency counts are generally based on printed frequencies (e.g., Kucera & Francis, 1967). For example, the word BIRD has a normative frequency per million words of 31, and the normative frequencies of its four neighbors (BARD, BIND, BYRD, AND GIRD) are 3, 4, 9, and 0, respectively. Thus, BIRD has no higher frequency neighbors. The word STEM has a normative frequency of 29, and the normative frequencies of its four neighbors (ITEM, SEEM, STEP, and STEW) are 54, 229, 131 and 5, respectively. Thus, STEM has two neighbors which are higher in frequency than itself.

Grainger and Segui (1990) reported that response times were slower for words with higher frequency neighbors relative to words with no higher frequency neighbors. This phenomenon has been termed the inhibitory neighborhood frequency effect, and it has been reported by a number of other researchers testing younger adults (e.g., Carrieras, Perea, & Grainger, 1997; Grainger & Jacobs, 1996). The inhibitory neighborhood frequency effect has also been demonstrated using other tests commonly used in word recognition, such as perceptual identification (Grainger & Jacobs, 1996), lexical decision, and semantic categorization (Carrieras et al., 1997). However, there are other reports of a facilitory neighborhood frequency effect using lexical decision and perceptual identification tasks (Forster & Shen, 1996; Sears, Hino, & Lupker, 1995; Sears, Lupker, & Hino, 1999; Siakaluk, Sears, & Lupker, 2002). That is, participants in these studies were faster to identify words with higher frequency neighbors than words without higher frequency neighbors.

Grainger and Jacobs (1996) have proposed a model of word recognition to explain the inhibitory neighborhood frequency effect, as well as other lexical effects (e.g., neighborhood size effects). The multiple read-out model is based on an interactive-activation model (McClelland & Rumelhart, 1981) in which there is competition between orthographic neighbors. According to Grainger and colleagues, high frequency words have increased resting activation levels and therefore create more competition for their lower frequency neighbors (Grainger & Segui, 1990). This competition therefore leads to interference.

This explanation is similar to the explanation of the results from the gating task used by Stine and Wingfield (1994). Stine and Wingfield discuss the cohort theory (Marslen-Wilson, 1987) with regards to the gating paradigm. The cohort theory states that initially all words with the same initial phonology would be activated and this 'cohort' of potential candidates would slowly become smaller and smaller as more and more of the word is presented. Similarly, in the progressive demasking task, all words in a neighborhood are activated and compete until the target is recognized.

Again, the idea in both cases is that following an initial spread of activation there is a necessary pruning of potential target candidates. Note that in both of these models the competition between candidates is an automatic process.

Sears et al. (1999) give a very different explanation of the inhibitory neighborhood frequency effect in the progressive demasking task. Their view is that the effect is due to erroneous hypotheses formed during the early presentations of the word. The idea is that these hypotheses impede the participant in making the correct identification, either by slowing reaction time or making the incorrect identification. The argument is that the way the task is constructed leads to an ambiguous situation in which hypothesis testing is likely to take place. Under these conditions a word with many neighbors, and specifically many higher frequency neighbors, is likely to be mistaken in early presentations and the observer is likely to form incorrect hypotheses. Sears et al. therefore contend that the inhibitory neighborhood frequency effect observed with the progressive demasking task has nothing to do with normal word recognition (i.e., recognizing words without any visual degradation). This explanation is similar to the explanations of the perceptual interference effect discussed earlier and, specifically, to the competitive activation model (Luo & Snodgrass, 1994).

The progressive demasking task is another way in which inhibitory processes of older adults could be examined. Further, older adults can be used to test the suggestion that the inhibitory neighborhood frequency effect seen in the progressive demasking task is due to hypothesis testing, and not due to automatic processes. If the neighborhood frequency effect is due to the formation of erroneous hypotheses then it can be predicted that older adults will be more affected by this competition among hypotheses than younger adults and thus should exhibit an increased inhibitory neighborhood frequency effect (as the older participants in the Lindfield et al. study were predicted to exhibit a larger perceptual interference effect).

The Present Study

The goals of the present study were two-fold. First, the present study will add to the literature investigating the inhibitory deficit hypothesis of cognitive aging (Hasher & Zacks, 1988) by using methodologies not previously employed with older adults. Recall that it now appears that if older adults do have an inhibitory deficit it is not a global deficit (McCrae & Abrams, 2001). Therefore, we must continue to identify those areas in which there are deficits and those in which there are not. The present study investigated inhibitory processes in hypothesis testing in the identification of visually degraded words. One of the suggested roles of inhibitory processes is to "serve a restraining function by preventing strong responses from immediately seizing control of thought and action effectors so that other, less probable, responses can be considered" (Chiappe et al., 2000, p. 9). When participants are presented with stimuli that are difficult to identify they are likely to form hypotheses about the stimulus identity. In order to make the correct identification they may need to inhibit hypotheses that may have been formed which, with more information provided, are now incorrect. All of the experiments to follow will address this aspect of inhibitory functioning in the identification of visually presented words. Experiment 1 will address this issue with the use of the progressive demasking task. An advantage over using line drawings of objects for stimuli (e.g., Lindfield et al., 1994) is that neighborhood frequency can be manipulated in order to gain some control over likely hypotheses formed. Experiment 2 used a similar paradigm, however, the main dependent measure of interest was accuracy, rather than reaction time. Experiment 3 aimed at manipulating hypotheses formed, even more so than in Experiments 1 and 2, by introducing a variation to the progressive demasking task, namely, presenting a prime before the progressive demasking series.

The second objective of the present study was to shed some light on the nature of the inhibitory neighborhood frequency effect observed in the progressive demasking task. Specifically, whether the effect is due to automatic processes in word recognition (Grainger & Jacobs, 1996), or due to perceptual interference produced by hypothesis testing (Sears et al., 1999; see discussion above).

Experiment 1

The present experiment used the progressive demasking task to investigate the neighborhood frequency effect in younger and older adults.

There were two lines of interest for the experiment. The first was to investigate the hypothesis that older adults have difficulties inhibiting irrelevant information. Specifically, the goal was to use a task similar to that used by Lindfield et al. (1994), however, with word stimuli rather than picture stimuli. A major advantage of using word stimuli is that one can manipulate the neighborhood size and frequency for a word. This allows some control over the potential hypotheses participants may form while trying to identify the words (i.e., neighbors of the target word). Secondly, the two opposing explanations of the inhibitory neighborhood frequency effect were explored. Using the progressive demasking task, words were presented which had no higher frequency neighbors, and words with one, two, three, four, or five or more higher frequency neighbors. Younger adults were expected to demonstrate an inhibitory neighborhood frequency effect, in which they would respond more slowly to words with many higher frequency neighbors relative to words with few higher frequency neighbors. This prediction was based on a number of findings in the literature (e.g., Grainger & Jacobs, 1996; Grainger & Segui, 1990). The inhibitory deficit hypothesis leads to the prediction that older adults should demonstrate a larger inhibitory neighborhood frequency effect relative to younger adults. An increased inhibitory neighborhood frequency effect could be revealed in one of two ways. Older adults could demonstrate an even larger increase (relative to younger adults) in reaction time for words with more higher frequency neighbors relative to words with fewer higher frequency neighbors. On the other hand, older adults may be more affected by higher frequency neighbors, such that they are slower to respond to words with only one or two higher frequency neighbors, where younger adults are not affected until words are presented with four or more higher frequency neighbors.

These predictions are also based on the assumption that the progressive demasking task is measuring hypothesis testing and is not an automatic process (Sears et al., 1999). Recall that Sears et al. suggest that the inhibitory effect seen in the progressive demasking task is due to participants forming hypotheses during the course of a trial. Based on this interpretation it is predicted that older adults would show a larger effect because they would have a more difficult time 'letting go of' initial hypotheses.

Recall that the alternative explanation of the inhibitory effect in the progressive demasking task suggests that it is due to competition between orthographic neighbors and this competition is an automatic process, as explained by the multiple read-out model (Grainger & Jacobs, 1996). Therefore, based on this explanation, one would expect no age interaction. This prediction is based on the literature which suggests that there are little, if any, age differences in automatic processes (e.g., Mayr & Kliegl, 2000). Given these two different predictions, the results from the present experiment could help to distinguish between the two competing hypotheses in the word recognition literature.

A number of paper and pencil tasks were also incorporated into the present experiment. These measures were used to gain further insight into the nature of the progressive demasking task. For example, a word fluency measure was utilized, in which participants are to name as many words as possible beginning with a specified letter (e.g., R). This task has been suggested to be a measure of inhibitory functioning (Arbuckle, et al., 2000). A correlation between this measure and a measure of interference (difference in reaction time to words without higher frequency neighbors and words with higher frequency neighbors) from the progressive demasking task would provide support for a common inhibitory underpinning for the two tasks.

Method

Participants. Twenty younger adults (*M* = 21.94, *SD* = 3.12) from the University of Calgary who received extra credit in a Psychology class volunteered to participate. Twenty older adults (*M* = 70.75, *SD* = 4.90) from the community, who received a $10.00 honorarium for their time, also participated. The younger participants ranged in age from 18 to 29 years and the older participants ranged from 62 to 80 years of age. Background information regarding relevant health issues was attained via a questionnaire (see Appendix A). This information was used to identify any participants who potentially could not be used in the study (e.g., participants on medication for Depression). However, no participants were removed from analyses due to health-related concerns. All participants reported normal or corrected to normal vision. Based on a 5-point scale (1=poor, 5=excellent), asking participants to rate their overall health compared to others their age, older adults reported good to excellent overall health ($M = 4.10$, $SD = .80$). All of the participants were native English speakers. Younger and older adults reported a similar number of years of education ($M = 14.33$, $SD = 1.73$, and $M = 13.25$, $SD = 2.31$, respectively). Older adults ($M = 58.95$, $SD = 6.72$) scored significantly higher than younger adults ($M = 53.60$, $SD = 6.08$) on the Vocabulary subtest of the Wechsler Adult Intelligence Scale-Revised (WAIS-R; Wechsler, 1981), $t(38) = 2.75$, $p = .009$. (This test has been used extensively in the cognitive aging literature and has a split-half reliability value of .96; Wechsler, 1981). It should be noted that these means are higher than the normative data, for both younger and older adults (Wechsler, 1981). However, these results are comparable to other studies in the cognitive aging literature (e.g., Oberauer, 2001; Persad, Abeles, Zacks & Denburg, 2002).

All participants signed informed consent forms and were told that they could request breaks at any time during the study.

Tasks and Procedures. The progressive demasking task was the same as that used by Grainger and Segui (1990). Participants were required to identify four-letter words. There were 6 levels of number of higher frequency neighbors with 18 words in each condition. The six levels consisted of words without higher frequency neighbors, with one higher frequency neighbor, two higher frequency neighbors, three higher frequency neighbors, four higher frequency neighbors, and five or more higher frequency neighbors. All the words were low frequency words (mean Kucera and Francis normative frequency of 22.4, range of 1 to 59). All the words had at least 6 neighbors ($M = 11.4$). Table 1 displays the stimuli characteristics. Appendix B lists all of the stimuli used in Experiment 1.

Table 1

Mean Word Frequency (WF) and Neighborhood (N) Size for Words without Higher Frequency Neighbors (HFN), and Words with One, Two, Three, Four, and Five or more HFNs

	No HFNs	1 HFN	2 HFN	3 HFN	4 HFN	5 HFN
WF	24.6	22.2	21.8	22.6	22.8	20.3
N Size	8.2	10.7	10.2	10.4	13.0	15.9

Stimuli were presented on a color VGA monitor driven by a Pentium-class microcomputer. At a viewing distance of 50cm, the stimuli subtended a visual angle of approximately 1.0 degrees. Presentation on each trial was as follows. The four-letter word appeared alternatively with a series of four ####'s, constituting one cycle. Each cycle lasted 300 ms. Initially, the word appeared for 14 ms and the mask for 286 ms of the total 300 ms. On each successive cycle the duration of the word increased by 14 ms and the duration of the mask decreased by 14 ms (see Figure 2). Words were presented in capital letters. Reaction time was measured to the nearest ms, from the onset of the first cycle until the participant pushed a key indicating they recognized the word. Participants were then asked to type in the word. Participants were instructed to respond as quickly as possible while maintaining accuracy. Prior to each trial a warning of a 1 second, 2000 Hz tone was followed by the word "READY?" presented in the center of the screen. Participants were asked to press the "R" on the keyboard when they were ready for the trial to begin which initiated the target of the first cycle following a one second delay.

Participants received 20 practice trials in which all six conditions were represented and in which feedback was given by the computer for each trial. That is, participants were informed whether or not their responses were correct. No feedback was provided during the actual experimental trials. The 108 trials of the experiment proper were randomized separately for each participant.

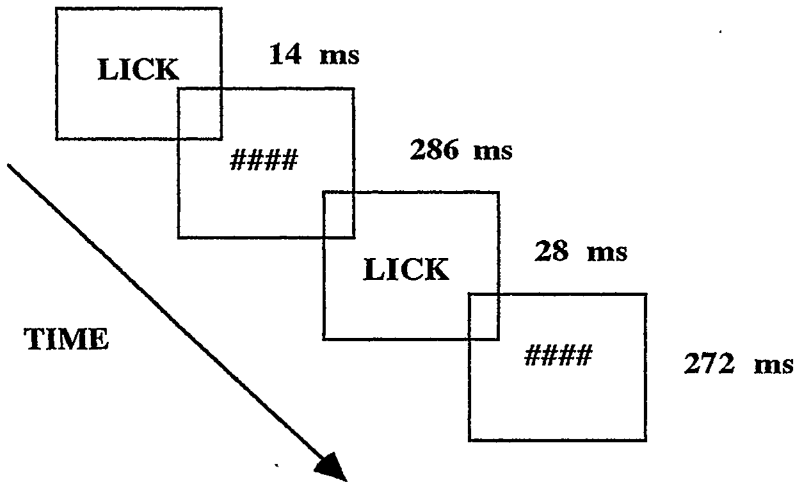

Figure 2. Example of the progressive demasking task used in Experiment 1.

