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The Interaction of Crystallized and Fluid Abilities in Aging and Speech Perception

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by

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Table of Contents

List of Figures

List of Tables

List of Appendices

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ABSTRACT

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In a series of studies, I examined the degree to which fluid and crystallized abilities contribute to and interact during speech perception. During the aging process, crystallized abilities (e.g., linguistic and word knowledge) are largely preserved, while fluid abilities involved in the online manipulation of information (e.g., working memory and inhibitory control) decline with age. Importantly, these two components are critical for successful speech perception and comprehension. While prior research has proposed that older adults rely on crystallized knowledge to compensate for cognitive deficits in difficult listening conditions, this hypothesis has not been directly tested. Younger and older adults completed a series of speech-in-noise identification tasks, in which they were presented with single-words and sentences in a noisy background and asked to identify key targets. Critically, I concurrently manipulated variables reflecting fluid demands (working memory and inhibitory demands) and crystallized support (linguistic knowledge in the form of semantic context and word frequency) across trials. The results showed that age differences in performance were greatly reduced for conditions in which linguistic support, i.e., predictable semantic context and highly frequent words, were present. That is, high linguistic support appeared to moderate increased cognitive task demands, showing

a direct demonstration of linguistic compensation. In some cases, older adults' performance even exceeded that of younger adults. These results are the first to directly demonstrate how older adults use linguistic knowledge to mitigate the effects of increased cognitive difficulty associated with challenging listening situations during speech perception. The results further shed light on the complex mechanisms underlying cognitive aging and the factors which contribute to speech processing across the lifespan.

CHAPTER 1: INTRODUCTION

Speech perception is a complex, multifaceted skill that involves the dynamic operation of many interrelated sensory and cognitive processes. It involves converting a highly variable and rapidly changing acoustic signal into a meaningful representation which can then be used for communication. Successful speech perception is critical for everyday communication, but due to a combination of auditory and cognitive declines, older adults often experience problems understanding speech in acoustically and informationally complex situations of everyday life (e.g., Dubno et al., 2008; Humes, 1996; Pichora-Fuller, Schneider, & Daneman, 1995).

One important aspect of the cognitive aging process is the distinction between ‘crystallized’ and ‘fluid’ abilities. Crystallized abilities (e.g., linguistic and world knowledge) are largely preserved during adult aging. In contrast, fluid abilities involved in the rapid processing of information (e.g., working memory and processing speed) decline with age (West et al., 1995). Critically, these two components of cognitive aging are highly relevant to speech perception and comprehension (Kemper, 1992). Studies have demonstrated that age-related impairments in fluid abilities such as working memory (WM) and inhibitory control negatively affect speech perception performance (e.g., McCoy et al., 2005; Sommers & Danielson, 1999; Wingfield & Tun, 2007). However, studies have also suggested that older adults’ preservation of stored knowledge and facility with environmental support/context may counteract the effects of fluid declines (Sommers & Danielson, 1999; Wingfield & Stine-Morrow, 2000; Wingfield & Tun, 2007).

In the current dissertation I directly address whether preserved crystallized abilities can offset age-related fluid declines in speech perception. Compensation refers to the closing of a gap or the reduction of a mismatch between current skills and environmental demands (Dixon & Backman, 1995). Prior research has proposed the possibility of compensation in speech perception as a dynamic relationship between the sensory signal and supportive cognitive processes, such that when bottom-up auditory processing of the incoming signal during perception is impoverished, top-down processing may enable compensation for the negative downstream effects of auditory aging, insofar as stored linguistic knowledge facilitates the listener in resolving the degraded incoming speech information (Craik, 2007; Li et al., 2004). However, the question remains as to whether preserved verbal knowledge and linguistic experience (e.g., Burke & Shafto, 2008; Verhaeghen, 2003; Wingfield & Tun, 2007) can directly counteract widespread declines in WM and inhibition previously demonstrated to impact speech performance independently of sensory declines (Humes, 2007; Sommers & Danielson, 1999). In the current dissertation, I directly address the compensation hypothesis by manipulating task demands to vary the degrees of fluid demand and the subsequent ability to benefit from crystallized function, in order to observe specific conditions under which there is a potential trade-off between preserved linguistic knowledge and impaired cognitive function.

Overview of Aging & Speech Perception

The most significant contributor to impaired speech perception in older adults is hearing loss, or *presbycusis*. Overall, 10% of the population has a hearing loss great enough to impair communication, and this rate increases to 40% in the population older than 65 years (Ries, 1994). This high prevalence of presbycusis in the older adult population is thus a common social issue with many implications for physical, social, and emotional health.

Most age-related hearing impairments are types of sensorineural hearing loss involving damage to the inner ear with low- and high-frequency audiometric threshold elevation (e.g., CHABA, 1988; Helfer & Wilber, 1990). Presbycusic changes also include losses in temporal synchrony and broadening of auditory filters (e.g., Duquesnoy, 1983; Humes & colleagues, 1990, 1991, 1996), first reducing the ability to understand speech and, later, the ability to detect, identify, and localize sounds. These changes have been collectively referred to as shifts in 'peripheral' processing, in contrast to 'central' auditory processing which concerns higher-level processes such as source segregation, auditory scene analysis, and release from informational masking (Schneider, Pichora-Fuller, & Daneman, 2010). Moreover, peripheral hearing loss has been identified as the major cause contributing to speech perception problems in older adults (e.g., Dubno, Ahlstrom, & Horowitz, 2000; Humes & Roberts, 1990; Humes, 2002; Humes et al., 1994; Jerger, Jerger & Pirozzolo, 1991; van Rooij & Plomp, 1990), typically accounting for 50-90% of the total variance in performance (Humes & Dubno, 2010, for a review). It should be noted, however, that for the majority of these studies, the primary listening conditions have been quiet or steady-state background noise, which is not necessarily reflective of real-life listening situations.

