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Aging and the inhibition of competing hypotheses during visual word identification: evidence from the progressive demasking task

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Two experiments used the progressive demasking (PD) task to examine age differences in the ability to inhibit higher frequency competitors during the process of identifying a visually degraded word. In Experiment 1, older adults exhibited a larger inhibitory neighborhood frequency effect (i.e., slower identification of words with many higher frequency competitors) than younger adults, but additional analyses indicated that this difference could be explained by general slowing rather than a deficit in inhibitory abilities. In Experiment 2, a primed version of the PD task was used to promote hypothesis testing by semantically priming the target word (e.g., *cry–weep*) or a higher frequency competitor of the target (e.g, *day–weep*) prior to the onset of the demasking sequence. Although older adults were more likely to make identification errors consistent with an inhibitory deficit (e.g., identifying *weep* as *week*), these errors were infrequent overall and there was no corresponding evidence of a larger interference effect in the older adults' identification latencies. Taken together, performance in these two tasks provides little evidence of reduced inhibitory functioning in older adults. The implications for the inhibitory deficit hypothesis of cognitive aging and directions for future are discussed.

Keywords: aging; inhibition; progressive demasking task; semantic priming; hypothesis testing

Over the past several decades, researchers have documented age-related differences on a number of measures of cognitive functioning, including working and episodic memory (e.g., Chiappe, Siegel, & Hasher, 2000; Craik & Jennings, 1992; Wingfield, Stine, Lahar, & Aberdeen, 1988), speed of information processing (e.g., Salthouse & Meinze, 1995), spoken word recognition (Sommers & Danielson, 1999; Taler, Aaron, Steinmetz, & Pisoni, 2010), and selective attention (e.g., Earles et al., 1997; Plude & Hoyer, 1986). At the same time, gerontologists have attempted to integrate these findings into a general theory of cognitive aging. One theoretical framework, which is the focus of the present study, is the inhibitory deficit hypothesis (Hasher, Lustig, & Zacks, 2007; Hasher & Zacks, 1988; Hasher, Zacks, & May, 1999).

According to the inhibitory deficit hypothesis, aging weakens inhibitory processes, especially the processes responsible for regulating and controlling the information that enters and leaves working memory. Hasher et al. (1999) proposed that inhibitory processes serve three different functions in regulating information in working memory. The first is to prevent the entry of goal-irrelevant information. The second function, which has

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been termed the deletion function (Hasher et al., 1999), is to suppress information that may have been activated initially, but is no longer relevant. The third function, the restraining function, works to prevent strongly activated, but incorrect responses, from being executed. According to Hasher et al., many of the documented age-related differences in cognition can be explained by deficits in inhibitory processes that affect the operation of one or more of these functions. For older adults, the main consequence is that irrelevant information is more likely to enter working memory, is not deleted, and then creates interference.

The hypothesized age deficit in the ability to inhibit irrelevant information is predicted to manifest itself in situations where there is competition between target and nontarget information. That is, to efficiently process target information, one must inhibit competing nontarget items to reduce the amount of interference they create during processing. This prediction has gained support in several different areas of study, including visual attention (e.g., Lahar, Isaak, & McArthur, 2001; McDowd & Oseas-Kreger, 1991), language processing (e.g., Hamm & Hasher, 1992; Hartman & Hasher, 1991; Hasher, Quig, & May, 1997), and memory (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). On the other hand, there is research that suggests that older adults do not have a global inhibitory processing deficit (e.g., Andrés, 2009; Kemper & McDowd, 2006; Verhaeghen & De Meersman, 1998). A major goal of cognitive aging research in recent years has been to distinguish between aspects of inhibitory processing that decline with age and those that do not (e.g., Collette, Germain, Hogge, & Van der Linden, 2009). The present study focused on inhibitory processes in hypothesis testing, using a task that examined older and younger adults' ability to inhibit competing hypotheses while trying to identify a visually degraded word.

Inhibitory processes in hypothesis testing

One theme in studies that have investigated inhibitory processes in older adults is that older adults have more difficulty with "pruning." That is, following an initial stage of diffuse activation of concepts or ideas, older adults have more difficulty inhibiting material that is no longer relevant to the task at hand, leading to increased competition and interference in the performance of the task. Some of this evidence comes from studies of inference making in discourse comprehension (Hamm & Hasher, 1992; Hasher et al., 1997), directed forgetting (Andrés, Van der Linden, & Parmentier, 2004; Zacks, Radvansky, & Hasher, 1996; although see Hogge, Adam, & Collette, 2008, for a different interpretation), and the processing of metaphors (Morrone, Declercq, Novella, & Besche, 2010). On the other hand, in some tasks older adults do not experience significantly greater interference than younger adults despite the fact that the task requires participants to inhibit competing alternatives. For example, using an auditory word identification task, Stine and Wingfield (1994) found that both older and younger adults required longer presentation times to identify a target word when the target possessed a high-probability competitor compared to when it possessed a low-probability competitor, with the interference effect being no larger for the older adults.

In a study with a similar motivation, Lindfield, Wingfield, and Bowles (1994) examined inhibitory processes in younger and older adults via the perceptual interference effect (Bruner & Potter, 1964). The perceptual interference effect occurs when participants are asked to identify a degraded stimulus that is gradually made more visible. In Bruner and Potter's original study, participants were presented with a sequence of degraded photographs of common objects that were gradually “filled-in” and completed. Identification accuracy was worse the more degraded the initial presentation, even though all the images ended at the same level of completion. According to the competitive activation model (Luo & Snodgrass, 1994), the perceptual interference effect occurs because the initial presentations lead to the activation of hypotheses about the identity of the target. On some trials, participants form incorrect hypotheses early in the sequence of presentations and these hypotheses compete with the correct identification and produce interference.

Lindfield et al. (1994) reasoned that inhibitory processes could play a role in eliminating hypotheses that are initially generated but are later rejected as more information becomes available, and if so, the perceptual interference effect could be used to test the inhibitory deficit hypothesis of cognitive aging. Using drawings of familiar objects, they compared the identification latencies and errors of younger and older adults in two presentation conditions that differed in how the objects were visually degraded. In the fixed presentation condition, participants were presented with a line drawing at a predetermined level of fragmentation (fragmentation was achieved by removing blocks of pixels from the image). 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 used in the fixed presentation condition.

As expected, Lindfield et al. (1994) found that both younger and older adults’ accuracy was lower in the ascending presentation condition, replicating the basic perceptual interference effect. Contrary to their prediction, however, the perceptual interference effect was not significantly larger for older adults. Nonetheless, Lindfield et al. argued that the trend in the accuracy data was generally consistent with the prediction that older adults would experience more difficulty eliminating erroneous hypotheses in the ascending condition, as the difference in accuracy between the ascending and fixed presentation conditions was slightly larger for older adults. In addition, for the identification latency data, older and younger adults performed similarly in the fixed presentation condition, whereas in the ascending presentation condition older adults took significantly longer to respond than younger adults, which also suggested that older adults experienced more interference. In the end, however, Lindfield et al.’s results were mixed and lent only partial support to the inhibitory deficit hypothesis.