Participants also completed the forward and backward digit span tests from the WAIS-R (test- retest reliability equals .83; Wechsler, 1981), two word fluency tasks (P and R), the digit symbol subtest from the WAIS-R (test- retest reliability equals .82; Wechsler, 1981), and the Finding A's test. These specific tasks were included for a number of different reasons. First, word fluency and Finding A's require language skills and the progressive demasking task also involves language processing, therefore, it was hoped that the inclusion of these tasks could potentially provide more information as to the nature of the progressive demasking task. As well, the word fluency task is thought to be a measure of inhibitory abilities (Arbuckle, et al., 2000) which is of critical interest for the present experiment. The digit symbol subtest is also widely used as a measure of cognitive speed (Wielgos & Cunningham, 1999) and is therefore relevant for the present study because response latency was measured. As well, the backward span measure is seen as a working memory measure which is of interest given the proposed relationship between working memory and inhibitory processes (e.g., Lustig, May, & Hasher, 2001). Furthermore, these tasks are commonly used by researchers when they are comparing younger and older adults on measures of cognitive abilities. Participants completed these paper and pencil tasks before the progressive demasking task.

Results

Progressive Demasking Task. The percentage of identification errors were analyzed using a 2 (Age: younger, older) X 6 (Neighborhood Frequency: zero, one, two, three, four, five or more higher frequency neighbors) mixed model ANOVA. No significant effects were found (all *F*s < 1), thus ruling out a speed-accuracy trade-off. As can be seen in Table 2, participants recorded relatively stable and low error rates across all conditions.

Table 2

Means and Standard Deviations (in parentheses) for Younger and Older Adults Error Rate (Percentage Error) Data for Words with Zero, One, Two, Three, Four, and Five or More Higher Frequency Neighbors (HFN)

	0 HFN	1 HFN	2 HFN	3 HFN	4 HFN	5 HFN
Younger	4.77 (5.33)	5.70 (6.09)	4.60 (5.21)	4.37 (5.86)	5.47 (5.32)	5.13 (5.78)
Older	6.00 (6.63)	4.15 (6.06)	3.65 (5.58)	5.70 (5.47)	6.25 (6.19)	5.35 (8.31)

Means and standard deviations for the progressive demasking response latency data appear in Table 3. The response latency data are based on correct identifications only. A 2 (Age: younger, older) X 6 (Neighborhood Frequency: zero, one, two, three, four, five or more higher frequency neighbors) mixed model analysis of variance (ANOVA) was conducted on these data. There was a significant main effect of Age, F (1, 38) = 30.35, p < .001, as younger adults (M = 1354.83, SD = 511.35) responded significantly faster than older adults (M = 2164.65, SD = 424.30). There was also a significant main effect of Neighborhood Frequency, F (5, 190) = 18.31, p < .001, as words with higher frequency neighbors were generally responded to more slowly than words without higher frequency neighbors. Follow-up tests were not conducted on these data in light of the significant Age by Neighborhood

Frequency interaction, F (5, 190) = 2.25, p = .05 (see Figure 3). For younger adults, there was no significant difference in reaction time between words without higher frequency neighbors (M = 1326.81, SD = 574.35) and words with one (M = 1322.17, SD = 555.68), t (19) = .18, p = ..86, two (M = 1308.49, SD = 509.02), t (19) = .50, p = .62, or three (M = 1339.10, SD = 497.02), t (19) = .32, p = .76, higher frequency neighbors. However, words with four higher frequency neighbors (M = 1437.49, SD = 478.96) were identified significantly more slowly than words without higher frequency neighbors (M = 1326.81.24, SD = 574.35), t (19) = 2.99, p = .008. Words with five higher frequency neighbors (M = 1394.88, SD = 500.15) were not responded to significantly more slowly than words without higher frequency neighbors, t (19) = 1.71, p = .10.

For older adults, however, words with just one higher frequency neighbor (M = 2143.73, SD = 444.11) were responded to significantly more slowly than words without higher frequency neighbors (M =2055.84, SD = 375.80), t (19) = 3.06, p = .006. There was no significant difference between words with two higher frequency neighbors (M = 2095.30, SD = 430.18), and words without higher frequency neighbors, t (19) = 1.05, p = .31. Words without higher frequency neighbors were responded to more quickly than words with three (M = 2141.47, SD = 439.39), t (19) = 2.09, p = .05, four (M = 2310.42, SD = 453.89), t (19) = 6.66, p < .001, and five (M = 2241.13, SD = 397.33), t (19) = 5.43, p < .001, higher frequency neighbors.

Table 3

Means and Standard Deviations (in parentheses) for Younger and Older Adults Response Latency (ms) Data for Words with Zero, One, Two, Three, Four, and Five or More Higher Frequency Neighbors (HFN)

	0 HFN	1 HFN	2 HFN	3 HFN	4 HFN	5 HFN
Younger	1326.81 (574.35)	1322.17 (555.68)	1308.49 (509.02)	1339.10 (497.02)	1437.49 (478.96)	1394.88 (500.15)
Older	2055.84 (375.80)	2143.73 (444.11)	2095.30 (430.18)	2141.47 (439.39)	2310.42 (453.89)	2241.13 (397.33)

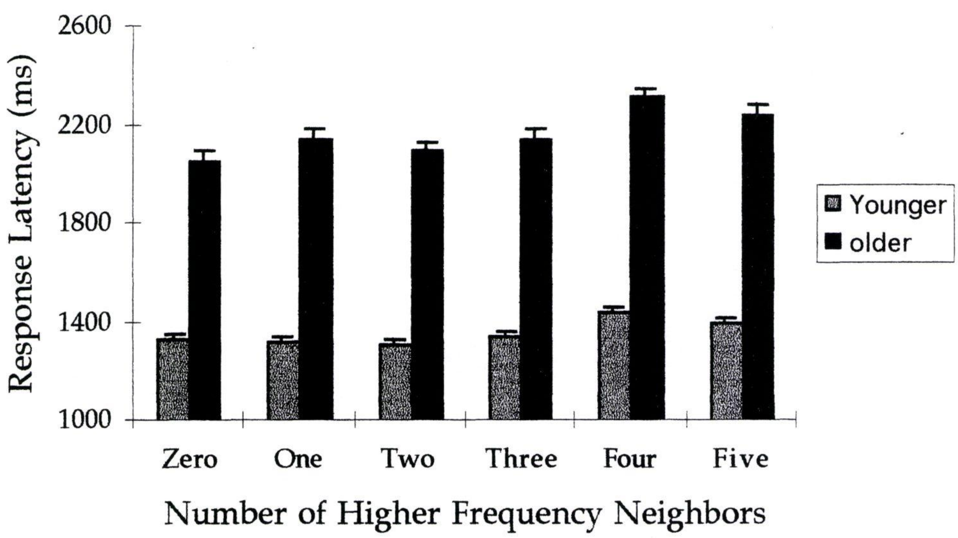

Figure 3. Response latency as a function of number of higher frequency neighbors (HFN) for younger and older adults.

Further analyses were conducted to examine the age interaction in more detail. A median split separated the older adults into 2 age groups - 10 older adults ($M = 67.70$, $SD = 2.45$) and 10 oldest adults ($M = 74.70$, $SD = 3.53$). The older group ranged in age from 62 to 70 and the oldest group ranged in age from 71 to 80. The response latency data were analyzed using a 3 (Age: younger, older, oldest) X 6 (Neighborhood Frequency: zero, one, two, three, four, five or more higher frequency neighbors) mixed model ANOVA.

A significant main effect of Age was once again found $F\ (2, 37) = 16.11$, $p < .001$. The oldest adults responded the slowest ($M = 2290.59$, $SD = 410.81$), followed by the older adults ($M = 2038.71$, $SD = 402.59$), with the youngest adults responding the fastest ($M = 1354.83$, $SD = 511.35$). The main effect of Neighborhood Frequency was significant, $F\ (5, 185) = 21.61$, $p < .001$, and there was a significant Age by Neighborhood Frequency interaction, $F\ (10, 185) = 3.09$, $p = .001$. It was found that the older and oldest adults demonstrated a different pattern of results. For the older adults, there was no significant difference in reaction time between words without higher frequency neighbors ($M = 1996.75$, $SD = 391.26$) and words with one higher frequency neighbor, ($M = 2022.10$, $SD = 430.91$),$t\ (9) = .89$, $p = .40$. However, participants identified words without higher frequency neighbors significantly faster than words with two ($M = 1930.67$, $SD = 366.71$),$t\ (9) = 3.03$, $p = .01$, three ($M = 1962.40$, $SD = 384.34$),$t\ (9) = 2.32$, $p = .05$, four ($M = 2214.55$, $SD = 481.33$),$t\ (9) = 4.16$, $p = .002$, and five ($M = 2105.79$, $SD = 385.77$),$t\ (9) = 2.58$, $p = .03$, higher frequency neighbors. However, for the oldest group of adults, words with just one higher frequency neighbor (M = 2265.37, SD = 444.77) were responded to significantly more slowly than words without higher frequency neighbors (M = 2114.93, SD = 370.53), t (9) = 3.54, p = .006. As well, relative to words without higher frequency neighbors, participants were slower to identify words with two (M = 2259.92, SD = 442.69), t (9) = 2.65, p = .026, three (M = 2320.54, SD = 434.28), t (9) = 3.40, p = .008, four (M = 2406.29, SD = 427.57), t (9) = 5.21, p = .001, and five (M = 2376.46, SD = 379.17), t (9) = 6.09, p < .001, higher frequency neighbors (see Table 4).

Table 4

Means and Standard Deviations (in parentheses) for Younger, Older, and Oldest Adults Response Latency (ms) Data for Words with Zero, One, Two, Three, Four, and Five or More Higher Frequency Neighbors (HFN)

	0 HFN	1 HFN	2 HFN	3 HFN	4 HFN	5 HFN
Younger	1326.81 (574.35)	1322.17 (555.68)	1308.49 (509.02)	1339.10 (497.02)	1437.49 (478.96)	1394.88 (500.15)
Older	1996.75 (391.26)	2022.10 (430.91)	1930.67 (366.71)	1962.40 (384.34)	2214.55 (481.33)	2105.79 (385.77)
Oldest	2114.93 (370.53)	2265.37 (444.77)	2259.92 (442.69)	2320.54 (434.28)	2406.29 (427.57)	2376.46 (379.17)

Another way to investigate the effect that higher frequency neighbors has on response latency is by obtaining an interference measure. An interference measure was computed for each individual by calculating the average response latency for words with higher frequency neighbors (one through five) and then subtracting this value from the response latency to words without higher frequency neighbors. It was found that there was no significant difference in interference between the younger (M = -33.62, SD = 137.66), and older adults (M = -50.35, SD = 58.84), p = .72. However, the oldest adults (M = -210.78, SD = 132.22) demonstrated a significantly larger interference effect compared to the older adults, t (18) = 3.51, p = .003. This finding is consistent with other researchers who have found age differences within an older population (e.g., Barresi, Nicholas, Tabor Connor, Obler, & Albert, 2000; Persad, et al., 2002). It should also be noted that there was no statistically significant difference between these two oldest age groups on the backward span (p = .42) or digit symbol (p = .52) measures.

Paper and Pencil Tasks. Younger adults (M = 71.75, SD = 8.87) performed significantly better than older adults (M = 53.00, SD = 8.82) on the digit symbol task, t (38) = 6.70, p < .001. As with the vocabulary scores (see Method section), these means are higher than the normative data (Wechsler, 1981). However, they are consistent with the literature on cognitive aging (e.g., Madden, Pierce, & Allen, 1993; Pesta & Sanders, 2000). Younger (M = 6.10, SD = 2.45) and older (M = 5.15, SD = 2.41) adults performed similarly on the backward span measure (p=.22). Again, these results are consistent with a number of findings in the cognitive aging literature (e.g., Kemper & Sumner, 2001; Light, Prull & Kennison, 2000).

Correlational Analyses. The correlations of interest were those with the overall interference measure (discussed above) from the progressive demasking task. There were no critical correlations with this measure to report.

Discussion

The first thing to note about the results of Experiment 1 is that both younger and older adults demonstrated an inhibitory neighborhood frequency effect. That is, words with many higher frequency neighbors were responded to more slowly than words without higher frequency neighbors. This is consistent with previous research with younger adults (e.g., Grainger & Jacobs, 1996; Grainger & Segui, 1990). However, the pattern of this effect was different for younger and older adults. Younger adults were not affected until words had four or more higher frequency neighbors, where they then identified the words more slowly than for the words without higher frequency neighbors (and the words with one, two or three higher frequency neighbors too). However, older adults were slower to identify words with just one higher frequency neighbor relative to words without any higher frequency neighbors. Therefore, it appears that fewer higher frequency neighbors are 'needed' in order for an inhibitory effect to appear for older adults compared to younger adults. It was also found that, following a median split of the older age group, group differences emerged within this age group. It is becoming clear that looking at age changes within an older population is worthwhile as there are often differences within this older age group (Persad, et al., 2002). The present results demonstrated that the older adults were hampered when a target word had two higher frequency neighbors and the oldest adults were hampered when the target word had just one higher frequency neighbor. Recall that both of these findings are different from the younger adults, who were not impeded in performance until a word had four higher frequency neighbors. Again, these results support the contention (e.g., Persad et al., 2002) that we must look deeper into older adults' performance on measures of cognitive functioning, and look for potential differences within an older age group.

We can now explore the implications of the present results for different explanations of the inhibitory neighborhood frequency effect. Recall that Sears et al. (1999) claim that the inhibitory neighborhood frequency effect in the progressive demasking task is due to hypothesis testing effects (non-automatic processes). That is, that the task itself lends itself to hypothesis testing. Therefore, when a word is presented that has many higher frequency neighbors the participant is more likely to form an erroneous hypothesis, eventually leading to longer reaction times. On the other hand, Grainger and Jacobs (1996) suggest that the inhibitory neighborhood frequency effect is an automatic process and is due to competition between orthographic neighbors. That is, when a target word has higher frequency neighbors these neighbors create more competition for the target.