Nevertheless, speech perception in noise presents a singular challenge to older adults (Gelfand, Piper & Silman, 1986; Humes, 1996), and such difficulties increase as a function of degree of hearing loss (Dubno, Dirks, & Morgan, 1984; Gordon-Salant & Fitzgibbons, 1993), reflecting both central and peripheral auditory deterioration associated with age. This results in older listeners requiring more advantageous signal-to-noise ratios (SNR) for speech intelligibility performance equivalent to young, normal-hearing listeners, such that the relative loudness of the signal must be disproportionately greater compared to the masking noise for older adults in order to achieve an equivalent level of performance to younger adults (e.g., Souza & Turner, 1994).

Although hearing loss accounts for most of the speech-recognition problems experienced by healthy older adults in quiet (Humes & Dubno, 2010), the elevated thresholds and reduced sensory acuity associated with presbycusis cannot fully account for the difficulties that older adults experience in noisy situations. Rather, a complete account of speech perception requires an understanding of both basic auditory processes as well as higher-level cognitive processes (e.g., Davis & Johnsrude, 2007; Schneider, Pichora-Fuller & Daneman, 2010). In order to communicate effectively in a multitalker situation, listeners must do more than rely on their sensory systems to merely recognize and repeat speech. Communication requires keeping track of who said what, extracting and storing the meaning of each utterance for future use, integrating incoming information with preceding information, and drawing on his/her own knowledge of the topic in order to extract general themes and formulate responses. These processes clearly reflect the demands of cognitive processing, and given the plethora of anecdotal evidence for older individuals struggling during communicative situations, it is highly probable that speech perception difficulties in older listeners are not solely due to age-related hearing loss, but to age-related changes in cognitive function.

One view to approaching cognitive changes across the adult lifespan has been to consider the distinction between *crystallized* and *fluid* abilities (Horn & Cattell, 1967). Crystallized abilities, such as semantic and vocabulary knowledge are largely preserved and sometimes enhanced during adult aging (e.g., Verhaeghen, 2003; Verhaeghen & Salthouse, 1997). In contrast, fluid abilities involved in the temporal rapid processing of information, such as aspects of memory, reasoning, and speed of processing, show declines with age (Park, Lautenschlager, Smith, & Earles, 1996; Salthouse, 2009; West et al., 1995). Although the specific terminology varies across studies, there is relative consensus on the general pattern of cross-sectional age-cognition relations with respect to these abilities. Until the age of 60, there is an increase for crystallized measures representing task performance in which the relevant acquisition of information occurred earlier in one's life, e.g., verbal and world knowledge. In contrast, there is a nearly linear decline from early adulthood on measures representing the efficiency of processing involving manipulations or transformations of information, including memory and processing speed (Salthouse, 2010).

Critically, both of these functions are crucial to online speech perception. Communication and listening, particularly in an acoustically complex environment, requires the manipulation and moment-to-moment processing of information, as well as stored knowledge and representations to inform perception. This discussion now turns to specific crystallized and fluid abilities which have been demonstrated to account for age-related changes in auditory speech perception.

a. Fluid Function I: Working Memory and Speech Perception

Working memory (WM) has been at the forefront of examining the relationship between cognitive function and speech, from early conceptions of information-processing (Atkinson & Shiffrin, 1968) to more recent models of the interplay between acoustic and cognitive factors (Rönnberg, Rudner, Foo, & Lunner, 2008). A functional definition of the WM construct has been somewhat elusive, in which some theories encourage consideration of interrelated but distinct mechanisms (e.g., Engle & Kane, 2004), while others posit an "embedded processes" approach (e.g., Cowan, 1999). Nevertheless, however fuzzy the strict boundary conditions of WM, the majority of research converges on the following broad description: WM is a limited capacity system responsible for temporarily and actively retaining information in an accessible state to be processed and/or manipulated at a later stage. The following section will begin with a brief discussion of early work in WM and language comprehension, and then proceed with more recent investigations of WM in speech perception.

In most contemporary models of language comprehension, WM represents “the critical bottleneck in which signals are decoded, concepts are activated, linguistic constituents are parsed, thematic roles are assigned and coherence among text-based ideas is sought” (Stine et al. 1995, p. 1). Consequently, it is not surprising that age-related declines in language comprehension are frequently attributed to age-related declines in WM capacity and processing (e.g., Brébion, 2003; Dede, Caplan, Kemtes, & Waters, 2004; Kemper & Herman, 2006; Kemper, Crow, & Kemtes, 2004; Kwong See & Ryan, 1995). Evidence from (visual) reading and language comprehension has found that sentences that have more complex syntactic structures are more difficult and time consuming to understand (e.g., MacDonald, 1997, for a review). The evidence that syntactic structural complexity is associated with increased difficulty in sentence processing for older adults has been found in eye-fixation durations, self-paced word-by-word and phrase-by-phrase reading and lexical decision times, and self-paced listening times, showing that these measurements show increases at points in a sentence where models of sentence processing predict an increased ‘processing load’ (Caplan, Hildebrandt, & Waters, 1994; Ferreira et al., 1996; Ford, 1983;Frazier & Rayner 1982; King & Just, 1991). Such findings follow from seminal work by Daneman and colleagues (Daneman & Carpenter, 1980, Daneman & Merikle, 1996), who demonstrated that individual differences in WM storage and processing contribute to differences in sentence comprehension, suggesting that processing complex syntactic structure in sentences puts individuals with low or impaired WM capacity at a disadvantage.