The present research

The present study investigated age-related differences in inhibitory processes associated with hypothesis testing during the identification of visually degraded words. We used the progressive demasking task from the word identification literature (Grainger & Segui, 1990) because of its similarity to the ascending presentation task used by Lindfield et al. (1994). In this task, a trial consists of a number of word/mask cycles. While the length of presentation for the entire cycle remains constant, the relative durations of the word and mask are varied, such that over the course of a trial the presentation time of the word increases and that of the mask decreases. This creates a situation in which the word becomes increasingly identifiable over time. The participants’ task is to stop the demasking sequence as soon as they believe they have identified the word. Like the ascending presentation task used by Lindfield et al. (1994), the progressive demasking task encourages participants to use information from the early exposures to generate and test hypotheses about the stimulus on the later exposures. Given that there will often be some ambiguity as to the word's identity based on the early exposures, selection of the incorrect candidate for hypothesis testing will occur occasionally. The result would be either an identification error (if the participant chooses to respond with that candidate before the stimulus has been unambiguously identified) or a delay in producing the correct response. To our knowledge, no other investigators have used this task to investigate age-related differences in inhibitory processes.

A major advantage of the progressive demasking task is that one can gain some control over the potential hypotheses that participants may form while trying to identify words (unlike the situation when using line drawings of objects as stimuli). This can be accomplished by using words that possess *orthographic neighbors* higher in printed frequency than the word itself. A word's orthographic neighbors are the set of different words that can be created by changing one letter of the word while maintaining letter positions (Coltheart, Davelaar, Jonasson, & Besner, 1977). For example, *lime* has 12 orthographic neighbors, including *dime*, *limp*, *lame*, *life*, *like*, *live*, and *time*. For many words, some, or many, of the neighbors are higher in frequency than the word itself. For example, *lime* has eight higher frequency neighbors (*like*, *time*, *line*, *life*, *live*, *mime*, *lame*, and *dime*). The more higher frequency neighbors a word has, the more likely it will be misidentified as one of the higher frequency neighbors under degraded presentation conditions (Andrews, 1997; Sears, Lupker, & Hino, 1999; Slattery, 2009).

Beginning with Grainger and Segui (1990), a number of researchers using the progressive demasking task have reported slower identification latencies for words with higher frequency neighbors than for words without higher frequency neighbors (e.g., Carrieras, Perea, & Grainger, 1997; Grainger & Jacobs, 1996). This phenomenon has been termed the inhibitory neighborhood frequency effect. There is some debate as to the predominant source of the inhibition effect in this task. Grainger and colleagues argue that a large component of the effect is due to competition among the lexical representations of the word and its neighbors during the processing that culminates in word identification. Others argue that the effect is due to erroneous hypotheses formed during the early presentations of the word that hamper identification performance (Andrews, 1997; Forster & Shen, 1996; Sears et al., 1999), much like the situation in experiments investigating the perceptual interference effect (Bruner & Potter, 1964; Lindfield et al., 1994). However, all investigators agree that the progressive demasking task, like all perceptual identification tasks, involves decision-making/guessing strategies, and that the task encourages participants to use information from the early exposures to generate and test hypotheses about the target's identity while simultaneously inhibiting high-probability competitors. As a result, the progressive demasking task provides an ideal opportunity to compare the inhibitory processes of older and younger adults. If a large component of the neighborhood frequency effect is due to the formation of erroneous hypotheses, then older adults should be more affected by this competition among hypotheses than younger adults and should therefore exhibit an increased inhibitory neighborhood frequency effect.

The present study contributes to the literature testing the inhibitory deficit hypothesis of cognitive aging (Hasher & Zacks, 1988; Hasher et al., 1999) by using methodologies not previously employed with older adults. Although a few studies have used the lexical decision task to examine the neighborhood frequency effect in younger and older adults (in which participants make speeded "word" and "nonword" decisions to single word and nonword stimuli), to our knowledge no other study has used the progressive demasking task for this purpose. Moreover, the lexical decision studies have reported conflicting findings. That is, whereas Stadtlander (1995) found that the neighborhood frequency effect was no different for younger and older adults (both groups had slower lexical decision latencies to words with higher frequency neighbors than to words without higher frequency neighbors), Robert and Mathey (2007) observed a neighborhood frequency effect only for younger adults. More importantly, in our view the progressive demasking task is a better task to test for age-related differences in inhibitory processes related to hypothesis testing, because participants are encouraged to create, and test, hypotheses as to the word's identity during the progressive demasking sequence, which is not the case for the lexical decision task. These hypotheses can then compete with the correct identification and produce interference. Our study contributes to the literature documenting which aspects of inhibitory functioning are susceptible to aging and which are not, as there is a growing consensus that if older adults do have an inhibitory deficit, it is not a global impairment (e.g., Andrés, 2009; McCrae & Abrams, 2001). As our tasks examined age-related differences in the ability to inhibit prepotent, but erroneous, hypotheses, and perhaps also the ability to subsequently remove these hypotheses from working memory, both the restraint and deletion components of inhibitory processing, as proposed by Hasher et al. (1999), were the focus of our investigation.

Experiment 1

In Experiment 1, the progressive demasking task was used to look for evidence of age-related differences in the inhibition of competing hypothesis. The words that were presented had zero to five higher frequency neighbors. As the number of higher frequency neighbors increases, the interference effect was also expected to increase, because the more higher frequency neighbors a word has, the more likely it will be misidentified as one of those neighbors (higher frequency competitors) during the progressive demasking sequence. Younger adults were expected to exhibit an inhibitory neighborhood frequency effect like they have in other progressive demasking experiments (e.g., Grainger & Jacobs, 1996; Grainger & Segui, 1990). For older adults, the inhibitory deficit hypothesis predicts that they will exhibit a larger inhibitory neighborhood frequency effect. This age-related difference could be manifested in one of two ways. The first possibility is that older adults will exhibit an even larger increase (relative to younger adults) in response latencies for words with higher frequency neighbors relative to words without higher frequency neighbors (i.e., a magnitude effect). The second possibility is that older adults will be more affected by the presence of even one or two higher frequency competitors, such that they will be slower to respond to these words relative to words without higher frequency neighbors, whereas the responding of younger adults will not be affected until words have many higher frequency neighbors (i.e., a threshold effect). Both of these possibilities were tested in the analyses reported below.

Method

Participants. Twenty younger adults (M = 21.9, SD = 3.1) from the University of Calgary volunteered to participate in exchange for extra credit in a psychology course. Twenty older adults (M = 70.7, SD = 4.9) were recruited from the community and received a Can $10.00 honorarium for their participation. All of the participants were native English speakers. The younger adults ranged in age from 18 to 29 years and the older adults ranged from 62 to 80 years of age. A demographics questionnaire was used to collect information regarding health issues, and this information was used to identify participants whose health might impact their performance in the study (e.g., participants taking medication for depression; participants experiencing vision difficulties). None of the participants had to be excluded from analyses because of health-related issues. Participants were also asked to rate their overall health compared to others their age, using a 5-point scale from 1 (*poor*) to 5 (*excellent*). Older adults reported very good overall health (M = 4.10, SD = .80). All participants reported normal or corrected-to-normal vision. Younger and older adults reported a similar number of years of education (M = 14.3, SD = 1.7, and M = 13.2, SD = 2.3, respectively), $t(38) = 1.72$, $p = .09$.