There is no real reason to believe that older adults would be more affected by this competition in automatic processes. Therefore, there is no reason to predict that older adults demonstrate an increased inhibitory neighborhood frequency effect relative to younger adults, according to this explanation. However, there is reason to believe that younger and older adults may be differentially affected by erroneous hypotheses being formed (Lindfield et al., 1994). This reasoning is in line with increasing evidence that older adults demonstrate strategic (attentional) effects but not automatic effects in a number of different areas. For example, there is evidence in the visual search literature that older adults perform similarly to younger adults on automatic processes, however, on strategic processes, older adults demonstrate impairments (e.g., Foster, Behrmann, & Stuss, 1995; Gorman & Fisher, 1998). Similarly, there is evidence in the priming literature to suggest that on purely semantic processing there are no age deficits and when age deficits appear it is due to some other non-semantic process (Mayr & Kliegl, 2000).

In sum, the finding that the older adults in the present experiment did in fact demonstrate an increased inhibitory neighborhood frequency effect supports the hypothesis testing explanation of the inhibitory neighborhood frequency effect observed using the progressive demasking task (Sears et al., 1999).

The second question to be addressed is whether older adults demonstrated an inhibitory deficit in this task. On the assumption that we are correct in our first conclusion (above), the answer would be yes. Older adults were slower to identify words with just one higher frequency neighbor compared to words without any higher frequency neighbors. However, younger adults were not affected in reaction time until words with four higher frequency neighbors were presented. Again, going with the hypothesis testing explanation of the task, participants are slower to respond to words with higher frequency neighbors because it is more likely in these situation that erroneous hypothesis will be formed. These hypotheses end up impeding performance. It appears, then, that older adults experience this effect with fewer higher frequency neighbors than younger adults. As well, they still appear to be affected by even more higher frequency neighbors, as can be seen by the greater increase in reaction time to words with four higher frequency neighbors. It is possible to explain this with an inhibitory perspective by suggesting that, for younger adults, when a word only has, one, two, or three higher frequency neighbors, they may generate some erroneous hypotheses, however, they are able to inhibit these hypotheses and make the correct identification. It is not until a word has four higher frequency neighbors that interference from potential alternatives is observed. However, for older adults, a word having only one higher frequency neighbor is enough to cause interference in making the correct identification.

There are a couple of potential problems with these conclusions that will be briefly mentioned here and then discussed in greater detail in the General Discussion. The first is that we have no independent measure of hypothesis testing. That is, we do not know that participants are forming hypotheses at all. Secondly, assuming that inhibitory abilities have a direct influence on working memory performance, as suggested by Hasher and Zacks (1988), then we might expect some relationship between the backward span measure, which is thought to measure working memory ability, and the neighborhood frequency effect. However, no such relationship was found. It is also important to point out that there was no statistically significant difference between younger and older adults on backward span. Therefore, it could be argued that this older group of adults does not have an inhibitory deficit. Thus, explaining the observed age interaction on the progressive demasking as being due to decreased inhibitory ability is false. However, we must remember that it is now apparent that not all inhibitory processes are the same. There may be some tasks in which older adults as a group perform similarly to younger adults, and others where there are differences. As well, just because one older sample demonstrates a deficit on one age-dependent 'inhibitory' task does not mean they will demonstrate a deficit on all age-dependent 'inhibitory' tasks. Some tasks may be more sensitive to decrements than others. A third potential problem has to do with the classification of higher frequency neighbors. The frequency counts which were used (Kucera & Francis, 1967) were based on younger adults. Therefore, it is conceivable that some words which are considered low frequency for younger adults are actually high frequency for older adults and vice versa. However, this explanation seems an unlikely candidate to explain the overall pattern of results. It is possible that there may be individual differences for younger and older adults, however, the likelihood that the specific difference would lead to an overall effect seems minimal.

One conclusion of Experiment 1, therefore, is that the progressive demasking task should be used to investigate hypothesis testing (Sears et al., 1999) and not automatic processes (Grainger & Jacobs, 1996) in visual word recognition. Secondly, older adults seem to be affected by a target word's higher frequency neighbors to a greater degree than younger adults. It is suggested that this is due to the fact that older adults are not as able to 'let go of' erroneous hypotheses formed, while trying to correctly identify the word.

Experiment 2

Experiment 2 further investigated the role of competing hypotheses in the identification of perceptually degraded words by using a task more similar to that of Lindfield et al. (1994). Instead of the stimuli being line drawings of objects, as Lindfield et al. used, stimuli were four-letter words, as in Experiment 1. As in the Lindfield et al. study, there were two presentation conditions. In the fixed condition, words were presented at a set level of fragmentation (through the removal of pixels). In the ascending condition, the word was initially presented very fragmented and was gradually made more visible, to the level of fragmentation of the fixed condition. One major difference between the present experiment and that conducted by Lindfield et al. was the inclusion of another variable. Number of higher frequency neighbors was also manipulated in the present experiment so that words had no higher frequency neighbors, or one, two, three, or four or more higher frequency neighbors. This aspect of the experiment was aimed at shedding further light on the contradictory results between Grainger and colleagues and Sears and colleagues. As well, this manipulation allows us to have some control over potential hypotheses formed, which is an advantage over using simple line drawings.

It was predicted that older adults would perform similarly to younger adults in the fixed condition. However, in the ascending condition, they should demonstrate decreased accuracy, relative to younger adults. This prediction is based on the idea that, in the ascending condition, participants form hypotheses about the correct identification of the word and that these hypotheses interfere with making the correct identification (i.e., the perceptual interference effect). As well, older adults have increased difficulties in 'letting go of' no longer relevant information (the inhibitory deficit hypothesis). These results would support the conclusions by Lindfield et al. (1994) but using word identification instead of picture identification.

It was also predicted that, in the fixed condition, a facilitory neighborhood frequency effect would be observed, such that participants would be more accurate when a word had higher frequency neighbors relative to words without higher frequency neighbors. This prediction is based on previous findings of a facilitory neighborhood frequency effect using standard perceptual identification task (i.e., a single presentation of the stimulus), in which hypothesis testing is not likely to occur (Sears et al., 1999). In the ascending condition, however, an inhibitory neighborhood frequency effect should be observed, in which words with higher frequency neighbors are identified less often that words without higher frequency neighbors. The results in this condition should be similar to those seen in Experiment 1. This is due to the fact that both the progressive demasking task (Experiment 1) and the ascending fragmentation condition lend themselves well to the formation of hypotheses and, therefore, having many higher frequency neighbors acts as a hindrance rather than an aid. It is expected that the nature of the inhibitory effect will be similar to that observed in Experiment 1. That is, while it is expected that younger adults will demonstrate an interference effect (i.e., slower to respond to words with higher frequency neighbors), older adults should experience interference to words with fewer higher frequency neighbors than younger adults.

Method

Participants. Thirty-three younger adults (M = 21.81, SD = 5.50) from the University of Calgary volunteered for course credit. Twenty-six older adults (M = 71.04, SD = 6.11) were recruited from the community and received a $10.00 honorarium for their time. The younger participants ranged in age from 17 to 40 years and the older participants ranged from 61 to 85 years of age. Background information regarding relevant health issues was attained via a questionnaire (see Appendix A). This information was used to identify any participants who potentially could not be used in the study (e.g., participants on medication for Depression). However, no participants were removed from analyses due to health-related concerns. All participants reported normal or corrected to normal vision. Based on a 5-point scale (1=poor, 5=excellent), asking participants to rate their overall health compared to others their age, older adults reported good to excellent overall health (M = 4.15, SD = .82). All participants reported English as their first language. Younger (M = 14.21, SD = 1.43) and older (M = 13.74, SD = 2.32) adults reported similar years of education and scored similarly on the WAIS-R vocabulary test (M = 52.85, SD = 5.93; and M = 54.67, SD = 6.81, respectively). For information regarding the WAIS-R vocabulary test see the Participants section of Experiment 1.

All participants signed informed consent forms and were asked to request breaks at any time during the procedure.

Stimuli and Procedures. All participants completed the ascending and fixed fragment tasks. Stimuli consisted of words without higher frequency neighbors, and words with one, two, three, or four or more higher frequency neighbors. There were fifteen words in each condition. Words were matched for frequency and neighborhood size (see Appendix C for a full list and description of the stimuli). Table 5 displays the stimuli characteristics. There were two stimulus sets made, to be presented in either the Ascending or Fixed presentation condition. For each participant, the order of tasks (Fixed and Ascending) was counterbalanced. As well, both lists were equally presented in the Fixed and Ascending conditions and this was counterbalanced with order of tasks.

Table 5

Mean Word Frequency (WF) and Neighborhood (N) Size for Words without Higher Frequency Neighbors (HFN), and Words with One, Two, Three, and Four or more HFNs for Lists 1 and 2

	No HFNs	1 HFN	2 HFN	3 HFN	4 HFN
List 1					
WF	25.2	24.9	25.7	23.0	27.6
N Size	10.5	12.1	12.3	13.4	15.3
List 2					
WF	26.3	26.2	25.9	23.4	28.1
N Size	10.0	12.3	12.4	13.7	16.7

Stimuli were presented on a color VGA monitor driven by a Pentium-class microcomputer. The presentation of stimuli was synchronized with the vertical retrace rate of the computer monitor (14 ms). Stimuli were presented in the center of the screen, in upper case letters, and at a viewing distance of 50 cm subtended at a visual angle of approximately one degree. Stimuli were presented in white text on a black background.

At a screen resolution of 640 pixels by 480 pixels (VGA mode) each word was 11 pixels in height and 32 pixels in width. Degradation of the stimuli was accomplished by displaying a randomly selected subset of the pixels used to draw the word on the monitor screen.

Each trial was initiated by a 2000 Hz warning tone, after which a fixation point and the prompt "READY?" appeared in the center of the screen. Participants were instructed to keep their eyes fixated on the center of the screen and when they were ready to initiate the trial to press the space bar on the keyboard. In the Fixed condition, each trial consisted of a one-second presentation of the target word with 44% of the word's pixels deleted (i.e., 56% of the word's pixels were drawn). In the Ascending condition, each trial consisted of four one-second presentations of the target word at decreasing levels of degradation (i.e., increasing in visibility). The target word was first presented at 62% degradation, followed by 56% degradation, 50% degradation, and finally 44% degradation. Therefore, over the course of the 4-second trial, presentation visibility increased from 38% of the pixels being drawn to 56%. The particular pixels deleted was randomly determined for each word.

Following the presentation of the word, the prompt "What was the word?" was presented at the bottom of the screen. Participants were asked to type in their response and hit the "ENTER" key on the keyboard. There were no time constraints for responding.

Each participant completed 10 practice trials in each condition (Fixed and Ascending) prior to the collection of data. The practice stimuli consisted of five-letter, low-frequency words. Accuracy feedback was provided only during the practice trials. The order in which the stimuli were presented was randomized separately for each participant.

Results

Because two different stimulus sets were used (see Stimuli and Procedures section) in this experiment it was necessary to determine whether stimulus set had any impact on the results. Participants were classified according to which list they received for the ascending presentation and which they received for the fixed presentation. A 2 (List: ascending list A/fixed list B, ascending list B/fixed list A) X 2 (Condition: ascending, fixed) X 5 (Neighborhood Frequency: zero, one, two, three, four or more) mixed model ANOVA was conducted on the overall error rate (number of errors) to determine the effect that List had on the results. It was found that there were no significant effects involving List. Therefore, from this point on, List was not included in the analyses to recover the degrees of freedom for the remaining analyses. Appendix D displays the mean identification accuracy (percent correct) for each stimulus item for younger and older adults.

Accuracy (percent correct) for each of the conditions was calculated for each participant. A 2 (Age: younger, older) X 2 (Condition: ascending, fixed) X 5 (Neighborhood Frequency: zero, one, two, three, four or more higher frequency neighbors) mixed model ANOVA was conducted on the accuracy data. Table 6 displays the means and standard deviations for younger and older adults in the fixed condition. Table 7 displays the means and standard deviations for younger and older adults in the ascending condition.

There was a significant main effect of Age, F (1, 57) = 17.32, $p < .001$; as the younger adults (M = 63.09, SD =3.44) were significantly more accurate, overall, than the older adults (M = 53.96, SD = 3.53)[1]. There was also a significant main effect of Condition, F (1, 57) = 20.52, $p < .001$, as participants were significantly more accurate in the fixed condition (M = 61.35, SD = 4.99) compared to the ascending condition (M = 55.70, SD = 5.29). No other effects were statistically significant, $F < 1$. Therefore, older adults were not hampered by the ascending condition any more so than the younger adults (see Figure 4).

Table 6

Accuracy (percent correct) Means and Standard Deviations (in parentheses) for Younger and Older Adults in the Fixed Condition

	0 HFN	1 HFN	2 HFN	3 HFN	4 HFN
Younger	67.06 (13.97)	66.61 (15.29)	65.61 (16.56)	65.88 (13.15)	64.09 (11.26)
Older	57.19 (15.43)	59.89 (12.15)	54.77 (16.52)	55.19 (15.17)	57.19 (14.12)

Note. Higher frequency neighbors (HFN).

[1]As a follow-up, a median split separated the older participants into two age groups, as in Experiment 1, however, no effects of interest were significant.

Table 7

Accuracy (percent correct) Means and Standard Deviations (in parentheses) for Younger and Older Adults in the Ascending Condition

	0 HFN	1 HFN	2 HFN	3 HFN	4 HFN
Younger	64.06 (16.71)	60.06 (14.16)	57.36 (11.34)	59.03 (11.77)	61.15 (12.44)
Older	53.81 (16.82)	51.58 (13.30)	50.46 (20.59)	50.23 (19.01)	49.27 (14.31)

Note. Higher frequency neighbors (HFN).