The findings from visual sentence comprehension have also extended to auditory sentence comprehension, demonstrating a similar pattern of results in which WM constraints impact processing of spoken sentences (Fallon, Peelle, & Wingfield, 2006; Titone et al., 2006; Van der Linden et al., 1999; Wingfield & Tun, 2007; Zurif et al., 1995). That is to say, there is evidence that differences in WM capacity are significant contributors to age-related variance in many verbal, (i.e., language) tasks, such that older adults' smaller span measures correlate with both language comprehension and language production. For instance, Stine-Morrow and Wingfield (1990) observed that age was a strong predictor of recall of expository passages that systematically varied in terms of propositional density and prose length. For simpler texts, these age effects were predicted by individual differences in WM storage capacity as measured by word- and sentence-span tasks, such that smaller WM spans were linked to poorer recall. Such links between age-related reductions in WM span and processing have been similarly reported in other studies examining recall and comprehension of spoken text varying in complexity (Norman et al., 1991; Tun, Wingfield, & Stine, 1991).

As briefly reviewed in the evidence above, the majority of work that has examined the relationship between WM and speech has done so at the level of speech *comprehension*. This stands in contrast to speech *perception*. Humes and Dubno (2010) make the crucial distinction between the two, stating that "comprehension is assessed with phrases or sentences and involves the deciphering of the talker's intended meaning", and is a higher-level process than either speech recognition/identification (both measures of *perception*, which do not necessitate comprehension). For example, a recognition task might require the listener to repeat an auditorily-presented sentence in the form of a question, and a speech-recognition score could be determined by counting the number of words correctly repeated. In contrast, an example of a comprehension task might present the same sentence but ask the listener to answer the question, wherein a correct answer implies correct comprehension of the stimulus. Thus, comprehension is clearly a higher-level process than direct speech perception, and it is not unsurprising that it has been the focus of early work examining the relationship between cognition and language. However, the majority of WM studies with language have been conducted under ideal reading and listening conditions where perceptual processing is largely undisturbed and unlikely to tax WM. In contrast, speech presented in noisy listening conditions may require additional top-down, i.e., cognitive processing to recover the lost information in the acoustic signal. Thus, given age-related deterioration in auditory processing as well as in WM capacity and processing, it is not surprising that age effects have been linked to WM during speech perception in noise tasks.

Pichora-Fuller, Schneider, and Daneman (1995) were among the first to examine the relationship between age-related impairments in WM and speech perception. They presented sentences in noise to young and elderly listeners who recalled the final word of each sentence or the final words of the last *n* sentences in a set. Older listeners were less able than younger listeners to recognize speech in all conditions, but the introduction of a concurrent memory task did not influence word recall for either age group. The researchers interpreted these results as supporting the notion that it is auditory processing, rather than WM capacity, which primarily influences speech perception. However, a later study by Gordon-Salant and Fitzgibbons (1997) found that while both age groups showed comparable performance in word recall, older listeners were significantly impaired compared to younger adults in sentence recall. These results were interpreted to suggest that older adults' speech perception performance (in noise) is particularly affected by the additional memory demands of more linguistically complex stimuli. No WM measures were directly obtained in this study, however. Similarly, Tun, O'Kane, and Wingfield (2002) addressed the role of WM in speech perception by examining the presence of competing speech during perception. The researchers hypothesized that attempting to listen to a target speaker while ignoring a background competing voice creates a unique situation of divided attention that increases processing demands in WM. Consistent with this prediction, they observed that the presence of (meaningful) background speech was more detrimental to the older than to the younger adults, resulting in poorer recall of the targets. A further study tested age differences in the recognition of consonants and sentences presented at two different speaking rates in noise, and also administered two WM tasks of serial recall and digit ordering (Cervera, Soler, Dasi & Ruiz, 2009). As expected, younger listeners outperformed older listeners in consonant recognition in both quiet and noise, although noise produced a similar decrease in consonant recognition for both age groups. For sentence recognition however, older listeners were disproportionately impaired compared to younger listeners in recognition in the fast speaking-rate condition. Moreover, not only did older listeners perform more poorly on the WM tasks, their scores were also highly positively correlated with sentence recognition performance in the fast speaking rate condition. The presence of distorted temporal acoustic cues in rapid speech has been previously demonstrated to negatively affect older listeners' performance (e.g., Gordon- Salant & Fitzgibbons, 2001; Pichora-Fuller et al., 1995), such that an aging auditory system is unable to meet the challenges of a degraded sensory signal. Consequently, when listeners with poorer auditory acuity are presented with such a signal, WM demands may increase and potentially disrupt the temporary retention of the incoming speech signal, thereby impairing sentence recognition. It should also be noted that these results emerge even after controlling for age-related hearing loss, implying that speech difficulties are not solely constrained by the effects of hearing loss.