Tasks and procedures. The progressive demasking task used in this experiment was identical to the one used by Grainger and Segui (1990). Each trial consisted of a succession of target word and pattern mask (####) presentations. Over the course of a trial, the duration of the target word was increased and the duration of the mask was decreased, which served to gradually increase the visibility of the target word. The participant's task was to identify the target word as quickly and as accurately as possible.

The stimuli consisted of six sets of four-letter low-frequency words, corresponding to six neighborhood frequency conditions: words with 0, 1, 2, 3, 4, or 5 or more higher frequency neighbors. To be considered a neighbor of a target word, a word had to appear in the English Lexicon Project database (Balota et al., 2007). All the words were four-letters in length, and there were 18 words in each condition. Printed word frequency (Kucera & Francis, 1967) was controlled to ensure that the words within and between conditions were of similar frequencies. The mean Kucera and Francis normative frequency per million words for all the words was 22.4 (range of 1 to 59) and normative frequency did not differ significantly across the six higher frequency neighbor conditions (p >.10). All the words had at least 6 neighbors (of higher or lower frequency), with a mean of 11.4 neighbors. Words with many higher frequency neighbors had, on average, more neighbors overall than words with few higher frequency neighbors (by necessity), but the differences were not large (the mean number of neighbors ranged from 8.2 to 15.9). (These stimuli are available from the authors.)

Stimuli were presented on a computer monitor driven by a desktop microcomputer. Words were presented in capital letters in white text on a black background. At a viewing distance of 50 cm, a word subtended a visual angle of approximately two degrees. At the start of each trial, a 1-s 2,000 Hz warning tone was followed by the word "READY?" presented in the center of the display. Participants were asked to press the "r" key on the keyboard when they were ready to proceed. After a 1-s delay, the word appeared in the center of the display, followed by a pattern mask (####). Initially, the word appeared for 14 ms and the mask for 286 ms. On each successive cycle, the duration of the word increased by 14 ms and the duration of the mask decreased by 14 ms, each cycle lasting 300 ms. Participants were instructed to press the spacebar on the keyboard as soon as they had identified the word, and to identify words as quickly as possible while maintaining accuracy. Response latencies were measured to the nearest ms, from the onset of the first cycle until the participant pressed the spacebar. When the spacebar was pressed the display was cleared immediately and the participant was prompted to type in the word they had identified. They were instructed to use the editing keys on the keyboard to correct any typing errors, and to press the "Enter" key when they were satisfied with their response. There were no time constraints for responding. The participant's response initiated the next trial after a timed interval of 3 s.

Each participant completed 20 practice trials prior to the collection of data. (The data from these practice trials was not analyzed.) During the practice trials participants were provided with feedback as to the accuracy of each response; if an error was made, the correct word was presented on the computer display. No feedback was provided during the experimental trials. The order in which the 108 experimental trials were presented was randomized separately for each participant.

Participants also completed the vocabulary, digit symbol, and forward and backward digit span tests from the Wechsler Adult Intelligence Scale-Revised (WAIS-R; Wechsler, 1981), two word fluency tasks (P and R), and the Finding A's test (Ekstrom, French, Harman, & Derman, 1976). Participants completed these paper-and-pencil tasks before they completed the progressive demasking task. These tasks were administered to examine associations between language and cognitive skills and performance in the progressive demasking task. The word fluency task is considered by some to be a measure of inhibitory abilities (e.g., Arbuckle, Nohara-LeClair, & Pushkar, 2000), which was the focus of the present study. The digit symbol subtest is widely used as a measure of cognitive speed (e.g., Wielgos & Cunningham, 1999) and was therefore relevant to the present experiment because identification latency was measured. The backward span test was used to assess working memory, and it allowed us to determine whether there would be a relation between working memory and inhibitory processes (e.g., Lustig, May, & Hasher, 2001).

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, $t(38) = 6.70$, $p < .001$, 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 test, $t(38) = 1.24$, $p > .10$. Although a number of studies have found that younger adults outperform older adults on this test (e.g., Kemper & McDowd, 2006), this is not always the case (e.g., Kemper & Sumner, 2001; Light, Prull, & Kennison, 2000). As expected, older adults (M = 58.9, SD = 6.7) scored significantly higher than younger adults (M = 53.6, SD = 6.0) on the vocabulary test, $t(38) = 2.75$, $p < .01$. Younger (M = 33.40, SD = 8.11) and older (M = 29.50, SD = 8.18) adults performed similarly on the Finding A's test. Younger (M = 7.34, SD = 1.68) and older (M = 6.84, SD = 1.95) adults also performed similarly on the forward digit span test, $t(38) = 1.51$, $p > .10$.

Results

Progressive demasking task. The mean percentages of identification errors are listed in Table 1. These were analyzed using a 2 (Age) × 6 (Number of Higher Frequency

Table 1. Mean identification latencies (in milliseconds) and identification errors (in %) for words with zero, one, two, three, four, and five or more higher frequency neighbors.

	Number of higher frequency neighbors					
Age group	Zero	One	Two	Three	Four	Five
Younger						
latencies	1,326 (128)	1,322 (124)	1,308 (113)	1,339 (111)	1,437 (107)	1,394 (111)
errors	3.8 (1.2)	1.8 (.73)	1.5 (.70)	1.5 (.70)	3.5 (1.1)	2.8 (.95)
Older						
latencies	2,055 (84)	2,143 (99)	2,095 (96)	2,141 (98)	2,310 (101)	2,241 (89)
errors	3.7 (1.2)	4.0 (1.4)	2.0 (1.0)	3.5 (1.2)	5.6 (1.3)	3.3 (1.8)

Note: Standard errors in parentheses.

Neighbors) mixed-model analysis of variance (ANOVA). No significant effects were found (all *F*s < 1). As can be seen in Table 1, identification errors were infrequent (5.6% of responses overall) and the frequency of identification errors was similar for younger and older adults (5.0% and 6.2%, respectively). An examination of the types of errors made revealed no systematic pattern for younger or older adults. There were no correlations, for younger or older adults, between identification latency and error rate (all *p*s >.10), and therefore no evidence of a speed-accuracy tradeoff in responding.

The mean identification latencies are also listed in Table 1. The latency data are based on correct identifications only. Identification latencies greater than three standard deviations from a participant's condition mean were excluded from the calculation of the mean (this resulted in the exclusion of less than 5% of latencies). These data were analyzed in the same way as the error data, and the analysis produced a significant effect of age, $F(1, 38) = 30.35$, MSE = 1,296,551.91, $p < .001$, as younger adults responded significantly faster than older adults (1,354 ms vs. 2,164 ms). There was also a significant effect of number of higher frequency neighbors, $F(5, 190) = 18.31$, MSE = 11,168.53, $p < .001$, replicating the basic inhibitory neighborhood frequency effect (e.g., Grainger & Jacobs, 1996). As can be seen in Table 1, words with higher frequency neighbors were identified more slowly than words without higher frequency neighbors. Most important was the significant Age × Number of Higher Frequency Neighbors interaction, $F(5, 190) = 2.25$, MSE = 11,168.53, $p = .05$. The data in Table 1 suggest that there was a neighborhood frequency effect for both younger and older adults and that the interaction occurred because older adults were more susceptible to the effect. To follow up this interaction, we used planned *t*-tests to compare the identification latencies for words with higher frequency neighbors to the latencies for words without higher frequency neighbors, for both older and younger adults.