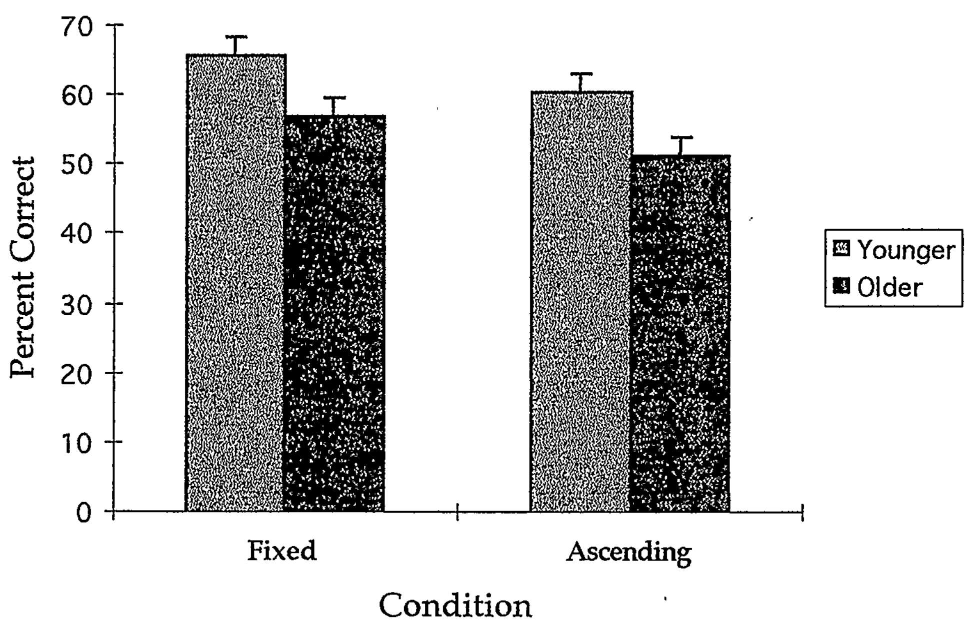

Figure 4. Accuracy (percent correct) in ascending and fixed conditions as a function of Age.

Error Analysis. The specific types of errors made was analyzed further. To this end, every error was first classified as a neighbor error or a non-neighbor error. The neighbor errors were then further divided into either high frequency or low frequency neighbor errors. A high frequency neighbor error was any error that was a neighbor of the target word that had a Kucera and Francis frequency of 90 or greater. For example, for the target word BUCK, the error BACK, which has a Kucera and Francis frequency of 907, was considered a high frequency neighbor error. A low frequency neighbor error was any error that was a neighbor of the target word that had a Kucera and Francis frequency of less than 90. For example, again for the target word BUCK, the error DUCK, which has a Kucera and Francis frequency of 9, was considered a low frequency neighbor error. Non-neighbor errors consisted of non-responses (no attempt made at identification), as well as responses that were not neighbors of the target word (e.g., BARK for BUCK). Using these classifications the proportion of each type of error was calculated with respect to the total number of errors in each condition. Figures 5 and 6 display the percentages of the different types of errors for younger and older adults, respectively.

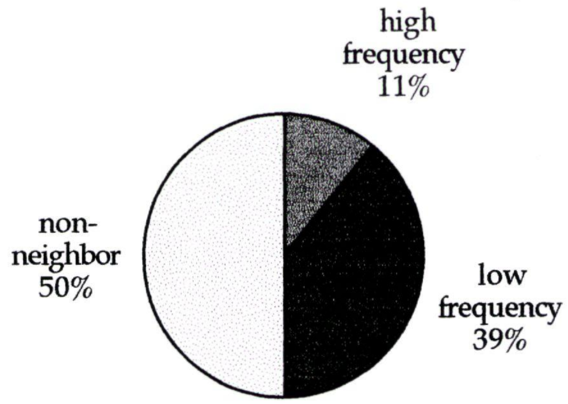

Figure 5 . Percentage of high frequency, low frequency and non-neighbor errors for younger adults.

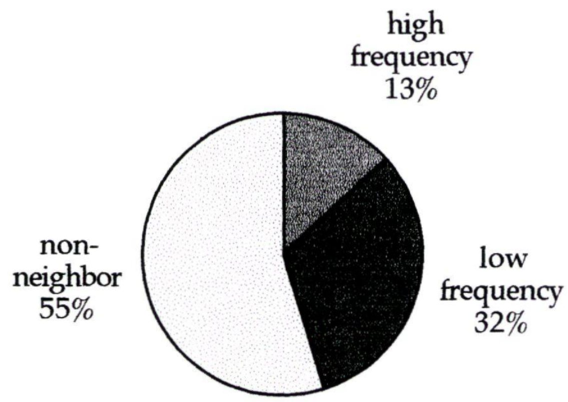

Figure 6 . Percentage of high frequency, low frequency and non-neighbor errors for older adults.

Neighbor errors

Tables 8 and 9 display the means and standard deviations for the proportion of neighbor errors (out of the total number of errors) for younger and older adults in the ascending and fixed conditions, respectively. The proportion of neighbor errors was analyzed using a 2 (Age: younger, older) by 2 (Condition: fixed, ascending) by 5 (Neighborhood Frequency: zero, one, two, three, four or more higher frequency neighbors) mixed model ANOVA. There was a significant main effect of Age, F (1, 57) = 8.15, p = .006, as a significantly greater proportion of neighbor errors were produced by the younger adults (M = .51, SD = .25) relative to the older adults (M = .45, SD = .21). There was also a significant main effect of Neighborhood Frequency, F (4, 228) = 10.11, p < .001. It was found that, relative to words without higher frequency neighbors (M = .39, SD = .23), a significantly larger proportion of neighbor errors were made in the one (M = .47, SD = .28), t (58) = 3.01, p = .004, two (M = .47, SD = .22), t (58) = 2.81, p = .007, and four (M = .57, SD = .20), t (58) = 6.77, p < .001, higher frequency neighbor conditions. As well, a significantly greater proportion of neighbor errors were made in the four higher frequency neighbor condition relative to the one, t (58) = 4.29, p < .001, two, t (58) = 3.36, p = .001, and three, t (58) = 3.20, p = .002, higher frequency neighbor conditions. No other differences were statistically significant.

Table 8

Neighbor Error Rate (proportion) Means and Standard Deviations (in parentheses) for Younger and Older Adults in the Ascending Condition

	0 HFN	1 HFN	2 HFN	3 HFN	4 HFN
Younger	0.484 (0.287)	0.597 (0.217)	0.519 (0.205)	0.455 (0.204)	0.570 (0.177)
Older	0.353 (0.183)	0.467 (0.209)	0.430 (0.226)	0.451 (0.229)	0.527 (0.176)

Note. Higher frequency neighbors (HFN).

Table 9

Neighbor Error Rate (proportion) Means and Standard Deviations (in parentheses) for Younger and Older Adults in the Fixed Condition

	0 HFN	1 HFN	2 HFN	3 HFN	4 HFN
Younger	0.379 (0.264)	0.504 (0.259)	0.486 (0.288)	0.510 (0.269)	0.616 (0.246)
Older	0.326 (0.202)	0.429 (0.228)	0.458 (0.174)	0.518 (0.217)	0.571 (0.184)

Note. Higher frequency neighbors (HFN).

High frequency neighbor errors

Tables 10 and 11 display the means and standard deviations for the proportion of high frequency neighbor errors (out of the total number of errors) for younger and older adults in the ascending and fixed conditions respectively. The proportion of high frequency neighbor errors was analyzed using a 2 (Age: younger, older) by 2 (Condition: fixed, ascending) by 4 (Neighborhood Frequency: one, two, three, four or more higher frequency neighbors) mixed model ANOVA (the zero higher frequency neighbor condition was eliminated from this analysis since, by definition, these words do not have any higher frequency neighbors). There was a significant main effect of Neighborhood Frequency, F (3, 171) = 13.64, $p < .001$. It was found that participants made a significantly larger proportion of high frequency neighbor errors in the four higher frequency neighbor (M = .24, SD = .13) condition relative to the one (M = .11, SD = .10), t (58) = 5.71, $p < .001$, two (M = .12, SD = .13), t (58) = 5.41, $p < .001$, and three (M = .14, SD = .15), t (58) = 3.70, $p < .001$, higher frequency neighbor conditions. No other effects were significant.

Table 10

High Frequency Neighbor Error Rate (proportion) Means and Standard Deviations (in parentheses) for Younger and Older Adults in the Ascending Condition

	1 HFN	2 HFN	3 HFN	4 HFN
Younger	0.111 (0.127)	0.124 (0.114)	0.137 (0.155)	0.202 (0.165)
Older	0.106 (0.109)	0.111 (0.138)	0.162 (0.173)	0.217 (0.161)

Note. Higher frequency neighbors (HFN).

Table 11

High Frequency Neighbor Error Rate (proportion) Means and Standard Deviations (in parentheses) for Younger and Older Adults in the Fixed Condition

	1 HFN	2 HFN	3 HFN	4 HFN
Younger	0.100 (0.120)	0.118 (0.146)	0.103 (0.134)	0.278 (0.188)
Older	0.133 (0.210)	0.121 (0.128)	0.166 (0.151)	0.243 (0.186)

Note. Higher frequency neighbors (HFN).

Low frequency neighbor errors

Tables 12 and 13 display the means and standard deviations for the proportion of low frequency neighbor errors (out of the total number of errors) for younger and older adults in the ascending and fixed conditions respectively. The proportion of low frequency neighbor errors was analyzed using a 2 (Age: younger, older) by 2 (Condition: fixed, ascending) by 5 (Neighborhood Frequency: zero, one, two, three, four or more higher frequency neighbors) mixed model ANOVA. There was a significant main effect of Age, F (1, 57) = 14.95, p < .001, in which younger adults (M = .39, SD = .23) produced a significantly larger proportion of low frequency neighbor errors compared to older adults (M = .32, SD = .19). No other effects were found to be significant.

Table 12

Low Frequency Neighbor Error Rate (proportion) Means and Standard Deviations (in parentheses) for Younger and Older Adults in the Ascending Condition

	0 HFN	1 HFN	2 HFN	3 HFN	4 HFN
Younger	0.478 (0.283)	0.394 (0.193)	0.395 (0.208)	0.318 (0.196)	0.368 (0.172)
Older	0.334 (0.165)	0.275 (0.18)	0.319 (0.186)	0.292 (0.212)	0.310 (0.171)

Note. Higher frequency neighbors (HFN).

Table 13

Low Frequency Neighbor Error Rate (proportion) Means and Standard Deviations (in parentheses) for Younger and Older Adults in the Fixed Condition

	0 HFN	1 HFN	2 HFN	3 HFN	4 HFN
Younger	0.379 (0.264)	0.404 (0.269)	0.369 (0.264)	0.403 (0.219)	0.338 (0.228)
Older	0.326 (0.202)	0.297 (0.195)	0.337 (0.183)	0.352 (0.206)	0.328 (0.170)

Note. Higher frequency neighbors (HFN).

Non-neighbor errors

Tables 14 and 15 display the means and standard deviations for the proportion of non-neighbor errors (out of the total number of errors) for younger and older adults in the ascending and fixed conditions respectively. The proportion of non-neighbor errors was analyzed using a 2 (Age: younger, older) by 2 (Condition: fixed, ascending) by 5 (Neighborhood Frequency: zero, one, two, three, four or more higher frequency neighbors) mixed model ANOVA. There was a significant main effect of Age, F (1, 57) = 7.35, p = .009, in which older adults (M = .55, SD = .21) produced a significantly larger proportion of non-neighbor errors relative to younger adults (M = .50, SD = .24). There was also a significant main effect of Neighborhood Frequency, F

(4, 228) = 9.90, $p < .001$. It was revealed that a significantly larger proportion of non-neighbor errors were made in the zero ($M = .62$, $SD = .23$) higher frequency neighbor condition relative to one ($M = .53$, $SD = .23$), $t(58) = 3.16$, $p = .003$, two ($M = .53$, $SD = .22$), $t(58) = 2.81$, $p = .007$, and four ($M = .43$, $SD = .20$), $t(58) = 6.77$, $p < .001$, higher frequency neighbor conditions. As well, there was a significantly smaller proportion of non-neighbor errors made in the four higher frequency neighbor condition relative one, $t(58) = 4.05$, $p < .001$, two, $t(58) = 3.36$, $p = .001$, and three ($M = .52$, $SD = .23$), $t(58) = 3.20$, $p = .002$, higher frequency neighbor conditions. No other effects were found to be significant.

Table 14

Non-Neighbor Error Rate (proportion) Means and Standard Deviations (in parentheses) for Younger and Older Adults in the Ascending Condition

	0 HFN	1 HFN	2 HFN	3 HFN	4 HFN
Younger	0.516 (0.287)	0.495 (0.217)	0.481 (0.205)	0.545 (0.204)	0.430 (0.177)
Older	0.647 (0.183)	0.592 (0.208)	0.570 (0.226)	0.549 (0.229)	0.473 (0.176)

Note. Higher frequency neighbors (HFN).

Table 15

Non-Neighbor Error Rate (proportion) Means and Standard Deviations (in parentheses) for Younger and Older Adults in the Fixed Condition

	0 HFN	1 HFN	2 HFN	3 HFN	4 HFN
Younger	0.621 (0.264)	0.496 (0.259)	0.514 (0.288)	0.490 (0.269)	0.384 (0.246)
Older	0.674 (0.202)	0.552 (0.254)	0.542 (0.174)	0.482 (0.217)	0.429 (0.184)

Note. Higher frequency neighbors (HFN).