Theories of the Relationship between WM and Speech Perception

The relationship between WM and speech perception has been conceptualized in several models. Rönnberg and colleagues have developed the *Ease of Language Understanding* (ELU) model (Rönnberg, Rudner, Foo, & Lunner, 2008; Rönnberg, Rudner, Lunner, & Zekveld, 2010; Rönnberg et al., 2013; Stenfelt & Rönnberg, 2009), which attempts to describe and predict the dynamic interplay between WM and the mechanisms associated with processing (degraded) speech signals. In short, the model proposes that an incoming speech signal includes multimodal information relevant to phonology, semantics, etc, which is then 'rapidly and automatically bound together at the cognitive level to form a stream of phonological information' (RAMBPHO, Rönnberg, Rudner, Foo, & Lunner, 2008). That is, lexical and acoustic characteristics are quickly integrated to inform the incoming phonological stream. Under optimal, i.e., clear, listening conditions, the RAMBPHO function mediates the rapid and implicit unlocking of the mental lexicon by matching acoustic input with stored phonological representations in long-term memory (LTM). That is, automatic matching occurs because the representations in clear listening conditions are nearly identical to those stored in LTM. Under sub-optimal conditions however, such as in the presence of noisy listening conditions or hearing loss, a mismatch is likely to occur because the degraded acoustic input no longer matches corresponding representations stored in LTM. Consequently, this mismatch triggers a demand for explicit and effortful processing and storage of the incoming signal in the form of increased WM capacity required to complete the task.

Several studies have supported the ELU including the mismatch assumption (e.g., Foo et al, 2007, Rudner & Rönnberg, 2008; Rudner et al., 2007; Rönnberg et al., 2008; Zekveld, et al., 2012; Zekveld, Kramer, & Festen, 2011), demonstrating how WM is engaged to support listening in adverse conditions in early attentional processing of speech. For example, Rudner et al. (2007) tested the mismatch hypothesis by training a group of hearing-aided listeners on a new set of compression release settings to their hearing instruments. They hypothesized that the change in signal processing parameters would trigger a mismatch, in that the incoming signal is no longer consistent with established memory representations. Accordingly, speech recognition performance would be associated with more explicit cognitive processing and stronger correlations with complex cognitive measures of span recall. After training, the researchers tested aided speech recognition in noise on several speech materials with both the trained and orthogonal settings. Consistent with their predictions, they observed stronger correlations between performance on speech recognition with highly-constrained sentence materials and reading span under mismatch conditions, along with poorer speech recognition for individuals with low reading span scores.

The ELU places emphasis on the distinction between the automatic processes and the effortful, explicit processes for speech understanding. For an individual with normal hearing, listening to speech presented in relatively good listening conditions (e.g., watching TV in a quiet room) would be considered an effortless process. In contrast, the presence of competing noise or other adverse listening conditions will negatively affect perception, resulting in increased effort required to perceive the target signal. That is, when the acoustic clarity of the signal is reduced, listeners are forced to engage additional cognitive processes to understand what they hear, termed *listening effort*.

The idea of additional cognitive demands being required to encode more degraded speech has been used to develop the concept of listening effort. McCoy et al. (2005) have proposed the *effortfulness hypothesis*: the notion that extra effort must be employed in order to counteract the effects of noisy listening conditions or hearing impairment, and that this extra effort involved in successful perception may come at the cost of processing 'resources' that might otherwise be available for encoding speech content. Moreover, the addition of individual hearing loss can exacerbate effortful demands, in which a degraded signal in combination with poor hearing loss can exaggerate the need for high listening effort (Kramer, Kapteyn & Houtgast, 2006).

Consequences of increased listening effort were first demonstrated by Rabbit (1968), in which normal-hearing adults demonstrated poorer recall for strings of spoken digits when the digits were noise masked compared to when they were spoken in the clear, even when the level of masking still allowed accurate recognition of the to-be-recalled digits. A later study (Rabbit, 1991) extended these findings to older adults with mild hearing loss, and demonstrated that word lists were better recalled by individuals with normal hearing than by those with mild hearing loss, even when both groups showed the ability to correctly repeat words presented at the same intensity level. The interpretation of these results suggest that individuals with impaired hearing may have to employ more effortful listening in order to identify spoken words than do individuals with better hearing, at a cost of reducing functions, such as rehearsal, that are required for maintenance of the item in WM.

If increased listening effort associated with perceptual challenges increases cognitive processing demands, then cognitive performance should vary as the effortfulness of listening is also varied. Indeed, recent studies have linked WM capacity to listening effort, showing that in demanding listening situations, an individual with a high WM capacity will be better able to compensate for the distorted signal, compared to an individual with a smaller WM capacity who may show performance decrements as a result (Amichetti et al., 2013; Heitz et al., 2008; Pichora-Fuller, 2003; Rönnberg et al., 2013). For instance, Rudner et al. (2012) used subjective ratings as a measure of listening effort in order to experimentally investigate how it is related to speech recognition performance under varying conditions and cognitive load, i.e., WM capacity. In addition to more difficult SNRs being rated as more effortful, the researchers also observed a consistently negative relationship between WM capacity and rated effort, such that individuals with greater WM capacity found listening less effortful under any given condition. Moreover, the researchers also found that WM capacity accounted for significant variance in accounting for ratings of listening effort, such that a greater proportion of variance was accounted for by WM in the most demanding listening conditions.

Given the well-established declines in WM capacity with age (e.g., Salthouse, 1991; Wingfield, Stine, Lahar, & Aberdeen, 1988), it is not surprising that there is also an age-related facet to listening effort and WM, such that poorer speech understanding in older adults may be a result of diminished WM capacity. That is, to the extent that older adults possess a reduced WM capacity compared to young adults, one would expect the effects of challenging listening conditions to be even greater for them. Tun, McCoy, and Wingfield (2009) used a dual-task interference paradigm to investigate the effect of listening effort on recall of spoken word lists by young and older adults. The secondary task was a visual target-pursuit task, unrelated to the auditory nature of the speech task. Thus, there was a single-task recall condition which involved recall of aurally presented words, and a dual-task recall condition with a tracking condition, in which participants performed the tracking task in between word lists. In addition to poorer recall accuracy overall, older adults – especially those with clinical hearing loss – showed larger secondary task costs from the tracking task while recalling word lists compared to younger adults, even though stimulus intensity levels were equated for both age groups. Moreover, listening effort as assessed by target tracking costs between a tracking-alone condition and the dual-task with tracking condition was also significantly greater for older adults, and especially hearing-impaired older adults. Thus, despite differences in hearing acuity, the older participants showed greater reductions in tracking accuracy during recall than the young participants, consistent with arguments that not only is retrieval more effortful for older adults than for young adults, but that this additional effort at the sensory–perceptual level has negative consequences to downstream recall.