For the older adults, words with one higher frequency neighbor were identified significantly more slowly than words without higher frequency neighbors (2,143 ms vs. 2,055 ms, an 88-ms difference), $t(19) = 3.06$, $p < .01$, which was not the case for the younger adults (1,326 ms vs. 1,322 ms, a 4-ms difference), $t(19) =.18$, $p > .10$. As can be seen in Table 1, relative to words without higher frequency neighbors, older adults were also slower identifying words with three higher frequency neighbors (an 86-ms difference), $t(19) = 2.09$, $p =.05$, words with four higher frequency neighbors (a 255-ms difference), $t(19) = 6.66$, $p < .001$, and words with five or more higher frequency neighbors (a 186-ms difference), $t(19) = 5.43$, $p < .001$. In contrast, for the younger adults, only when the words had four or more higher frequency neighbors was there any evidence of a neighborhood frequency effect. Relative to words without higher frequency neighbors, identification responses for younger adults were 111 ms slower for words with four higher frequency neighbors, $t(19) = 2.99$, $p < .01$, and 69 ms slower for words with five higher frequency neighbors, $t(19) = 1.71$, $p = .10$. These results suggest that older adults experienced greater interference from a word's higher frequency neighbors during the progressive demasking sequence (in particular, a threshold effect, as we defined earlier), an outcome consistent with the inhibitory deficit hypothesis.

We also evaluated whether older adults exhibited a larger increase (relative to younger adults) in identification latencies for words with higher frequency neighbors relative to words without higher frequency neighbors (i.e., a magnitude effect). To do so, we calculated an average interference measure for each participant by calculating the average identification latency for words with higher frequency neighbors (averaged over the 1, 2, 3, 4, and 5 or more higher frequency neighbor conditions) and then subtracting this value from the identification latency for words without higher frequency neighbors. An independent groups *t*-test on this interference score revealed that the interference effect was larger for older adults (M = −130.57, SD = 129.1) than for younger adults (M = −33.62, SD = 137.66), $t(38) = 2.30$, $p < .05$. We also performed trend analyses to determine if the linear trend in the neighborhood frequency effect differed for older and younger adults (i.e., the increase in response latencies as a function of the number of higher frequency neighbors of the target). The linear trend was significant for both older, $F(1, 19) = 56.06$, MSE = 11,051.25, $p < .001$, and younger adults, $F(1, 19) = 7.39$, MSE = 19,873.36, $p < .05$, with the trend being stronger for the older adults – this was confirmed by the significant interaction with age in an ANOVA analysis of these effects, $F(1, 38) = 5.28$, MSE = 15,462.30, $p < .05$.

On the other hand, the fact that older adults were slower than younger adults in all of the higher frequency neighbor conditions, as well as the zero higher frequency neighbor condition, leads one to suspect that the age effect may be due to differences in baseline performance rather than to differences in inhibitory functioning. To assess this possibility, the data were analyzed proportionally, an analysis technique recommended to control for differences in baseline performance (Borella, Delaloye, Lecerf, Renaud, & de Ribaupierre, 2009; De Frias, Dixon, & Strauss, 2006). Scores were calculated for each of the higher frequency neighbor conditions by subtracting the identification latency of the zero higher frequency neighbor condition from the latency of each of the higher frequency neighbor conditions, and then dividing by the identification latency of the zero higher frequency neighbor condition. (Note that this analysis assumes that any inhibitory processing amongst neighbors in the zero higher frequency neighborhood condition is equivalent for older and younger adults, and hence performance in this condition can serve as a comparable baseline for the two groups.). These data are shown in Table 2. A 2 (Age) × 5 (Number of Higher Frequency Neighbors) mixed-model ANOVA of these computed scores produced a significant effect of number of higher frequency neighbors, $F(4, 152) = 19.11$, MSE = .005, $p < .01$, but no effect of age and no interaction (both Fs < 1). A proportional analysis of the magnitude effect also eliminated the age effect ($p > .10$). These analyses indicate that the larger neighborhood frequency effect for older adults in the identification latency analyses can be explained by generalized slowing, as opposed to a deficit in inhibitory functioning.

Finally, to assess possible associations between performance in the progressive demasking task and the paper and pencil tasks, correlations between the average interference measure (both with raw scores and as a proportion relative to the zero higher frequency neighbor condition) and the paper and pencil tasks were computed. There were no statistically significant correlations to report (all rs < .25, all ps > .10). A statistical power analysis revealed that, given the sample size, the power to detect moderate correlations of .30 and .40 was 60% and 83%, respectively.

Table 2. Proportional scores (relative to words with zero higher frequency neighbors) for words with one, two, three, four, and five or more higher frequency neighbors.

	Number of higher frequency neighbors				
Age group	One	Two	Three	Four	Five
Younger	.003 (.02)	.002 (.02)	.033 (.02)	.120 (.03)	.078 (.03)
Older	.039 (.01)	.017 (.02)	.041 (.02)	.123 (.02)	.095 (.02)

Note: Standard errors in parentheses.

Discussion

The results of Experiment 1 revealed that, consistent with previous research with younger adults (e.g., Grainger & Jacobs, 1996; Grainger & Segui, 1990), both younger and older adults exhibited an inhibitory neighborhood frequency effect – words with many higher frequency neighbors were responded to more slowly than words without higher frequency neighbors. We suggest that participants are slower to identify words with higher frequency neighbors because the formation of incorrect hypotheses is more likely for these words, and this, in turn, impedes performance. Although the analysis of older and younger adults' identification latencies produced a significant Age × Number of Higher Frequency Neighbors interaction, the proportional analysis indicated that the interaction could be accounted for by generalized slowing. Thus, although older adults did exhibit a larger neighborhood frequency effect, we conclude that this effect is not due to reduced inhibitory functioning and appears to be merely an artifact of general slowing. This conclusion is consistent with the findings of Lindfield & Wingfield, 1999), who found that although older adults were more susceptible to perceptual interference (using the Lindfield et al., 1994, procedure), simulations showed that this effect could be explained by reduced processing rates. Our findings are also consistent with those of Stine and Wingfield (1994), who reported equivalent interference effects for younger and older adults using an auditory word identification task and the gating paradigm, which also involves successive presentations of a stimulus that becomes increasingly identifiable over time.

The correlational analyses proved to be inconclusive. Hasher and Zacks (1988) proposed that inhibitory abilities are directly related to working memory performance, so one would expect a negative correlation between the backward span test and the neighborhood frequency effect. There was no correlation between these measures, however. On the other hand, recent research has shown that this outcome is not uncommon, as several studies have reported no correlations between different measures of inhibitory functioning (e.g., Borella et al., 2009; Feyereisen & Charlot, 2008). The correlational analyses also suggested that age-related differences on the progressive demasking task are unlikely to be explained by differences in verbal ability, as there were no significant correlations with measures of verbal fluency or vocabulary.