Discussion

The first result to note is the finding that both younger and older adults performed more poorly (i.e., lower accuracy) in the ascending condition relative to the fixed condition (i.e., the perceptual interference effect). This finding supports previous research that only investigated younger adults (e.g., Bruner & Potter, 1964; Luo & Snodgrass, 1994; Snodgrass & Hirshman, 1991). Therefore, it appears that individuals are actually hampered by prior, incomplete, information when trying to identify words under degraded presentations. However, contrary to the findings by Lindfield et al. (1994), there was no age interaction. Recall that in Lindfield et al.'s investigation of the perceptual interference effect using picture stimuli, a trend toward an age interaction was observed. They reported that both younger and older adults performed more poorly given an ascending presentation relative to a fixed presentation, and that this effect was larger for older adults.

This type of age interaction (i.e., a larger deficit in performance for the ascending presentation for older adults) was also the prediction made by the inhibitory deficit hypothesis. Assuming that the explanation for the perceptual interference effect is valid (i.e., incorrect hypotheses are more likely to be formed with an ascending presentation and these hypotheses impede performance), an inhibitory deficit in older adults would predict that older adults would find the ascending condition particularly difficult and demonstrate a larger effect relative to the younger adults. Therefore, the present results of no age interaction would suggest that older adults do not have a difficulty in inhibiting competing hypothesis when they are required to identify a word under non-ideal conditions.

It has already been noted that these present results do not support the results of Lindfield et al. (1994). However, a couple of points are noteworthy here. Lindfield et al. concluded that older adults were more hampered in the ascending condition versus the fixed condition, compared to the younger adults. This conclusion was based on the 'close to significant' age interaction (p = .08) in accuracy and the significant age interaction in reaction time. However, their reaction time measure was post hoc in that participants were not instructed to respond with speed to the stimuli. The authors simply noted that the participants appeared to be responding as quickly as possible.

Although reaction time data was also available in the present experiment, it seemed it would not be a valid measure for two main reasons. The first problem has to do with the instructions given to participants. Because participants were not told that they would be measured on reaction time, and specifically told that there were no time constraints, the response latency data collected in the present experiment would have little validity. The second problem was that, because accuracy was relatively low, in some conditions, for some participants, there was not enough data to get a valid measure of reaction time.

This leads us to one of the potential problems for this experiment. Accuracy appears to be relatively low (and standard deviation very large) for older and younger adults, which makes one question whether or not the task may have been too difficult for participants. As well, there was a significant main effect of Age for overall accuracy in which older adults were less accurate than younger adults. If the task was not too difficult for younger adults, it may have been for older adults. However, it should be noted that an accuracy split on the data did not reveal any significant differences between the low- and high-accuracy participants.

The error analyses revealed some important points about the task as well. Every error was classified as either a non-neighbor error, a high frequency neighbor error, or a low frequency neighbor error. If we examine the proportion of these errors for younger and older adults we see the following (see Figures 5 and 6). First, for both younger and older adults, the largest proportion of errors appear to have been non-neighbor errors ($\underline{M}$ = .50 for younger adults and $\underline{M}$ = .55 for older adults). This finding adds to the feeling that the task may have been too difficult, as many of these errors were non-responses. Again, this is particularly evident for the older adults, as their proportion of non-neighbor errors was significantly larger than for younger adults. The next most common type of error for both younger and older adults was low frequency neighbor errors, in which younger adults had a significantly larger proportion relative to older adults (this result accounts for the finding that younger adults displayed a larger proportion of neighbor errors than older adults). The least common error, in which there was no age difference, was that of high frequency errors.

These results again suggest that the task may have been too difficult for both younger and older adults, and particularly for older adults. Second, and possibly related, is the finding that there were such few neighbor (particularly high frequency) errors suggests that hypothesis testing may not have been addressed in this task. The stimuli may have been too degraded for participants to even come up with potential hypotheses and this issue would have to be addressed in the future.

Another important issue to address is why there was not an inhibitory neighborhood frequency effect in the ascending condition nor a facilitory effect in the fixed condition. An inhibitory effect was predicted based on the findings from Experiment 1. Although the tasks are slightly different, it was speculated that both the progressive demasking task and the ascending presentation lend themselves to hypothesis testing. In both cases, therefore, one would predict that words with larger higher frequency neighborhoods would be more subject to competition from alternative hypotheses relative to words with few higher frequency neighbors. However, we must remember that the tasks were not the exact same. As mentioned above, one has to question whether or not the fixed and ascending presentation tasks may have been too difficult for participants.

The point that keeps cropping up in this discussion is that the task may have been too difficult, in general, and particularly for older adults. In future research one would want to ensure that the task is equated for younger and older adults. To try to address these issues in future research, one could set an accuracy criterion for performance. One possibility would be to set the final fragmented level for the ascending condition and the fragmented level for the fixed condition for each individual. This would be similar to what Lindfield et al. (1994) did for their study. Their level of fragmentation for the fixed condition was based on no more than 60% accuracy in the pretest calibration.

Experiment 3

The results of the first two experiments were somewhat unsettling and needed further exploration. Experiment 3 aimed to further invoke hypothesis testing in participants. In order to do this, a modification of the progressive demasking task used in Experiment 1 was introduced in Experiment 3. The idea was to try to manipulate participant's hypotheses concerning the target. A prime word was introduced before the 'regular' progressive demasking procedure began. The prime word was either unrelated to the target word, related to the target word, or a foil word. The foil prime was related to a neighbor of the target word (e.g., DOCTOR would be the prime for the target word PURSE; due to it's relationship with NURSE). This procedure was expected to further promote the use of hypothesis testing during the identification of the target word. It was expected that, in the foil condition, the prime word, along with the initial presentation of the target word, would start participants off with the incorrect hypothesis and, therefore, hamper their performance. This process is thought to occur both at an automatic level (through spreading activation) as well as at an attentional level. This effect could be displayed either by delaying the correct response (relative to the unrelated condition) or by causing participants to make an incorrect response. Therefore, it was also predicted that the most common errors in the foil condition would be the primed neighbor of the target word (e.g., NURSE). According to the inhibitory deficit hypothesis, it was expected that, relative to younger adults, older adults demonstrate a greater interference effect (i.e., slower in the foil condition relative to the unrelated condition). If older adults begin on the wrong track, according to the inhibitory deficit hypothesis, they should have an especially difficult time abandoning this idea and moving on to something else (the correct response). Recall that one of the proposed roles of inhibition is to suppress strong responses in order to allow for the consideration of other, less probable, responses (Chiappe et al., 2000).

It was also expected that both younger and older adults will exhibit a semantic priming effect (i.e., faster in the related condition than in the unrelated condition). There is still some debate in the literature with regards to age effects in semantic priming. Many studies have reported equivalent priming effects for younger and older adults (e.g., Bowles & Poon, 1985; Madden, et al., 1993). However, more recent research (e.g., Laver, 2000) is pointing to older adults demonstrating a larger facilitory effect. It has also been suggested that semantic processing in the pure sense does not decline with age, and that non-semantic effects (e.g., executive functioning) in tasks which claim to be investigating semantic processing may create age differences (Mayr & Kliegl, 2000). The third experiment will add to this literature as well.

As in Experiment 1, a number of paper and pencil tasks were also incorporated into the present experiment. These measures were incorporated for the same reasons as in Experiment 1. The prime task was such that a measure of interference could be obtained. Therefore, a correlational analysis with this measure and some of the paper and pencil tasks was worthwhile.

Method

Participants. Thirty younger adults ($M = 22.37$, $SD = 4.01$) from the University of Calgary volunteered for the study and received course credit for their participation. Thirty older adults ($M = 71.60$, $SD = 6.90$) were recruited from the community and received a $10.00 honorarium for their time. Some of the older participants had also participated in Experiment 2. The younger participants ranged in age from 17 to 32 years and the older participants ranged from 65 to 80 years of age. Background information regarding relevant health issues was attained via a questionnaire (see Appendix A). This information was used to identify any participants who potentially could not be used in the study (e.g., participants on medication for Depression). However, no participants were removed from analyses due to health-related concerns. All participants reported normal or corrected to normal vision. Based on a 5-point scale (1=poor, 5=excellent), asking participants to rate their overall health compared to others their age, older adults reported good to excellent overall health ($M = 4.16$, $SD = .73$). All participants reported English as their first language. The younger adults reported significantly more years of education ($M = 14.87$, $SD = 1.38$) than the older adults ($M = 13.33$, $SD = 2.32$), $t\,(58) = 3.11$, $p = .02$. However, younger ($M = 51.67$, $SD = 5.93$) and older ($M = 52.31$, $SD = 9.35$) adults performed similarly on the WAIS-R vocabulary test. For information regarding the WAIS-R vocabulary test see the Participants section of Experiment 1.

All participants signed informed consent forms and were asked to request breaks at any time during the study.

Tasks and Procedures. A variant of the progressive demasking task, incorporating a prime preceding the first progressive demasking cycle (priming task), was used in this experiment. There were three prime conditions; Unrelated, Related and Foil. In the Unrelated condition the prime was unrelated (associatively or orthographically) to the target word or any of its neighbors (e.g., DOCTOR - CARD). In the Related condition, the prime was associatively related to the target word (e.g., DOCTOR - NURSE). Finally, in the Foil condition, the prime was associatively related to the one of the target word's neighbors (e.g., DOCTOR - PURSE). The neighbor which was primed in this condition was always a higher frequency neighbor of the target. Primes for all conditions ranged in length from four to six letters, and all targets were four-letter words. Targets in all conditions were matched for word frequency, number of higher frequency neighbors, and neighborhood size (see Appendix E for a full list and description of the stimuli). Table 16 displays the stimuli characteristics. Stimuli were presented on a color VGA monitor driven by a Pentium-class microcomputer. At a viewing distance of 50cm, the stimuli subtended a visual angle of approximately 1.0 degrees.

Table 16

Mean Word Frequency (WF), Neighborhood (N) Size, and Number of Higher Frequency Neighbors (HFNs) for Words in the Unrelated, Related and Foil Conditions

	Unrelated	Related	Foil
WF	14.6	13.9	21.5
N Size	12.1	13.3	13.6
# of HFNs	3.5	3.7	3.6

To determine whether the target words were equated on difficulty, the target words (without the primes) were tested on a group of 23 younger adults ($M = 21.34$, $SD = 2.45$) from the University of Calgary. That is, the targets were presented in the exact same way (progressive demasking) as for the present experiment, the only difference being that there was no prime presented before the target. A repeated measures ANOVA revealed that there was no significant difference in response latency for the targets to be used in the unrelated ($M = 1191.11$, $SD = 421.36$), related ($M = 1212.83$, $SD = 242.54$) and foil conditions ($M = 1210.63$, $SD = 435.74$), $F(2, 44) = .58$, $p = .56$.

The task for the experiment proper went as follows. As in Experiment 1, a trial began with the presentation of a "Ready?" sign in the center of the computer screen. Participants pressed the "R" key which initiated the trial.

The prime word then appeared in the center of the screen for 500ms. This was directly followed by the first cycle of the progressive demasking portion of the task which proceeded exactly as in Experiment 1 (see Figure 7). Participants were again instructed to respond as quickly and as accurately as possible to the target word. They also received the further instruction to pay attention to the first word. There were 23 pairs in each condition, with no prime or target being repeated. Again, trials were randomized for each participant.

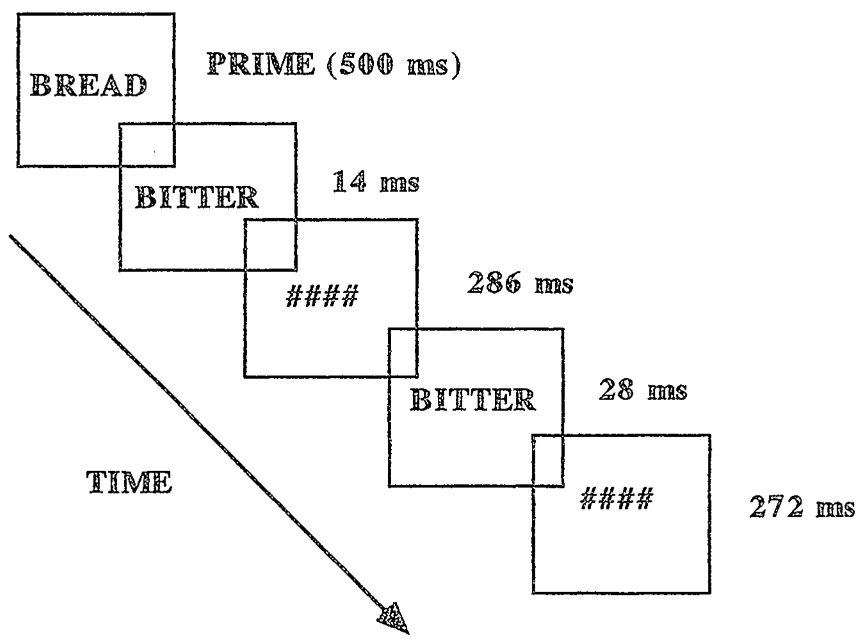

Figure 7. Example of progressive demasking task with prime, used in Experiment 3.

Participants also completed the forward and backward digit span tests from the WAIS-R, two word fluency tasks (P and R), the digit symbol from the WAIS-R and the Finding A's test. These specific tasks were included for the same reasons as for Experiment 1. Participants completed these paper and pencil tasks before the priming task.

Results

Appendix F displays the mean identification accuracy (percent correct) and response latency (ms) for each stimulus item, for younger and older adults. The response latency and accuracy data from the priming task were analyzed using a 2 (Age: younger, older) by 3 (Condition: unrelated, related, foil) mixed model ANOVA.

Error Rate Data. The means and standard deviations for the error rate data (percent errors) for the priming task appear in Table 17. The data revealed a significant main effect of Condition, F (2, 116) = 8.56, $p < .001$. Overall, participants were most accurate in the unrelated ($M = 2.25$, $SD = 4.48$) and related ($M = 2.78$, $SD = 5.16$) conditions, and least accurate in the foil condition ($M = 5.47$, $SD = 6.79$) (see Figure 8). However, there was no significant main effect of Age, or Age by Condition interaction.