Although the ELU and effortfulness hypothesis provide a basis for understanding the relationship between WM and speech perception, there are a number of inconsistencies that belie definitive claims. First, while listening effort appears to be sensitive to types and levels of noise (Hällgren et al, 2005; Zekveld et al, 2010), it is concerning that subjective methods of assessing listening effort (e.g., self-report) often do not correlate with objective measures (e.g., pupil response, dual-task costs) (Gosselin & Gagné, 2011), although recent work described above suggests that individual WM capacity predicts perceived effort (Rudner et al., 2012). Secondly, there is no consistent mechanistic account of listening effort. As discussed above, there appear to be both sensory and cognitive factors which contribute to outcomes of perceived effort, but such accounts lack unity in accounting for individual differences in speech performance as have been observed across studies. Thus, while there is clear evidence for an association between WM and speech perception, studies of listening effort have tended to conflate both cognitive and sensory processes that contribute to perception. It therefore remains unclear to what extent cognitive processing contributes to speech perception independently of sensory processing.

b. Fluid Function II: Inhibition and Speech Perception

In contrast to WM, which has primarily been the focus of investigations into cognitive functioning and speech perception (e.g., Cervera et al., 2009; Kemper et al., 2010; Rönnberg et al., 2010; Rudner et al., 2012; Sörqvist & Rönnberg; 2012), there is also some work suggesting an influence of additional cognitive processes. Whereas WM capacity and control can be collectively considered as the active maintenance of information, there are a number of mechanisms within the WM store itself which are responsible for manipulating this information. One such process is inhibition, which generally refers to the ability to inhibit the processing of irrelevant stimuli. Formalized as the *inhibition deficit hypothesis*, Hasher and colleagues have proposed that age-related difficulties in language comprehension are due in part to the failure of inhibitory mechanisms in regulating the flow of information to, from, and within WM which would otherwise disrupt the processing of goal-relevant information (e.g., Hasher & Zacks, 1988; Hasher, Zacks, & May, 1999; Zacks & Hasher 1994). Specifically, the inhibition construct is described as having three primary functions directed at the contents of WM: *access*, *deletion*, and *restraint*. *Access* refers to the prevention of irrelevant information entering the WM space, ensuring that only goal-relevant representations are allowed to enter the focus of attention. *Deletion* refers to the suppression of representations already within WM if they have become irrelevant to task performance, either because of error or purposeful goal-shifting. *Restraint* refers to situations in which there is a strong, dominant response, and thus requires the active suppression of such a response in favor of an alternate, less dominant response. Collectively, these three functions work in tandem to maintain goal-relevant representations in the focus of attention, while actively suppressing those that could potentially interfere with task performance.

With regards to language comprehension, inhibitory failures in older adults are thought to impair comprehension processes if activation of off-goal information is sustained during the construction of coherent situation-based representations, such that the presence of extraneous information creates competitive 'noise' during the development of language representations (Gernsbacher, 1989, 1990; Hamm & Hasher, 1992; Kintsch, 1988; Zacks & Hasher, 1994; but see Burke, 1997).

One plausible concern for the legitimacy of the inhibition construct is that it may not be entirely independent of WM, given their close theoretical association. However, some early studies directly assessed the role of inhibition in language processing independently of WM and obtained promising results (Kwong See & Ryan, 1995, Van der Linden et al., 1999). Kwong See and Ryan (2005) administered young and old participants with several measures of written discourse comprehension (reading comprehension, sentence recognition, text recall), measures of WM (backward span and N-back lag task), processing speed (color-naming), and the Stroop color-word task as a measure of inhibitory efficiency. Regression analyses revealed that each of these measures significantly predicted language performance and accounted for variance in language performance that would otherwise be attributed to age. When processing speed was entered first into the equation, the mediating influence of both the inhibition and WM measures remained significant. Van der Linden et al. (1999) followed up on these findings, constructing several structural models to account for the relationship between cognitive variables (including inhibition) and language performance, and observed that the best-fitting model was one in which age-related reductions in language performance were mediated through age-related reductions in speed, inhibition, and WM. Moreover, when speed and WM were entered first into the models, inhibition remained a significant predictor of language performance, suggesting some degree of independence from the WM construct.