Experiment 2

In Experiment 2, we modified the progressive demasking task used in Experiment 1 to further promote hypothesis testing and to influence participants' hypotheses concerning the target. Given the mixed results of Experiment 1, we speculated that the standard progressive demasking task might not be sufficiently sensitive to individual differences in hypothesis testing, therefore making it difficult to observe an age-related difference in performance. In order to further promote hypothesis testing, we modified the task by presenting a prime word prior to the progressive demasking sequence. The prime word was either related to the target word (e.g., *cry–weep*), unrelated to the target word (*cook–weep*), or was a foil prime. A foil prime was semantically related to a higher frequency neighbor of the target word (e.g., *day–weep*, where the prime *day* is semantically related to the higher frequency neighbor *week*). The foil condition was expected to promote incorrect hypotheses during the identification of the target word: the expectation was that the prime word, along with the initial presentation of the target word, would cause participants to develop an incorrect hypothesis as to the identity of the target, which would in turn hamper their performance. This process is presumed to occur at an automatic level (through spreading activation) as well as at an attentional level (e.g., Giffard, Desgranges, Kerrouche, Piolino, & Eustache, 2003). Identification performance in the foil condition could be affected either by delaying the correct identification (relative to the unrelated prime condition) or by causing participants to respond incorrectly. 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., *week*). Recall that one of the proposed roles of inhibition is to suppress highly probable competitors in order to allow for the consideration of other, less probable, alternatives (Chiappe et al., 2000). Thus, the prediction was that older adults would have more difficulty abandoning their initial guess (based on the prime) in the foil condition, which would in turn produce a larger interference effect (i.e., slower responding in the foil condition relative to the unrelated condition).

Incorporating a priming procedure into the progressive demasking task also allowed us to look for evidence for age-related differences in the semantic priming effect (see McNamara, 2005, for a review of the semantic priming literature). It was expected that both younger and older adults would exhibit a semantic priming effect (i.e., faster responding in the related condition than in the unrelated condition); the interesting question was whether the priming effect would be larger for the older adults. Although many studies have reported equivalent semantic priming effects for younger and older adults (e.g., Bowles & Poon, 1985; Madden et al., 1993), other research (e.g., Laver, 2000; Laver & Burke, 1993) points to a larger facilitatory effect for older adults. One explanation for a larger facilitatory effect is that older adults are influenced by context to a greater degree (e.g., Jacoby, Rogers, Bishara, & Shimizu, 2012). A major advantage of the primed progressive demasking task is that it allows one to examine age-related differences in both hypothesis testing and semantic priming.

Method

Participants. Thirty younger adults (M = 22.3, SD = 4.0 years) from the University of Calgary volunteered for the study in exchange for extra credit in a psychology course. Thirty older adults (M = 71.6, SD = 6.9 years) were recruited from the community and received a Can$10.00 honorarium. The younger adults ranged in age from 17 to 32 years and the older adults ranged from 65 to 80 years of age. All participants were native English speakers. As in Experiment 1, participants were asked to rate their overall health compared to others their age, using a 5-point scale from 1 (*poor*) to 5 (*excellent*). The older adults reported very good overall health (M = 4.16, SD = 0.73). All participants reported normal or corrected-to-normal vision. The younger adults had significantly more years of education (M = 14.8, SD = 1.3) than the older adults (M = 13.3, SD = 2.3), $t(58) = 3.11$, $p < .05$, although the older adults were well-educated relative to their birth cohort.

Tasks and procedures. As described previously, for this experiment the progressive demasking task was modified by presenting a prime word prior to the first progressive demasking cycle. There were three prime conditions: unrelated, related, and foil. In the unrelated condition, the prime was unrelated semantically and orthographically to the target word or to any of its orthographic neighbors (e.g., *cook–weep*). In the related condition, the prime was semantically related to the target word (e.g., *cry–weep*). In the foil condition, the prime was semantically related to one of the target word's neighbors (e.g., *day–weep*); the neighbor that was primed in this condition was always a higher frequency neighbor of the target (i.e., *week*). For the foil condition, the letter position that differed between the target and the primed neighbor (e.g., weep/week) varied from trial to trial and was not predictable (there were an approximately equal number of differences at the four letter positions). Primes for all conditions ranged in length from four to six letters, and all targets were four-letter words. For the targets in all conditions printed word frequency (M = 16.6), number of higher frequency neighbors (M = 3.6), and neighborhood size (M = 13.0) was controlled. (These stimuli are available from the authors.) The apparatus was the same as that used in Experiment 1.

To ensure that the target words used in the three different prime conditions were equated on processing difficulty, the target words (without the primes) were used in a standard progressive demasking task (as described in Experiment 1). The participants were a group of 23 younger adult volunteers (with a mean age of 21.3 years) from the University of Calgary. For this control experiment, the procedure was identical to the procedure of Experiment 1. The identification latencies were analyzed using a repeated-measures ANOVA, which revealed that identification latencies for targets used in the unrelated (1,191 ms), related (1,212 ms), and foil conditions (1,210 ms) were not significantly different ($F < 1$). Therefore, any differences between the responses to the words in these conditions in the primed progressive demasking task could not be attributed to differences in the processing difficulty or familiarity of the different word sets.

The task for the experiment proper was as follows. A trial began with the presentation of the word "Ready?" in the center of the computer display. Participants pressed the "r" key on the keyboard in front of them to initiate the trial. After a one second delay, the prime word then appeared in the center of the screen for 500 ms. This was immediately followed by the first cycle of the progressive demasking sequence. Initially, the target word appeared for 14 ms and the mask for 286 ms. On each successive cycle the duration of the target word increased by 14 ms and the duration of the mask decreased by 14 ms, each cycle lasting 300 ms (as was the case in Experiment 1). Participants were instructed to press the spacebar on the keyboard as soon as they had identified the target, and to do so as quickly as possible while maintaining accuracy. Participants were instructed to pay attention to the prime word because it could help them determine the identity of the target (participants were not informed of the different prime conditions). There were 23 prime and target pairs in each of the related, unrelated, and foil conditions, with no prime or target being repeated. The order in which the trials were presented was randomized separately for each participant.

Participants also completed two word fluency tasks (P and R), the Finding A's test, and the vocabulary test, digit symbol tests, and forward and backward digit span tests from the WAIS-R. On the word fluency task (P and R combined), the younger adults (M = 14.07, SD = 2.86) scored significantly higher than the older adults (M = 12.35, SD = 3.27), $t(58) = 2.16$, $p < .05$. Younger (M = 26.73, SD = 7.59) and older (M = 30.50, SD = 8.70) adults performed similarly on the Finding A's test. Younger (M = 51.6, SD = 5.9) and older (M = 52.3, SD = 9.3) adults also performed similarly on the WAIS-R vocabulary test. For the digit symbol test, as was the case in Experiment 1, the younger adults (M = 73.0, SD = 8.76) performed significantly better than the older adults (M = 45.90, SD = 11.05), $t(58) = 9.24$, $p < .001$. Younger (M = 6.83, SD = 1.55) and older (M = 7.33, SD = 1.15) adults did not differ in their forward digit span. Unlike Experiment 1, younger adults (M = 5.60, SD = 1.33) had a significantly larger backward span than the older adults (M = 4.80, SD = 1.40), $t(58) = 2.27$, $p < .05$.[1]

Results

The mean identification latencies and percentage of identification errors are listed in Table 3. The latency data are based on correct identifications only. Identification latencies greater than three standard deviations from a participant's condition mean were excluded from the calculation of the mean. These data were analyzed using a 2 (Age: younger, older) × 3 (Priming Condition: unrelated, related, foil) mixed-model ANOVA.