Table 17

Error Rate (Percent Errors) Means and Standard Deviations (in parentheses) for Younger and Older Adults

	Unrelated	Related	Foil
Younger	3.03 (5.42)	4.30 (6.06)	5.43 (6.18)
Older	1.25 (3.17)	1.22 (3.58)	5.75 (7.44)

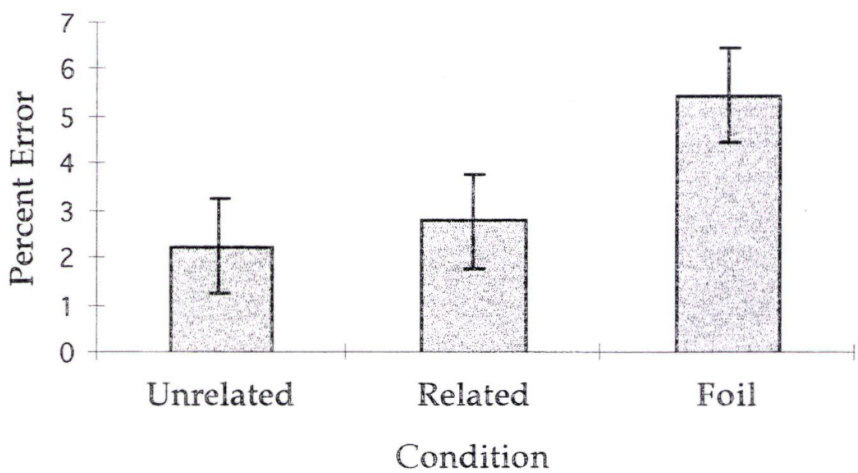

Figure 8. Error rate (percent error) for unrelated, related and foil conditions.

Error Analyses. The type of errors made was also investigated. It was found that, for the older adults, 79% of the errors in the foil condition were the higher frequency neighbor that was related to the prime word (e.g., mistaking EAST for EASE when the prime word was WEST). For the younger adults, only 42% of the errors in the foil condition were the higher frequency, 'primed', word. There were 16 younger adults and 18 older adults who made errors in the foil condition. For each of these individuals the proportion of primed higher frequency neighbor errors (e.g., EAST for EASE, with target WEST) out of total errors for the foil condition was calculated. An independent samples t-test revealed that older adults ($M = .81$, $SD = .35$) had a significantly larger proportion of errors in the foil condition which were the primed higher frequency neighbor relative to the younger adults ($M = .35$, $SD = .39$), $t\ (32) = 3.61$, $p = .001$ (see Figure 9).

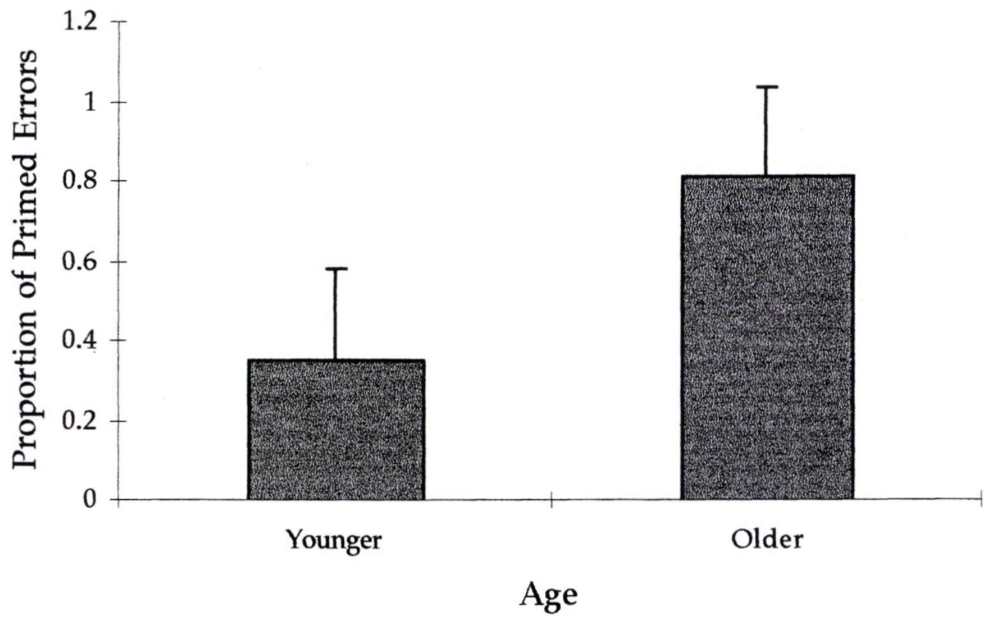

Figure 9. Proportion of primed higher frequency neighbor errors for the foil condition for younger and older adults.

Response Latency Data. The means and standard deviations for the response latency data for the priming task appear in Table 18. The response latency data are based on correct identifications only. There was a significant main effect of Age, F (1, 58) = 86.71 , $p < .001$, as the younger adults (M = 1670.22, SD = 426.50) responded significantly faster than the older adults (M = 2950.60, SD = 685.77)[2]. There was also a significant main effect of Condition, F (2, 116) = 93.03, $p < .001$. Overall, participants responded the fastest in the related condition (M = 2074.25, SD = 784.40), followed by the unrelated condition (M = 2406.24, SD = 871.88), and were slowest in the foil condition (M = 2450.74, SD = 878.99).

Table 18

Response Latency (ms) Means and Standard Deviations (in parentheses) for Younger and Older Adults

	Unrelated	Related	Foil
Younger	1727.32 (428.13)	1504.78 (384.83)	1778.57 (427.83)
Older	3085.17 (639.99)	2643.73 (657.82)	3122.91 (673.86)

There was also a significant Age by Condition interaction, F (2, 116) = 8.27, $p < .001$. Younger adults, responded significantly faster to words in the

[2]As a follow-up, a median split separated the older participants into two age groups, as in Experiment 1, however, no effects of interest were significant.

related condition ($M = 1504.78$, $SD = 384.83$) relative to the unrelated condition ($M = 1727.32$, $SD = 428.13$), $t\,(29) = 8.94$, $p < .001$. Older adults also responded significantly faster to words in the related condition ($M = 2643.73$, $SD = 657.82$) relative to words in the unrelated condition ($M = 3085.17$, $SD = 639.99$), $t\,(29) = 7.64$, $p < .001$. However, this difference was much larger for the older adults compared to the younger adults. Younger adults were significantly slower to identify words in the foil condition ($M = 1778.57$, $SD = 427.83$), relative to the unrelated condition ($M = 1727.32$, $SD = 428.13$), $t\,(29) = 2.20$, $p = .04$. However, for older adults, the difference between the foil ($M = 3122.91$, $SD = 673.86$), and unrelated ($M = 3085.17$, $SD = 639.99$) conditions was not significant, $t\,(29) = 1.07$, $p = .29$.

To examine this data further, a facilitation score was calculated for each individual by subtracting the related condition response latency from the unrelated condition response latency. The older adults demonstrated a much larger facilitation effect ($M = 441.44$, $SD = 316.57$) compared to the younger adults ($M = 222.54$, $SD = 136.31$), $t\,(58) = 3.48$, $p = .001$. An interference score was also calculated for each individual, in which the foil condition response latency was subtracted from the unrelated condition response latency. The interference effect was statistically equivalent for younger ($M = -51.25$, $SD = 127.78$) and older adults ($M = -37.74$, $SD = 192.56$), $t\,(58) = .32$, $p = .75$ (see Figure 10).

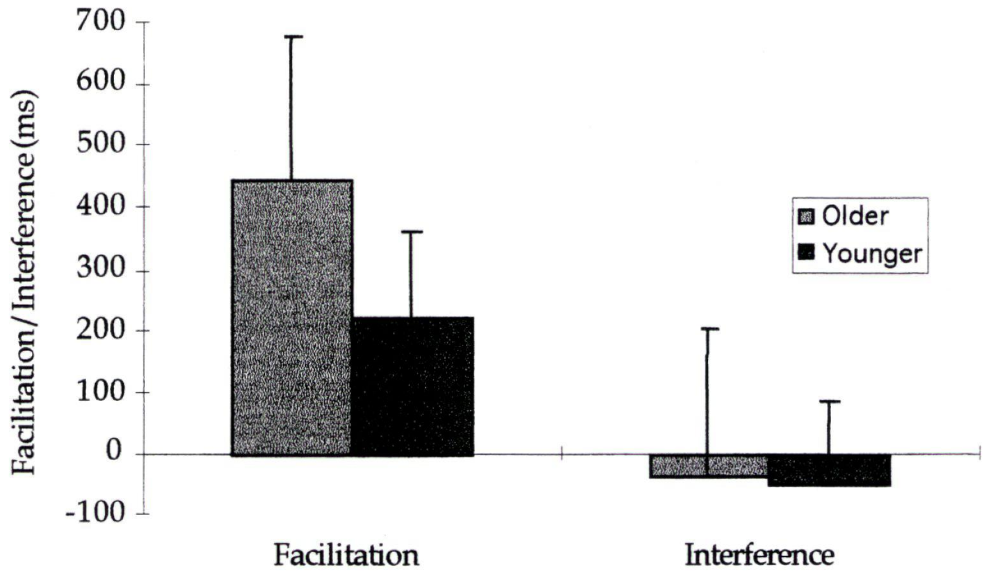

Figure 10. Facilitation and interference effects as a function of Age. Facilitation scores were calculated by subtracting the related condition response latency from the unrelated condition response latency. Interference scores were calculated by subtracting the foil condition response latency from the unrelated condition response latency.

Paper and Pencil Tasks. Younger adults ($M = 5.60$, $SD = 1.33$) had a significantly larger backward span compared to the older adults ($M = 4.80$, $SD = 1.4$), $t\ (58) = 2.27$, $p = .03$. On the digit symbol task the older adults ($M = 45.90$, $SD = 11.05$) completed significantly fewer items compared to the younger adults ($M = 73.03$, $SD = 11.70$), $t\ (58) = 9.24$, $p < .001$. For a discussion of performance on these tasks see Experiment 1. As well, on the word fluency task (P and R combined) the younger adults ($M = 14.07$, $SD = 2.86$) recorded significantly more items than the older adults ($M = 12.35$, $SD = 3.27$), $t\ (58) = 2.16$, $p = .04$.

Correlational Analyses. Some of the correlations which were of interest were with the facilitation and interference measures (described above). For younger adults, facilitation was significantly correlated with the unrelated response latency, $r = .4608$, $p = .01$, foil response latency, $r = .4233$, $p = .02$, and forward digit span, $r = .3594$, $p = .05$. There were no significant correlations with interference. For older adults, the facilitation score was negatively correlated with the digit symbol score, $r = -.4435$, $p = .01$. As well, the interference score was negatively correlated with years of education, $r = -.3825$, $p = .04$. Overall, there was no systematic pattern to these correlations.

Discussion

There were two main effects of interest in the third experiment. First, a facilitory semantic priming effect was observed for both younger and older adults. That is, words that were preceded by a related prime were responded to more quickly than words that were preceded by an unrelated prime. In the present experiment older adults demonstrated a significantly larger facilitory effect relative to younger adults. The second, and initially more relevant, effect of interest was the interference effect. In the present experiment both younger and older adults were slightly slower in the foil condition, however, the effect was not significant for older adults and marginally significant for the younger adults (p = .04). It had been hypothesized that participants would be slower to respond to words which were preceded by a foil prime relative to words preceded by an unrelated prime. Furthermore, it was predicted that, according to the inhibitory deficit hypothesis, older adults would find the foil condition particularly difficult and thus demonstrate a larger interference effect relative to the younger adults.

Therefore, there are two main results to be explained. The first is why the older adults demonstrated such a large facilitory effect relative to the younger adults. The second question is why there was no interference effect observed for either age group, let alone a larger interference effect for older adults. There is one possible explanation which could potentially answer both of these questions. What if older adults are not gaining so much more from a related prime compared to younger adults, but they are hampered so much more by an unrelated prime? Recall that the unrelated primes in the present experiment consisted of unrelated (semantically or orthographically) words to the target. Given that trials were not blocked and that primes were clearly visible, participants were most likely aware that some primes were related to the targets. In fact, many participants, particularly older participants (due to their more social nature in the course of an experiment), commented on the different conditions of the experiment. For example, participants made comments such as "You were trying to trick me...WEST and then EASE rather than EAST". This being the case, an unrelated prime is an invalid cue so to speak. This condition would therefore lead to a much slower reaction time. A very slow reaction time in the unrelated condition would lead to a very large facilitory effect and at the same time may lessen the potential interference effect. This, of course, is due to the fact that both the facilitation and the interference measure are difference scores in relation to the unrelated condition. Therefore, if participants find the unrelated condition to be particularly misleading, then the foil condition may not be that much worse. Similarly, there is more room for improvement in the related condition. Unfortunately, there is no clear way to distinguish between the two explanation (effects due to unrelated condition or to related and foil conditions) except to suggest that in the future a neutral (XXXX) prime should be utilized.

Another explanation for the large age difference in the facilitory effect is that the older adults demonstrated more priming than the younger adults. Priming is often described as potentially being comprised of an automatic (spreading activation) and an attentional component. The nature of this task (relatively long prime presentation and progressive presentation of the target) requires us to accept that both types of priming are most likely taking place. One of the largest debates in the priming literature, with regards to aging, is whether or not there are true differences in automatic priming. As mentioned in the discussion to Experiment 1, there is much stronger evidence for age-related deficits on controlled, or strategic processes than for automatic processes (e.g., Mayr & Kliegl, 2000). Consequently, it is not that surprising that older adults demonstrate a larger facilitory priming effect relative to younger adults, again, given the nature of the task. However, it is suggested, based on previous research (Mayr & Kliegl, 2000) that this is mostly, if not entirely, due to strategic processes and not automatic ones. One way to address this issue in future research would be to vary the length of prime presentation.