Support for the role of inhibition in speech perception has also been found in more recent studies examining speech comprehension, as well as speech perception. Tun, O'Kane, and Wingfield (2002) designed a series of experiments to investigate age differences in distraction from competing speech while listening to a target stream. Although no direct measure of inhibition was administered, the results showed that neither young nor older participants recalled target speech as well with distractor speech as they did for target speech heard alone. This general interference effect was interpreted to reflect the effects of informational masking caused by the competing speech and in part to the effects of attempting to keep the two auditory streams segregated and inhibiting the nontarget speech. Moreover, older adults were significantly impaired at identifying target speech when the nontarget speech was meaningful rather than nonmeaningful, in comparison to younger adults who showed similar effects of distraction for both meaningful and nonmeaningful speech. These latter findings are particularly interesting because they suggest an age-specific impairment for meaningful distraction, i.e., that which bears semantic similarity to target speech. If the negative effects of interference were due primarily to age-related sensory decline or nonspecific effects of background noise, the degree of interference should be independent of the content of the competing speech (with equivalent masking energy). That was not the case however, suggesting that difficulties in listening with noise may be caused not only by acoustic masking of the target speech but also by informational interference that occurs when words are heard with a background that includes intelligible speech (Carhart, Tillman, & Greetis, 1968). Although this is generally true throughout adulthood, older adults appear to be even more susceptible than younger adults to informational interference (Carhart & Nicholls, 1971).

The potential root of such interference can be attributed to inhibitory function, in which older adults are less efficient at distinguishing task-relevant information from irrelevant information. Because listening in quiet does not require such inhibition or rapid alternation of attention between speech streams, it is unsurprising that younger and older adults would perform similarly. In the case of competing speech however, inhibitory ability is linked to maintaining attention to the target speech and suppressing the distractor speech. Accordingly, while younger adults would be more efficient in their ability to filter competing speech using intact inhibitory function, older adults would be less able to do so. This pattern of findings is supported by a number of other studies which have demonstrated the deleterious effects of competing speech and informational masking on older adults' speech perception (e.g., Dubno, Ahlstrom, & Horwitz, 2002; Duquesnoy, 1983; Tun & Wingfield, 1999), such that older adults show greater interference from competing signals.

The construct of inhibition has also been explicitly incorporated into current models of spoken word recognition which describe speech processing within the context of energetic masking, rather than informational. The Neighborhood Activation Model (NAM) describes the process of lexical discrimination and access of phonological representations in the mental lexicon (Luce & Pisoni, 1998). It proposes that words in the lexicon are organized into similarity neighborhoods, which are defined operationally as all words that can be created from a target item by adding, deleting, or substituting a single phoneme from a target word. Crucially, the NAM proposes that the number of words within a neighborhood, termed *neighborhood density,* contributes to the overall intelligibility of that word. Thus, words can be classified as being *low* in density (LD), i.e. words with relatively sparse neighborhoods that have relatively higher intelligibility), or *high* in density (HD) (i.e. words with relatively densely populated neighborhoods that are relatively lower in intelligibility). According to the model, the process of accessing a single target proceeds within an activation-competition framework in which recognition of a target occurs by relative *heightened* activation of the target, and relative *inhibition* of phonetically similar competitor words within the neighborhood. Thus according to the model, HD words should be identified less accurately than LD items because of the relatively greater number of competitors (Goldinger, Luce, & Pisoni, 1989; Luce & Pisoni, 1998; Sommers, 1996). Furthermore, Sommers (1996) observed that older adults show greater performance decrements for HD words in comparison to younger adults under conditions in which LD identification was equated across age groups. These results were interpreted to suggest that this disproportionate impairment in identifying HD words is because of age-related declines in inhibitory control, making it more difficult for older adults to reduce activation levels on competitors.

Further direct evidence for the role of inhibition was obtained in a further study (Sommers & Danielson, 1999), which observed that even after equating younger and older listeners for 50% performance on LD word identification, older adults were still disproportionately impaired in identifying HD words. Performance on HD words was found to be negatively correlated with an inhibition index, consisting of response latencies from an auditory Stroop task and a Garner (1974) speeded classification task, suggesting that correct lexical selection and recognition in speech is related to successful inhibition of task-irrelevant information. Thus, older adults' impaired inhibitory function has negative consequences for identifying words that necessitate greater inhibitory demands (Dey & Sommers, 2015; Sommers & Danielson, 1999; but see Carter

& Wilson, 2001; Takayanagi, Dirks, & Moshfegh, 2002). Moreover, as previously mentioned, investigating the role of inhibition in spoken word recognition by measuring effects of lexical density at the item-level avoids the potential problems associated with introducing a competing signal as a measure of inhibition (which masks the target signal). It should be noted, however, that while inhibition was a significant predictor of speech performance in the aforementioned studies, there was also a large proportion of variance unaccounted for, implicating additional potential factors which were not tested.

c. Crystallized Function I: Vocabulary and Word Knowledge

In contrast to the wealth of literature investigating the contribution of declining cognitive functions to speech perception in aging as outlined in the previous section, there is considerably less research examining the contribution of preserved abilities.

One such ability is preserved vocabulary and word knowledge. Vocabulary knowledge shows very little decline across the lifespan; it may even be augmented (Schaie, 1996). By the time adults reach old age (60-65 years, Rönnlund et al., 2005), they have accumulated several decades worth of knowledge about language and vocabulary, having used it for far longer than young, typically university-aged adults, and are often more highly educated (see Verhaeghen, 2003, for a meta-analysis). One theory for such findings attributes spared performance to greater experience or practice across the adult lifespan (e.g., Cattell, 1998; Gollan, Montoya, Cera, & Sandoval, 2008). A similar theory posits that lexical information is concentrated into ‘nodes’ and organized according to a spreading activation model; with advancing age, the connections become universally weaker or less efficient but strengthen with cumulative usage, so that vocabulary knowledge is preserved (the *transmission deficit hypothesis*, Burke, MacKay, & James, 2000; MacKay & Abrams, 1998).