Identification latencies. There was a significant effect of age, $F(1, 58) = 86.71$, MSE = 850,816.80, $p < .001$, as the younger adults responded more quickly than the older adults (1,670 ms vs. 2,950 ms). The effect of priming condition was also significant, $F(2, 116) = 93.03$, MSE = 27,296.82, $p < .001$, with identification latencies fastest in the related condition (2,074 ms) and substantially slower in the unrelated (2,406 ms) and foil conditions (2,450 ms). The faster identification latencies in the related condition relative to the unrelated and foil conditions confirmed that younger and older adults were using the prime words to help identify the target. Most important was the significant interaction between age and priming condition, $F(2, 116) = 8.27$, MSE = 27,296.82, $p < .001$. Recall that, according to the inhibitory deficit hypothesis, relative to younger adults, older adults would be expected to exhibit a larger interference effect (i.e., slower responding in the foil condition relative to the unrelated condition). As can be seen in Table 3, younger adults were 51 ms slower to identify words in the foil condition (1778 ms) than in the unrelated condition (1,727 ms), whereas older adults were 37 ms slower (3,122 ms vs. 3,085 ms). This difference (51 ms vs. 37 ms) was not statistically significant, $t(58)$ =.32, $p > .10$, which indicates that the interference effect was no larger for the older adults. In fact, additional analyses showed that for younger adults the 51 ms interference effect was statistically significant (i.e., greater than zero), $t(29) = 2.20$, $p < .05$, whereas for older adults there was no interference effect: the 37 ms difference between the foil condition and the unrelated condition was not significant, $t(29) = 1.07$, $p > .10$. The absence of an interference effect for the older adults is counter to the prediction that older adults would have more difficulty inhibiting incorrect hypotheses in this task.

As predicted, for both younger and older adults responses were significantly faster in the related condition than the unrelated condition, due to semantic priming. For younger adults the semantic priming effect was 223 ms, $t(29) = 8.94$, $p < .001$, and for older adults it was 442 ms, $t(29) = 7.64$, $p < .001$. The semantic priming effect was significantly larger for the older adults, $t(58) = 3.48$, $p < .01$.

Table 3. Mean identification latencies (in milliseconds) and identification errors (in %) for the unrelated, related, and foil conditions.

	Priming condition		
Age group	Unrelated	Related	Foil
Younger			
latencies	1,727 (78)	1,504 (70)	1,778 (78)
errors	3.6 (.69)	3.6 (.66)	5.9 (.98)
Older			
latencies	3,085 (116)	2,643 (120)	3,122 (123)
errors	2.3 (.54)	1.6 (.53)	6.5 (1.3)

Note: Standard errors in parentheses.

Table 4. Proportional facilitation and interference scores (as a proportion of identification latency in the unrelated condition).

	Priming condition	
Age group	Facilitation	Interference
Younger	–.128 (.01)	.033 (.01)
Older	–.145 (.02)	.013 (.01)

Note: Standard errors in parentheses.

As was the case in Experiment 1, older adults were slower than younger adults in all conditions. Therefore, a proportional analysis was carried out to evaluate a generalized slowing explanation of the significant Age × Priming Condition interaction. For each participant, a proportional interference score was calculated by subtracting the identification latency of the unrelated condition from the identification latency of the foil condition and then dividing by the identification latency of the unrelated condition. Similarly, a proportional facilitation score was calculated by subtracting the identification latency of the unrelated condition from the identification latency of the related condition and then dividing by the identification latency of the unrelated condition. These data are shown in Table 4. A 2 (Age) × 2 (Priming Condition) mixed-model ANOVA of these computed scores produced a significant effect of priming condition, $F(1, 58) = 149.22$, MSE = .005, $p < .01$. However, neither the main effect of age nor the Age × Priming Condition interaction was significant, $F(1, 58) = 1.57$, MSE = .006, $p > .10$; $F < 1$, respectively. This outcome suggests that there were no genuine age-related differences among the priming conditions.

We carried out several correlational analyses to explore possible associations between the facilitation and interference effects and our other measures. For younger adults, the facilitation effect (i.e., the difference in identification latencies between the unrelated and related conditions) was significantly correlated with forward digit span, $r(28) = .36$, $p = .05$. There were no significant correlations with the interference measure (i.e., the difference in identification latencies between the unrelated and foil conditions). For older adults, the facilitation effect was negatively correlated with the digit symbol score, $r(28) = -.44$, $p < .05$, and the interference effect was negatively correlated with years of education, $r(28) = -.38$, $p < .05$. Considering all of these results, there was no systematic pattern to these correlations.

Identification errors. The mean identification errors are listed in Table 3. There was a significant effect of priming condition, $F(2, 116) = 20.21$, MSE = 11.82, $p < .001$, but no effect of age, $F(1, 58) = .98$, MSE = 38.70, $p > .10$, and no Age × Priming Condition interaction, $F(2, 116) = 2.30$, MSE = 11.82, $p > .10$. Participants made the fewest errors in the unrelated condition (2.9%) and the related condition (2.6%) and the most errors in the foil condition (6.2%). There were no significant correlations, for younger or older adults, between identification latency and identification errors (all *p*s > .10), which indicates that there was not a speed-accuracy tradeoff.

Age-related differences in the type of identification errors made in the foil condition. Although the error rates for younger and older adults in the foil condition were low (5.9% and 6.5%, respectively), the type of errors made in the foil condition was examined to determine if there were any age-related differences. 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., misidentifying *ease* for *east* when the prime word was *west*). For the younger adults this type of error was much less frequent, with 42% of the errors in the foil condition being the higher frequency, primed, word. This difference was explored further by confining the analysis to the participants who made this type of identification error. There were 16 younger adults and 18 older adults who made this particular type of error in the foil condition (53.3% and 60.0% of the younger and older adults, respectively). For each of these individuals, the percentage of primed higher frequency neighbor errors out of the total number of errors in the foil condition was calculated. These proportions were analyzed with an independent groups *t*-test, which revealed that older adults had a significantly higher proportion of these errors relative to younger adults (81% vs. 35%), $t(32) = 3.61$, $p <.01$. Together these analyses suggest that older adults were more influenced by the prime presentation in the foil condition, as they were more likely to make identification errors that were semantically related to the prime. Of course, the fact that these types of errors were infrequent indicates that both younger and older adults were much more inclined to delay their identification responses until they were certain of the identity of the target.

Discussion

The key findings of this experiment were as follows. First, there was an interference effect on identification latencies for younger adults, but not for older adults: younger and older adults were slower in the foil condition than in the unrelated condition, but this difference was statistically significant only for the younger adults. Recall that the inhibitory deficit hypothesis would predict that older adults would find the foil condition more difficult than younger adults due to an increased difficulty “letting go of” initial hypotheses promoted by the primes. Thus, the fact that older adults did not exhibit a larger interference effect is contrary to this prediction.