We must also address the exploratory error analysis which showed that, for those individuals that did make errors in the foil condition, the older adults were more likely to make the higher frequency, primed error. That is, given the prime RIGHT, and the target LIFT, making the mistake of identifying the target as LEFT. This finding is promising, and consistent with predictions, suggesting that participants are being 'fooled' by the foil condition. Recall that one of the purposes of Experiment 3 was to guide the participants in their hypotheses. Again, these results suggest that the manipulation was successful in this regard.

General Discussion

The goal of the present study was to investigate the inhibitory deficit hypothesis of cognitive aging (Hasher & Zacks, 1988). Specifically, potential age-related differences in inhibitory processes in hypothesis testing during visual word recognition were investigated. As mentioned in the introduction, it is now clear that inhibitory processes are multi-faceted and there is evidence of decline (e.g., Arbuckle, et al., 2000) and stability (e.g., Stine & Wingfield, 1994) in the cognitive aging literature. The present study looked to shed light on one potential role for inhibitory processes; in the 'letting go of' erroneous hypotheses formed during visual word identification. Previous research had shown that when participants are given contextual support to form specific interpretations of written text, that are later shown to be incorrect, older adults have a more difficult time abandoning their initial interpretations compared to younger adults (Hamm & Hasher, 1992). The present study used a similar idea, however, with less contextual support driving the hypotheses. Other research had shown that when participants are presented with incomplete visual information they have a more difficult time in making a correct identification the more prior incomplete information they receive (Bruner & Potter, 1964). It has been suggested that this effect is due to the formation of erroneous hypotheses (Luo & Snodgrass, 1994). As well, it had been demonstrated that older adults may be impeded in such situations to a greater extent than younger adults (Lindfield et al., 1994). The present study also used this idea, however, with the use of word stimuli rather than line drawings. It was hoped that, with the use of word stimuli, we could have more control over the formation of hypotheses.

Experiment 1 revealed some support for an inhibitory deficit in that older adults demonstrated a larger inhibitory neighborhood frequency effect compared to younger adults. However, little support for an inhibitory deficit was found in the other two experiments. We could take these results to suggest that older adults do not experience inhibitory deficits in these processing situations. This would suggest that, under conditions of reduced visibility, older adults do not find competing hypotheses for target identification to be more problematic than they are for younger adults. However, in order to make such a conclusion, more research needs to be carried out as there were a number of potential problems with the present experiments; thus suggesting it may be premature to abandon the idea that older adults my have an inhibitory deficit in these types of situations. The limitations and problems with the individual experiments have already been discussed so we will now turn to some problems common to all three experiments.

All of the tasks presented words which were degraded in some way. It was hypothesized that this situation leads individuals to form hypotheses as to the identity of the word (Bruner & Potter, 1964). The question then was how these hypotheses would affect performance for younger and older adults. What needs to be addressed is that, at present, we do not really know if hypotheses are formed, and if they are, that younger and older adults are forming the same hypotheses. Without knowing this it is difficult to say whether or not older adults are more hampered by erroneous hypotheses. This issue is discussed in more detail below.

Incorporating other measures of both inhibitory processes and working memory would strengthen the work in this area. One would want an inhibitory measure which has a longer history (e.g., Stroop interference) and which has been shown to be a relatively sensitive measure of inhibitory decline. As well, other, potentially more sensitive, measures of working memory (e.g., reading span) could be incorporated.

There are a number of alternative explanations for the present results which should be considered. The first of these is a speed of processing explanation. The question is whether or not the present results could be explained solely due to older adults processing information more slowly than younger adults. There are a number of places we can turn to in an attempt to answer this question. In Experiments 1 and 3, participants completed the digit symbol subtest of the WAIS-R, which has been used as an indication of cognitive speed (Wielgos & Cunningham, 1999). However, in neither experiment was digit symbol correlated with the interference measure. As well, in Experiment 1, where it was suggested that older adults did demonstrate an inhibitory deficit, there is no real reason to suspect that slower processing speed would lead to a difference in the overall pattern of the effect. That is, that older adults demonstrated the inhibitory neighborhood frequency effect for words with one higher frequency neighbor, when younger adults only demonstrated the effect once a word had four higher frequency neighbors. As well, we saw that the oldest adults demonstrated a significantly larger interference score relative to the older adults even though these two groups did not differ significantly on digit symbol performance. A Brinley analysis, in which the mean reaction time of younger adults is plotted against the mean reaction time of the older adults per condition, was conducted for Experiment 1. When the Brinley plot produced is linear, the slope is thought to be an indication of generalized slowing (Pfutze Sommer, & Schweinberger, 2002). The plot created for Experiment 1 showed a non-linear function, ruling out a purely speed explanation.

A second potential explanation is that age differences are due to changes in the visual system. An acuity measure would have helped in ruling out this explanation, and in future studies one should be utilized, however, none was taken. The best answer, therefore, is that there is no apparent reason why you would see qualitative differences in performance across conditions and not simply an overall lowering in performance for older adults. Experiment 2 seems the most likely candidate for a visual explanation since it did seem like a very difficult task, especially for older adults. At least part of this difficulty for older adults could conceivably be due to visual problems. As mentioned previously, in a future study, younger and older adults would be equated similar to the way that Lindfield et al. (1994) equated their younger and older adults.

Third, is the issue of potential differences in semantic networks. This was discussed earlier in the discussion specific to Experiment 1. Although it is possible, it seems unlikely that there are age differences in semantic networks which could account for any of the observed differences in the present study. One of the most widely documented areas of stability in aging is in the area of semantic ability (Burke, 1997). It has also been reported that the organization of concepts is similar for younger and older adults (Gunter, Jackson & Mulder, 1998). However, it would still be fruitful to investigate this idea in the future.

A last potential explanation of the results is age differences in forming hypotheses. As mentioned above, the assumption underlying these tasks is that participants are forming hypotheses. There are two areas of issue here. Are there any reasons to suspect that younger and older adults may form different hypotheses or differ in their ability to form hypotheses at all? Second, if there is reason to believe there may be age differences, then what effect would these differences have on task performance? It is difficult to say whether or not older adults would form different hypotheses from younger adults, however, we can look at the word fluency literature to investigate whether they may have more difficulties in creating hypotheses. The literature on fluency is mixed, as there are reports of age equivalence (e.g., Kemper & Sumner, 2001) as well as age differences (e.g., Salthouse, 1993) in tasks where participants are required to name words beginning with a particular letter. In fact, the present study echoed these results as Experiment 1 demonstrated no age differences on the verbal fluency measure, however, in Experiment 3 younger adults produced significantly more words than older adults. However, in Experiment 3, verbal fluency was not correlated with the interference or facilitation measures. One way to address this issue in future research would be to get a measure of participant's hypotheses while they are doing the task. As Lindfield et al. (1994) did in their picture identification task, participants could be required to make an attempt at identification following each cycle of presentation. One could then compare the hypotheses of younger and older adults.

The next question of course is whether or not age differences in this regard could explain any of the present findings. It is interference from competing hypotheses that is thought to cause an increase in response latency or increase in errors. Therefore, one would expect that the more hypotheses one has formed, the more likely they are to interfere with making the correct identification. If older adults had difficulties forming hypotheses then you might expect them to be less likely to demonstrate an interference effect, not demonstrate a larger effect, as Experiment 1 showed. As mentioned above, however, one could investigate this in the future by having participant's make attempts at identification after each cycle of presentation.

Conclusions

Are older adults more likely to have difficulties reading a sign that is not entirely visible, due to decreased inhibitory abilities? Unfortunately, we are not able to conclusively answer this question at this time. Only results from Experiment 1 demonstrated that older adults may find these situations more difficult. These experiments should be followed up in the future (incorporating the previously mentioned suggestions), to examine these effects in more detail. If the results of Experiment 1 are replicated we can consider ways in which we can make these situations easier for older adults in their living environments. For example, whenever possible, signs using words with few (or no) higher frequency neighbors should be used.

The other question concerns the validity of the progressive demasking task to uncover automatic word processing (Grainger & Jacobs, 1996). The present results support the view that the inhibitory neighborhood frequency effect observed using the progressive demasking task is due to hypothesis testing (Sears et al., 1999) rather than an automatic process (Grainger & Jacobs, 1996). This being the case, researchers should not use the progressive demasking task to investigate automatic processing as the task appears to be susceptible to non-automatic, controlled, processes.

The delineation of inhibitory effects with regards to aging is an ongoing process and we are still far from having a complete picture. Therefore, it is still fruitful to continue to investigate inhibitory processes in as many avenues as possible. The present study has shed some light on the potential role of inhibitory processes taking place during hypothesis testing when attempting to identify visually degraded words. This is a starting point for future research, where these effects can be examined in more detail. It is hoped that through further research we are able to develop a comprehensive theory of inhibitory aging, incorporating areas of decline and areas of stability.

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Appendix A

Health and Background Information Questionnaire.

Background information and health - confidential.
Participant # __________

Gender: Male __________ Female __________

Age: ______

What is the first language you learned as a child? ________________________

What is the highest level of education (degree or completed grade level) that you have completed? ______________________________

Are you taking any medications on a regular basis? yes _____ no _____

If yes, what are the medications and what is being treated?

____

____

Please check the response below that best represents how frequently you drink alcoholic beverages.

Never: _____ Yearly: ______ Monthly:______Weekly:______ Daily:____

Please check the response below that best represents how frequently you visit a doctor.

Never: _____ Yearly: ______ Monthly:______Weekly:______ Daily:____

How would you rate your **overall health** compared to others of your age?

Poor: ______ Fair: ________ Average:______Good:_____ Excellent: _________

How would you rate your **vision** compared to others of your age?

Poor: ______ Fair: ________ Average:______Good:_____ Excellent: ________

Appendix B

Word stimuli for Experiment 1. Higher Frequency Neighbors (HFN).

	0 HFN	1 HFN	2 HFN	3 HFN	4 HFN	5 HFN
	RAFT	MUCK	WELD	SOUR	BEAD	LAME
	SLAB	MINK	SWAY	LARD	HIND	MALL
	HUFF	LASH	ROAM	BIND	FOLD	PEST
	DUKE	BONG	BOOM	CORD	LACE	LEAR
	RIBS	TACT	CORK	HOOD	POUR	LUST
	SUMS	TART	PORK	SACK	YELL	DAME
	SPAN	MILD	HALT	WEPT	RACK	CAVE
	SOAP	LUNG	MEEK	RUST	RAKE	CAKE
	JOKE	LINK	GAZE	ZONE	HEAP	LIME
	BOWL	BUCK	SHOE	FORK	MIST	BELL
	PEAS	LOOP	HIRE	CAFE	HERD	FAME
	JUMP	BATH	CURE	WORN	GEAR	NEST
	GIFT	WEAK	RICE	DEAN	FATE	MATE
	PUSH	CASH	TAPE	TOUR	BENT	GATE
	PLOT	TOOL	MOOD	MEAT	SELL	EASE
	LOAN	CODE	PACE	SOLD	GOLD	CAST
	SALT	PULL	FORT	WOOD	BEAR	REAR
	SKIN	SAFE	SNOW	COOK	HOLE	DEAR
WF	24.6	22.2	21.8	22.6	22.8	20.3
N	8.2	10.7	10.2	10.4	13.0	15.9

	0 HF N	1 HF N	2 HF N	3 HF N	4 HF N	5 HF N
W F	24.6	22.2	21.8	22.6	22.8	20.3
N	8.2	10.7	10.2	10.4	13.0	15.9
1 HF	14.8	536.8	484.4	582.0	663.5	870.2
2 HF		42.3	169.4	287.2	324.1	474.2
3 HF			47.2	155.9	171.2	303.2
4 HF				50.4	132.8	189.3
5 HF					53.4	129.3
6 HF						115.3
7 HF						48.9

Appendix C

Word Stimuli for Experiment 2. Word frequency (WF), Neighborhood size(N) and Higher Frequency Neighbors (HFN).

List 1

0 HFN		WF	N
RAFT		4	7
SKIP		5	8
DOCK		8	13
BEAM		21	9
JOKE		22	6
GANG		22	10
DECK		23	8
SINK		23	14
TAIL		24	12
RANK		24	12
BEND		24	13
PILE		25	14
SALT		46	5
SICK		51	14
WAGE		56	12
	Means	25.2	10.5

1 HFN		WF	N
LICK		3	13
DIME		4	12
PAIL		4	16
TACT		6	6
MINT		7	13
BUCK		20	12
BATH		26	10
HANG		26	13
DULL		27	15
ROOT		30	14
BEER		34	14
CASH		36	12
FAIL		37	14
WILD		56	9
SAFE		57	8
	Means	24.9	12.1

2 HFN		WF	N
PORK		10	9
SHOE		14	6
BARK		14	14
ROPE		15	16
RAGE		16	13
COLT		18	13
DARE		21	17
COPE		21	17
TIRE		22	11
HIDE		22	12
HARM		25	7
BELT		29	11
WAVE		46	17
BAND		53	16
SNOW		59	6
	Means	25.7	12.3

3 HFN		WF	N
REED		5	16
CART		5	13
FORE		7	16
BUST		7	14
TIDE		11	14
ZONE		11	8
HULL		13	14
BOLD		21	14
PORT		21	12
SAND		28	11
HOST		36	9
SAKE		41	17
LOAD		45	11
MOLD		45	14
RIDE		49	18
	Means	23.0	13.4

4+ HFN		WF	N
		2	13
SEEP		2	15
HEAL		7	12
FOLD		11	19
TEAR		13	18
CONE		17	17
LEST		20	16
TENT		22	9
HERD		25	16
PACK		36	11
WISE		41	14
SELL		50	16
FILL		54	17
LAKE		55	16
TALL		59	21
MINE	Means	27.6	15.3

List 2

0 HFN		WF	N
SLAB		9	11
HUFF		10	7
RIBS		11	11
HATS		14	18
SPAN		19	8
SOAP		22	6
BOWL		23	9
PEAS		24	13
JUMP		24	7
SANG		29	16
GIFT		33	6
PUSH		37	8
PLOT		37	8
SKIN		47	8
PICK		55	14
	Means	26.3	10.0

1 HFN		WF	N
MINK		5	14
LASH		6	14
TART		7	12
MILD		14	9
TORE		15	19
LUNG		16	10
LINK		16	11
LOOP		21	8
ROLL		35	9
CASH		36	12
TOOL		40	9
CODE		40	14
COAT		43	9
MILE		48	21
PULL		51	14
	Means	26.2	12.3

2 HFN		WF	N
WELD		4	10
SWAY		5	11
CORK		9	11
HALT		10	11
GAZE		12	12
HIRE		15	12
LOCK		23	15
WARD		25	14
CURE		28	13
RICE		33	14
TAPE		35	11
MOOD		37	10
PACE		43	13
SEAT		54	19
FORT		55	10
	Means	25.9	12.4

3 HFN		WF	N
SOUR		3	11
LARD		4	10
CORD		6	13
SACK		8	13
WART		11	18
BAKE		12	17
FORK		14	10
PAYS		17	21
MODE		21	12
NEAT		21	12
CORE		37	23
DEAN		40	9
MEAT		45	13
WOOD		55	11
COOK		57	12
	Means	23.4	13.7

4+ HFN		WF	N
PEST		4	16
LEAR		4	20
LUST		5	12
HIND		6	9
LONE		8	20
YELL		9	11
BELL		18	16
MATE		21	23
FATE		33	18
SEED		41	22
REAR		51	17
GOLD		52	13
DEAR		54	17
BEAR		57	20
HOLE		58	17
	Means	28.1	16.7

Appendix D

Item Analysis for Experiment 2. Percentage of older and younger participants' correct identifactions, for Fixed and Ascending presentations, for Lists 1 and 2. Higher frequency neighbors (HFN).