There is also evidence that prior knowledge of linguistic information influences memory in older adults. For example, Matzen and Benjamin (2013) investigated how older adults process words (out-of-context) and sentences by examining patterns of memory errors in a recognition test. To do so, they examined younger and older adults' sensitivity to semantic lures on a recognition test following a period of study. While younger and older adults showed similar levels of memory performance for out-of-context words, the sentence study context elicited superior memory performance in older adults. The researchers attributed this older adult advantage to the fact that older adults were able to capitalize on their intact schematic verbal knowledge, due to "skills honed through years of reading expertise" (Matzen & Benjamin, 2013, p. 765). Further evidence for the role of prior knowledge in memory has been demonstrated in studies showing that older adults remember more realistic grocery prices than unusual ones compared to younger adults (Castel, 2005), and that they are less prone to producing erroneous facts about the world despite being misled (Marsh, Balota, & Roediger, 2005; Umanath & Marsh, 2012). However, overreliance on prior knowledge can sometimes lead older adults astray (e.g., Arbuckle et al., 1994; Koutstaal et al., 2003; Radvansky, Copeland, & von Hippel, 2010; Rogers et al., 2012), resulting in increased errors of commission in both perception and memory studies.

While many aspects of language processing, including reading, lexical decision times, and comprehension have been linked to individual differences in vocabulary knowledge (Lewellen, Goldinger, Pisoni, & Greene, 1993; MacDonald & Christiansen, 2002; Martin, Ewert, & Schwanenflugel, 1994), the role of vocabulary has largely been ignored in the speech perception and aging literature; the vast majority of studies administer tests of vocabulary knowledge but use them as covariates or screening instruments in subsequent analyses. Nevertheless, there are a few indications that vocabulary may play an important role in explaining both individual- and age-related differences in speech perception. For instance, there is evidence to suggest that vocabulary knowledge may be an important contributor to age differences in word frequency effects (e.g., Balota & Ferraro, 1996; Spieler & Balota, 2000; Tainturier, Trembley, & Lecours, 1989, 1992; but see Whiting et al., 2003). Gomez (2002) suggested that older adults' greater vocabulary and verbal experience may affect lexical processing by increasing the relative frequency of low frequency words, thereby reducing the typical word frequency effect. In a homophone priming paradigm, younger adults showed greater priming effects with high frequency compared to low frequency words, whereas older adults did not show this effect. Moreover, older adults produced the low frequency version of a homophone in an unprimed spelling task significantly more often than younger adults, consistent with an age-related increase in relative frequency of use of low frequency words (e.g., Davis et al., 1990; Rose et al., 1986). Further suggestions of vocabulary influences on spoken language processing have been made by Wingfield and colleagues who have reported the facilitatory effects of linguistic constraints on comprehension and memory for speech at the sentence and discourse level (Benichov et al., 2013; Tun, 1998; Wingfield & Stine-Morrow, 2000; Wingfield & Tun, 2001; Wingfield, Poon, Lombardi, & Lowe, 1985). For example, Wingfield et al. (1985) used time compression to vary speech rates for younger and older adults as they heard speech materials varying in both length and degree of semantic and syntactic constraints. Although older adults showed predictable steeper rates of performance decline with increasing speech rate compared to younger adults, this decline was moderated by the structural constraints of the speech materials. That is, there was a progressive reduction of age differences moving from the random string stimuli, to syntactic strings, and, finally, to normal sentences. Such results suggest that contextual constraints had a powerful effect in minimizing the negative effects of time compression for older adults to a degree not necessary for the young adults.

d. Crystallized Function II: Semantic Context and Speech Perception

Given that the use of semantic context requires temporary maintenance of prior linguistic information (presumably tapping age-sensitive WM and executive functions), one might expect particular difficulties for older adults in using contextual information to aid speech performance. In actual fact however, available data suggests that elderly adults can make as good, or even better, use of semantic context than young adults in recognition and memory for written and spoken materials (Cohen & Faulkner, 1983; Hutchinson, 1989; Lieberman, 1963; Madden, 1988; Nittrouer & Boothroyd, 1990, Wingfield, Aberdeen, & Stine, 1991). This follows from a general principle in perception that the more probable a stimulus, the less sensory information will be needed for its correct identification (Morton, 1969). Accordingly, some of the greatest benefits for speech understanding with contextual support emerge from studies that have tested subjects in suboptimal listening conditions. Using materials from the Revised Speech Perception in Noise (SPIN-R) test (Kalikow, Stevens, & Elliott, 1977), Pichora-Fuller, Schneider, and Daneman (1995) tested younger and older listeners at various SNR levels in their ability to identify the final word in sentences with varying levels of contextual support, i.e., high, medium, and low-predictability (e.g., *The witness took a solemn oath* ("high") vs. *John hadn't discussed the oath* ("low)"). While older listeners were poorer than younger listeners in identifying the key words in noise, both groups benefitted greatly when words were presented in a supportive context, such that degraded words were identified with greater accuracy when heard in a highly predictable sentence context. However, compared to younger adults, older adults actually benefited *more* from context, particularly in conditions of only moderate signal degradation. Similar findings have been replicated in a number of studies (Dubno, Ahlstrom, & Horwitz, 2000; Rogers, Jacoby, & Sommers, 2012; Sommers & Danielson, 1999), demonstrating older adults' greater benefit from contextual support in mitigating age-related perceptual difficulties in spoken-word recognition. Moreover, Sommers & Danielson (1999) demonstrated that high contextual support can even mitigate the effects of lexical density, such that age differences in the ability to identify high-density (HD) words disappear in highly predictable (HP) contexts, but emerge when presented in low-predictability (LP) contexts or when the word was presented in isolation. The results were interpreted to suggest that the effects of semantic context reduce demands of inhibiting phonologically similar word candidates, thereby increasing target recognition. Of interest to the current dissertation, this latter study is the first to provide direct evidence of the compensatory properties of preserved knowledge, showing that older listeners are able to take advantage of the additional semantic information in HP sentence contexts to compensate for impaired inhibitory demands associated with HD targets.