Second, for those individuals who made identification 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*, older adults were likely to misidentify the target as *left*. This result is consistent with the possibility that older adults had more difficulty “letting go of” initial hypotheses in the foil condition, but the small percentage of errors in the foil condition (6.5% and 5.9% for the older and younger adults, respectively) indicates that this type of misidentification was uncommon. An age-related difference in the inhibition of higher frequency neighbors should therefore have manifested itself in the identification latencies given that both older and younger adults were making few identification errors, but, as described above, this was not the case. Nevertheless, the small age-related difference in the foil condition is intriguing and offers a direction for future research. Moreover, the tendency for older adults to make more identification errors in the foil condition is similar to a finding of Rogers, Jacoby, and Sommers (2012), who used an auditory priming task to investigate the use of context by younger and older adults (the dependent variable was identification accuracy). Rogers et al. found that in their incongruent priming condition (e.g., *barn–pay*) older adults were more likely than younger adults to mistake the primed associatively related word for the target (e.g., mistaking *pay* for *hay*). (Unlike our foil condition, the relative frequency of the primed word and the target was not an important consideration.) These instances of “dramatic false hearing,” as Rogers et al. referred to them, were much more common for the older adults in their experiments (approximately 25% of identifications in the incongruent priming condition) than were the analogous foil identification errors in Experiment 2. It is possible that this type of age-related difference is more likely to manifest itself in identification errors than identification latencies (the focus of Experiment 2), and so a modification of the primed progressive demasking task that reduced overall identification accuracy and focused on identification errors would seem to be a promising direction for future research.

We should point out that identification latencies were much slower in Experiment 2 than in Experiment 1, even though both tasks incorporated a progressive demasking sequence. Several factors were likely responsible for this difference. For one, the priming procedure used in Experiment 2, which involved a 500-ms prime presentation prior to the progressive demasking sequence, increased the complexity of the task because participants were likely still processing the prime when the progressive demasking sequence began. In addition, processing required to keep the prime word in working memory in order to detect and potentially benefit from the semantic relation between the prime and target would contribute to slower response times. Another contributing factor was that on two-thirds of the trials the prime word misled the participant as to the identity of the target (in the unrelated and foil conditions), and over time participants likely became aware of this contingency and adopted a cautious response strategy that would slow the overall speed of responding. For these reasons a better comparison between the two experiments would have been possible had a neutral prime condition been used (e.g., *XXXX–weep*); this condition would have permitted an assessment of target identification latencies when the impact of the prime was minimized. An additional advantage of a neutral prime condition is that it would have provided an alternative method for calculating the interference effect. We calculated the interference effect using the unrelated condition as a baseline (i.e., the difference between identification latencies in the foil condition and those in the unrelated condition), but it is possible that unrelated primes created some degree interference (because they were, like the foil primes, unrelated to the targets, and therefore misleading), in which case we may have underestimated the amount of interference created by foil primes. If unrelated primes do produce interference, the addition of a neutral prime condition would allow one to determine if younger and older adults differ in the degree of interference produced by these primes.

Finally, a facilitatory semantic priming effect was observed for both younger and older adults, with words that were preceded by a related prime being identified more quickly than words preceded by an unrelated prime. Using raw scores, the facilitatory semantic priming effect was larger for the older adults, but this age-related difference was eliminated when a proportional analysis was conducted. This outcome is consistent with the results of other investigators who have examined age-related differences in the semantic priming effect using both raw scores and proportional analyses (e.g., Giffard et al., 2003; Laver, 2009). As these other researchers have suggested, it is likely the larger facilitatory effect observed for older adults is largely or entirely due to general slowing.

General discussion

The purpose of this study was to examine age-related differences in inhibitory processes in hypothesis testing during visual word recognition using a standard progressive demasking task (Experiment 1) and a primed progressive demasking task (Experiment 2), neither task being used before in the gerontological literature. Like Lindfield et al. (1994), we used these tasks because they promote hypothesis testing, so that we could create a situation where participants formed incorrect hypotheses early in a sequence of presentations that would compete with the correct identification and produce interference (the perceptual interference effect; Bruner & Potter, 1964). Unlike Lindfield et al., we presented words rather than line drawings so that we could have more control over the number of competing hypotheses that, theoretically, lead to the interference effect.

In Experiment 1, we used a standard progressive demasking task (Grainger & Segui, 1990) and hypothesized that (1) words with many higher frequency neighbors would be identified more slowly than words without higher frequency neighbors (an inhibitory neighborhood frequency effect), and (2) that this effect would be larger for older adults due to their decreased ability to inhibit high-frequency competitors. The results indicated that both younger and older adults exhibited a neighborhood frequency effect, and that older adults exhibited a larger neighborhood frequency effect than younger adults, as would be predicted if the performance of older adults was more affected by the formation of erroneous hypotheses. However, the proportional analysis showed that this age difference could be explained by general slowing.

In Experiment 2, we incorporated a priming procedure into the progressive demasking task to further promote hypothesis testing. Three different prime conditions (unrelated, related, and foil) allowed us to test for age-related differences in interference and semantic priming effects. The inhibitory deficit hypothesis would predict that older adults would experience more difficulty inhibiting higher frequency competitors, and so the expectation was that the interference effect (the difference in identification latencies between the foil and unrelated conditions) would be larger for older adults. Contrary to this prediction, only the younger adults exhibited an interference effect. Thus, even when participants were led to generate incorrect hypotheses (via the foil condition), we still did not observe a larger interference effect for older adults. This result indicates that older adults did not experience any more difficulty inhibiting high-probability competitors in this task. The only evidence for an age-related deficit was in the error analyses of Experiment 2, where we found that older adults were more likely to misidentify a target as a higher frequency, primed word (e.g., mistaking *ease* for *east* when the prime word was *west*). Given this finding, we cannot completely rule out the possibility that older adult's performance on these tasks was affected by reduced inhibitory abilities. However, ultimately, this evidence was not conclusive and, therefore, warrants further investigation. Considered together, however, the results of our study would seem to be quite consistent with the recent findings of Borella et al. (2009). They used a number of different measures of inhibitory functioning and predicted that the determining factor for an age-related increase in interference would be the level of activation of irrelevant information. Contrary to that prediction, and consistent with our results, they did not find that making irrelevant information more salient led to an increased interference effect for older adults.

We should point out that our findings are different from those who have examined age-related differences in the effect of phonological neighborhood density in speech recognition tasks (Sommers, 1996; Sommers & Danielson, 1999; Taler et al., 2010). In these studies, older and younger adults were asked to identify isolated words or words presented in sentences, with some of the words having many phonologically similar neighbors (e.g., *sand*) and others having few (e.g., *idol*). The general finding is that for both younger and older adults, words with many phonological neighbors are identified less accurately than words with few phonological neighbors (a phonological neighborhood density effect). This finding has been interpreted as being due to competition among the lexical representations of phonologically similar words. The phonological neighborhood density effect is typically larger for older adults, although sometimes this is the case only when overall identification accuracy is low due to a low signal-to-noise ratio (e.g., Taler et al., 2010).

In addition to the difference in the modality of the stimulus presentation (visual vs. auditory), there are a few other important differences between our experiments and the phonological neighborhood density experiments (Sommers, 1996; Sommers & Danielson, 1999; Taler et al., 2010). The first is that manipulations of phonological neighborhood density are different than manipulations of orthographic neighborhood density, as a word's phonological neighbors can differ in both length and orthography (e.g., the phonological neighbors of *sand* include *tanned, signed,* and *band*). Additionally, there are differences in the dependent variables used, with our study focusing on identification latency and the phonological neighborhood studies focusing on identification accuracy. The possibility that the different findings for neighborhood effects in the visual and auditory modalities could reflect modality specific differences in age-related declines of inhibitory processes warrants further investigation. This is a point made in a recent review of the literature on inhibitory abilities in selective attention; Guerreiro, Murphy and Van Gerven (2010) concluded that it is important that researchers consider possible modality-specific differences in inhibitory processing.