List 1	Fixed Presentation		Ascending Presentation	
O HFN	Older	Younger	Older	Younger
BEAM	17	56	46	33
BEND	58	69	54	61
DECK	92	88	62	78
DOCK	67	69	38	56
GANG	50	75	31	89
JOKE	75	69	62	72
PILE	33	69	69	67
RAFT	67	63	54	78
RANK	17	19	23	17
SALT	67	94	85	83
SICK	83	88	77	100
SINK	50	88	77	50
SKIP	58	56	62	72
TAIL	58	69	69	78
WAGE	67	69	46	67
1 HFN				
BATH	25	44	23	61
BEER	25	25	15	39
BUCK	50	69	38	67
CASH	83	88	62	72
DIME	58	63	77	72
DULL	17	50	46	44
FAIL	42	100	23	61
HANG	42	50	38	44
LICK	83	81	69	89
MINT	75	69	77	72
PAIL	50	63	54	78
ROOT	42	50	46	44
SAFE	92	81	46	83
TACT	67	38	31	56
WILD	83	88	77	94

	Fixed Presentation		Ascending Presentation	
2 HFN	Older	Younger	Older	Younger
BAND	33	75	46	78
BARK	17	75	23	44
BELT	50	81	46	78
COLT	83	81	38	72
COPE	58	69	46	56
DARE	50	63	38	56
HARM	25	31	31	44
HIDE	33	19	54	56
PORK	42	81	77	61
RAGE	42	81	38	44
ROPE	58	63	38	44
SHOE	58	63	54	67
SNOW	50	63	54	78
TIRE	42	63	54	78
WAVE	67	81	69	61
3 HFN				
BOLD	50	69	38	44
BUST	33	56	0	50
CAPE	33	75	38	61
CART	50	81	46	72
FAKE	58	63	54	61
HEAP	67	31	62	28
HOST	33	50	62	61
HULL	17	19	31	39
LOAD	83	75	62	94
MOLD	92	100	46	78
PORT	67	69	38	61
RIDE	42	69	62	67
SAND	75	100	77	72
TIDE	67	56	69	72
ZONE	67	56	92	50

	Fixed Presentation		Ascending Presentation	
4+ HFN	Older	Younger	Older	Younger
CONE	42	56	38	61
FILL	92	75	38	56
FOLD	67	94	54	61
HEAL	42	25	54	72
HERD	17	19	31	22
LAKE	75	81	77	78
MINE	42	50	46	61
NEST	58	50	38	72
PACK	83	81	38	94
SELL	58	69	46	83
TALL	75	56	46	72
TEAR	58	69	46	56
TENT	50	69	38	50
TILL	67	50	69	33
WISE	92	81	54	83
LIST 2				
0 HFN				
BOWL	26	82	11	53
GIFT	75	82	100	93
HATS	25	47	56	40
JUMP	67	71	44	40
PEAS	83	71	56	67
PICK	83	88	89	73
PLOT	50	59	44	60
PUSH	83	88	56	80
RIBS	50	35	44	47
SANG	33	76	56	47
SCAR	58	59	22	40
SKIN	42	47	44	53
SLAB	25	59	22	60
SOAP	67	59	56	60
SPAN	42	53	33	53

	Fixed Presentation		Ascending Presentation	
1 HFN	Older	Younger	Older	Younger
CASH	100	82	78	80
COAT	67	82	67	67
CODE	83	82	67	40
LASH	67	76	78	40
LINK	75	65	56	67
LOOP	67	65	56	53
LUNG	33	41	33	53
MILD	83	82	78	80
MILE	75	71	67	60
MINK	67	35	33	53
PULL	58	59	56	53
ROLL	50	76	56	53
TART	58	71	67	53
TOOL	67	88	22	60
WARN	8	53	11	40
2 HFN				
CORK	67	88	67	73
CURE	67	71	67	67
FORT	42	65	56	27
GAZE	58	71	56	53
HALT	33	47	67	33
HIRE	33	41	11	40
LOCK	58	88	56	53
MOOD	58	88	56	53
PACE	58	59	56	53
RICE	75	82	56	67
SEAT	75	65	78	80
SWAY	50	47	56	53
TAPE	67	65	78	60
WARD	75	88	44	47
WELD	50	71	44	67

	Fixed Presentation		Ascending Presentation	
3 HFN	Older	Younger	Older	Younger
BAKE	42	65	44	67
COOK	42	94	89	67
CORD	75	76	89	67
CORE	42	59	78	60
DEAN	42	59	44	40
FORK	50	29	44	47
LARD	75	76	56	60
MEAT	67	71	56	87
MODE	58	88	44	67
NEAT	25	29	44	20
PAYS	58	53	11	40
SACK	83	65	44	73
SOUR	50	76	67	33
WART	42	65	67	47
WOOD	67	76	33	60
4+ HFN				
BEAR	17	41	67	47
BELL	42	59	44	40
DEAR	75	71	44	60
FATE	50	82	33	53
GOLD	67	82	89	87
HOLE	25	82	44	53
LEAR	42	76	44	71
LONE	42	59	44	73
LUST	50	71	33	53
MARE	67	29	44	20
MATE	67	59	33	80
PEST	58	76	67	73
REAR	67	71	11	47
SEED	67	53	67	33
YELL	50	88	56	80

Appendix E

Word Stimuli for Experiment 3. Word Frequency (WF), Neighborhood (N), and Higher Frequency Neighbors (HFNS).

Stimuli for Unrelated Condition.

PRIME	TARGET	WF	N SIZE	# of HFNS
DISH	BEAD	1	13	4
LAUGH	COVE	2	14	3
LIVE	TACK	4	14	3
LAKE	VEST	4	11	4
POLE	BIND	4	12	3
RAZOR	DAME	7	17	5
COOK	LACE	7	14	4
SNOW	OVEN	7	5	3
HAPPY	CAGE	9	14	3
GLASS	CAVE	9	17	5
BARN	SORE	10	17	4
KNEE	RUST	10	12	3
NEVER	VENT	10	11	3
CHAIR	RAKE	11	16	4
DOG	KEEN	11	7	3
HOUR	FAME	18	14	5
HANG	CAFE	20	9	3
SMILE	MESS	22	12	3
RING	TORN	25	12	3
SAVE	GEAR	26	13	4
DREAM	FEES	29	10	3
SHAVE	TOUR	43	8	3
ROCK	MERE	47	6	3
	Means	14.6086957	12.0869565	3.52173913

Stimuli for Related Condition.

PRIME	TARGET	WF	N SIZE	# of HFNS
HORSE	MANE	0	17	3
MAGIC	WAND	1	11	3
BEE	HIVE	2	10	4
SHOP	MALL	3	17	5
BIRD	DOVE	4	14	3
SOIL	WORM	4	8	3
WILD	TAME	5	15	6
FRUIT	PEAR	6	17	4
SAIL	MAST	6	17	5
SAD	WEPT	9	6	3
RAIN	POUR	9	8	4
SUN	RAYS	9	18	3
CANDY	CANE	12	18	3
SUGAR	CAKE	13	18	5
GREEN	LIME	13	13	5
FOG	MIST	14	11	4
POOL	DIVE	23	12	3
CAR	FORD	24	12	3
POKER	CARD	26	11	3
EAT	MEAL	30	12	3
CLEAN	MAID	31	7	3
FISH	BONE	33	17	3
LOVE	HATE	42	16	4
	Means	13.8695652	13.2608696	3.69565217

Stimuli for Foil Condition.

PRIME	TARGET	WF	N SIZE	# of HFNS
AIM	SOOT	1	14	3
LESS	MOLE	4	19	3
NOW	TEEN	6	9	3
BAD	HOOD	7	11	3
SMOKE	FARE	7	18	4
PHONE	GALL	7	15	5
ALIVE	DEED	8	15	4
HIT	MOSS	9	17	3
FRONT	RACK	9	12	3
DAY	WEEP	14	8	3
EMPTY	BULL	14	16	3
HOUSE	DOME	17	13	4
SLEEP	RENT	21	14	4
JOB	WORN	23	9	3
RIGHT	LIFT	23	10	3
WORST	BENT	34	15	4
FAR	WEAR	36	16	4
EARLY	GATE	37	16	5
RUN	RARE	41	15	3
WEST	EASE	42	8	4
MARRY	WIRE	42	17	4
PRICE	CAST	45	15	5
HOT	SOLD	47	10	3
	Means	21.4782609	13.5652174	3.60869565

Appendix F

Item Analysis for Experiment 3. Percentage of older and younger adults' correct identifcations and mean response latency (ms).

Unrelated Condition.

		Percent Correct		Response Latency	
PRIME	TARGET	Older	Younger	Older	Younger
DISH	BEAD	91	97	3263	2146
LAUGH	COVE	100	97	3302	1951
LIVE	TACK	100	97	2860	1773
LAKE	VEST	94	97	3433	1709
POLE	BIND	94	97	3158	1926
RAZOR	DAME	97	100	3352	2072
COOK	LACE	97	100	3035	1769
SNOW	OVEN	100	97	2981	1504
HAPPY	CAGE	91	97	3006	1859
GLASS	CAVE	97	97	2916	1661
BARN	SORE	97	100	2855	1653
KNEE	RUST	97	94	2814	1605
NEVER	VENT	100	97	3234	1612
CHAIR	RAKE	91	89	3261	2035
DOG	KEEN	100	100	3203	1966
HOUR	FAME	91	97	2959	1879
HANG	CAFE	100	97	3061	1919
SMILE	MESS	100	100	3295	2024
RING	TORN	97	100	2849	1680
SAVE	GEAR	100	100	2873	1743
DREAM	FEES	97	97	3537	2138
SHAVE	TOUR	94	97	2994	1624
ROCK	MERE	97	94	3461	2181

Related Condition.

PRIME	TARGET	Percent Correct Older	Percent Correct Younger	Response Latency Older	Response Latency Younger
HORSE	MANE	100	100	3055	1763
MAGIC	WAND	94	100	2730	1765
BEE	HIVE	100	100	2687	1529
SHOP	MALL	94	86	2636	1826
BIRD	DOVE	100	100	2745	1452
SOIL	WORM	100	94	2956	1676
WILD	TAME	97	97	2450	1515
FRUIT	PEAR	100	100	2511	1484
SAIL	MAST	100	97	2551	1741
SAD	WEPT	97	100	2834	1669
RAIN	POUR	100	100	2461	1367
SUN	RAYS	88	94	2764	1469
CANDY	CANE	100	100	2496	1645
SUGAR	CAKE	100	100	2637	1447
GREEN	LIME	97	100	2596	1644
FOG	MIST	100	100	2518	1385
POOL	DIVE	100	100	2619	1539
CAR	FORD	100	100	2562	1507
POKER	CARD	100	100	2517	1492
EAT	MEAL	100	100	2570	1610
CLEAN	MAID	97	100	2623	1726
FISH	BONE	100	100	2412	1466
LOVE	HATE	100	100	2581	1518

Foil Condition.

		Percent Correct		Response Latency	
PRIME	TARGET	Older	Younger	Older	Younger
AIM	SOOT	88	92	2779	1821
LESS	MOLE	91	92	2908	2047
NOW	TEEN	97	94	3169	1775
BAD	HOOD	100	100	3025	1830
SMOKE	FARE	94	100	3442	1877
PHONE	GALL	68	81	3340	2438
ALIVE	DEED	91	100	2946	1958
HIT	MOSS	97	100	3108	1741
FRONT	RACK	79	75	3081	1974
DAY	WEEP	97	92	3158	1773
EMPTY	BULL	94	100	3031	1787
HOUSE	DOME	97	97	3078	1866
SLEEP	RENT	100	97	3134	1728
JOB	WORN	94	100	3463	1838
RIGHT	LIFT	91	78	3038	1976
WORST	BENT	97	97	3032	1909
FAR	WEAR	97	97	3463	1996
EARLY	GATE	100	100	2978	1603
RUN	RARE	94	94	3587	2020
WEST	EASE	91	78	3177	1985
MARRY	WIRE	100	97	3326	2189
PRICE	CAST	91	97	2699	1539
HOT	SOLD	97	96	2870	1710