Our conclusions differ from those of Robert and Mathey (2007), who, as noted previously, compared the magnitude of the neighborhood frequency effect for younger and older adults using a lexical decision task and found that only younger adults exhibited the effect. They concluded that the absence of a neighborhood frequency effect for older adults was indicative of reduced inhibitory processes. Robert and Mathey reasoned that slower responding to words with higher frequency neighbors reflected an automatic lexical inhibition process (Grainger & Jacobs, 1996), and therefore, a smaller neighborhood frequency effect would be the outcome of reduced lexical inhibition. For the lexical decision task, this may very well be the case, as the task involves little in the way of hypothesis testing relative to the progressive demasking task. The two tasks do not have a great deal in common, as participants in a progressive demasking task are attempting to identify degraded words as soon as they are able, whereas participants in a lexical decision task are making speeded decisions as to whether an undegraded stimulus is a word or not (a *yes* or *no* response that does not require explicit identification). (Carrieras et al., 1997, reported a correlation of .57 between the latencies of the two tasks even when using the same set of words.) Moreover, the progressive demasking task (especially the primed version) promotes hypothesis testing due to the successive presentation of degraded words, whereas the lexical decision task does not – it is essentially a classification task that requires participants to quickly discriminate between words and nonwords. Of course, there is a decision-making component to the lexical decision task, because the participant must decide whether a stimulus is a word or a nonword, and the characteristics of the nonwords (their similarity to words, for example) can affect the difficulty of this discrimination. But this discrimination does not involve hypothesis testing, and it is not relevant to the progressive demasking task (because all the stimuli are words). Thus, while there may be an age-related difference in the inhibitory processes involved in the lexical processing that culminates in the identification of a word during a reading task, this difference may have no impact when the identity of a word is not immediately obvious due to visual degradation. We should also point out that Robert and Mathey did not control for differences in baseline lexical decision latencies in their analyses, and thus it is unclear whether the age-related difference they observed would have been eliminated in a proportionality analysis.

There are several alternative explanations for our results to consider. The first is related to changes in the visual system. Although participants reported normal, or corrected-to-normal vision, an acuity measure would have been preferred and in future studies one should be used to control for potential acuity differences. The role of sensory function in cognitive aging is well known. For example, Mund, Bell, and Buchner (2010) examined the role of perceptual-sensory deficits in accounting for age-related differences in irrelevant speech effects. They concluded that, although such deficits may explain some of the age-related differences in performance reported in the literature, they cannot explain all of them. Indeed, it is unlikely that changes in the visual system could explain the present findings. Recall that it was only in Experiment 1 that there was substantive evidence of increased interference for older adults, and it is difficult to explain how deficits in acuity could account for the threshold effect observed in that experiment (i.e., that older adults were slower to respond when a word had a single higher frequency neighbor, whereas younger adults were not slower unless a word had four or more higher frequency neighbors). Furthermore, the fact that the proportional analysis eliminated this effect suggests that a parsimonious explanation of general slowing best fits the data. Finally, in Experiment 2, although there was some evidence that older adults were more prone to be misled in the foil condition (as they were more likely to mistake the target for the primed neighbor), it is unclear how differences in acuity could explain this specific pattern of identification errors.

Another potential factor that should be considered, especially because our tasks required word identification, is that of age-related differences in orthographic and/or semantic networks. In our view, it is unlikely that there are age differences in such networks that could account for any of the differences observed in our experiments. In fact, one of the most widely documented areas of stability in aging is in semantic memory (Burke, 1997). It has also been reported that the organization of concepts is similar for younger and older adults (Gunter, Jackson, & Mulder, 1998). In addition, the effects of orthographic and semantic variables on lexical decision performance have been found to be similar for younger and older adults, which suggests that the underlying lexical processing system is relatively stable throughout adulthood (Balota, Cortese, Sergent-Marshall, Spieler, & Yap, 2004). Thus, although it is certainly possible that individual differences in orthographic and/or semantic networks could affect a participant's performance on the progressive demasking task, it is unlikely that such individual differences would be strongly age-related.

A final consideration is that there may be age differences in the creation of hypotheses that are generated during the progressive demasking task. As discussed previously, the assumption underlying both the primed and unprimed progressive demasking tasks is that participants are forming hypotheses during the progressive demasking sequence. It is difficult to say whether or not older adults would form different hypotheses than younger adults; however, we can look at the word fluency literature to assess whether they may experience more difficulty 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 asked to name words beginning with a particular letter. Perhaps not surprisingly then, the verbal fluency measure we administered yielded mixed results, with no age difference in Experiment 1, whereas in Experiment 2, younger adults produced significantly more words than older adults. Further analyses of the verbal fluency data from Experiment 2 indicated that verbal fluency was not associated with either the interference or facilitation measures, however, which suggests that it may not be a good measure for assessing the possible impact of age-related differences in hypothesis creation in these tasks (or that no such association exists). A more direct way to evaluate this possibility is to modify the progressive demasking task so that participants attempt an identification following each demasking cycle (similar to Lindfield et al.'s 1994, procedure for their picture identification task). One could then determine if older adults generated hypotheses with the same frequency as younger adults, and, in addition, if the neighborhood frequency effect is larger for those who generate a greater number of incorrect hypotheses.

Conclusions

The purpose of this study was to examine age-related differences in the ability to inhibit high-frequency competitors during the process of identifying visually degraded words. We used two tasks new to the aging literature and found that although older adults appeared to be impacted to a greater degree by interference from competitors, this outcome could be explained by age-related slowing. The results of both of our experiments provide little support for the claim that the identification performance of older adults is adversely affected by an inhibitory deficit that reduces the ability to inhibit high-probability competitors in tasks that promote hypothesis testing. Instead, our results are consistent with those of other researchers who have found that age-related differences on some measures of interference are an artifact of general slowing (e.g., Giffard et al., 2003; McLaughlin et al., 2010) and are entirely absent for some measures of inhibition (e.g., Andrés, 2009; Feyereisen & Charlot, 2008). On the other hand, we have identified several directions for future research, including altering the progressive demasking task to assess participants' hypothesis generation, focusing on identification errors rather than identification latency, closely examining the types of errors made, and using a neutral prime in the primed progressive demasking task to provide a different measure of the interference effect. Our study has contributed to the growing body of research that has refined researchers' understanding of changes in inhibitory processing in healthy aging (e.g., Borella et al., 2009; Feyereisen & Charlot, 2008).

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Note

1. The larger groups in Experiment 2 ($N = 30$ vs. $N = 20$ in Experiment 1) led to an increase in the statistical power to detect group differences on some of the measures and, as a result, a few discrepancies between the experiments. For the backward span test, the effect size was not large (d =.59), and the power to detect this difference was 61% in Experiment 2 versus 44% in Experiment 1. Similarly, for years of education (d =.81), power was 87% in Experiment 2 versus 70% in Experiment 1.

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