The mechanisms of older adults' benefit from contextual support have been debated. The *priming* argument (Pichora-Fuller, 2008; Wingfield & Tun, 2007) states that the use of supportive context facilitates implicit processing by providing an alternative faster route to a match between the speech signal and meaning despite degraded signal quality, similar to the ELU model. That is, contextual support acts as a priming mechanism to gradually lower recognition thresholds for words made more probable by the linguistic context and/or by inhibiting activation of phonologically similar lexical alternatives that have a weaker fit with the linguistic context, thereby reducing overall processing load (Goldinger, Luce, & Pisoni, 1989; Marslen-Wilson, 1987; Morton, 1969). This is consistent not only with findings (e.g., Pichora-Fuller et al., 1995) that found the greatest benefits of context at relatively lower levels of signal degradation, but also with broader claims of the relative automaticity of retrieving prior knowledge being preserved with advanced age (e.g., Craik & Jennings, 1992; Hasher & Zacks, 1979; Light, 1991; Roediger, Balota, & Watson, 2001). Thus, a major hypothesis as to how semantic context benefits older listeners is that preserved linguistic knowledge operates via an automatic route to benefit performance, in contrast to the cognitive and perceptual effort involved in challenging listening situations.

A similar account suggests that contextual support acts to *constrain* the range of possibilities during lexical discrimination (Sommers & Danielson, 1999). Sommers and Danielson observed that under conditions that produced approximately equivalent identification scores for LD targets across age groups, older adults exhibited significantly poorer recognition than young adults for HD words in both the single-word and LP contexts. In HP sentences, however, differences between identification scores for low-density (LD) and HD words did not vary as a function of age. The researchers interpreted these results to suggest that HP semantic context reduces demands on inhibitory abilities otherwise allocated to suppressing competing word candidates for HD targets. That is, in the presence of predictable context, lexical discrimination does not so heavily rely on inhibitory function to eliminate irrelevant word candidates. In the absence of predictable context however, i.e., under LP conditions, older adults' inhibitory impairments are more apparent, producing the disproportionate age differences in identifying HD words.

An alternate account posits that older adults' benefit from HP context is a result of a *bias effect* rather than constraint-based mechanisms. In contrast to the aforementioned constraint-based account, this account posits that older adults are biased to over-rely on context, regardless of sensory input. Rogers, Jacoby, and Sommers (2012) trained younger and older adults in learning cue-target pairs of semantic associates. Following training, participants were presented with target word in noise which were either congruent, incongruent, or neutral relative to the cues learned during training. For example, the cue "BARN" could be paired with the congruent target "HAY", the incongruent but phonologically similar target "PAY", or the neutral "FUN". The researchers found that not only were older adults less accurate in correctly identifying incongruent targets than younger adults, they were also more likely to indicate high confidence in their response. That is, even if the context and the sensory signal were incongruent, i.e., the context predicts "HAY" but "PAY" is presented, older adults were more likely to produce a response that is consistent with the predictable context and be more confident in doing so (false hearing, Rogers et al., 2012). This bias is thought to occur because, generally speaking, context *is* highly reliable, and older adults have learned to capitalize on this predictability. Cases of false hearing demonstrate that older adults consistently make expectations about the nature of semantic context, such that they are more likely to adhere to these prior expectations despite conflicting sensory information, in contrast to younger adults who are more flexible in their attention to sensory input.

Compensation

The research reviewed above presents a clear delineation between two major processes in cognitive aging of fluid and crystallized function. There is overwhelming evidence for decline in multiple cognitive domains, including aspects of impaired memory, information processing speed, and reasoning. On the other hand, there is evidence showing relative maintenance, and sometimes enhancement, of language-related processes in aging, including vocabulary knowledge and use of semantic context. The asymmetrical pattern of function corresponding to these two processes illustrate a striking paradox in the field of cognitive aging, as well as the need to resolve such a paradox by systematically examining the interaction between these abilities, independently of age-related sensory decline. In the following section, I review research that investigates potential mechanisms of how older adults are able to maintain use of linguistic knowledge in speech despite general declines in cognition.

Studies of expertise have indirectly demonstrated that preserved expert knowledge in a particular domain may offset age differences, and even some negative consequences of cognitive aging (e.g. Charness & Bosman, 1990; Ericsson & Charness, 1994; Li et al., 2004). For example, work investigating the link between bilingualism and executive function has reported that after comparing the performance of monolingual and bilingual older adults on tasks of interference resolution such as the Simon and Stroop task, the latter group showed smaller interference effects (e.g., Bialystok, Craik, & Ryan, 2006; Bialystok et al., 2004; Carlson & Meltzoff, 2008; Martin-Rhee & Bialystok, 2008). The mechanism of such an advantage is hypothesized to stem from the fact that bilinguals are required to constantly manage attention to two active language systems, and thus necessitate a higher degree of cognitive flexibility across a range of executive function abilities. Moreover, research has also suggested that this enhanced executive function in bilingual individuals may even delay the onset of dementia symptoms (e.g., Bialystok and colleagues, 2007, 2010, 2013). The protective effect of bilingualism has also been linked to the concept of cognitive reserve (Craik, Bialystok, & Freedman, 2010; Gold, Johnson, & Powell, 2013; Schweizer et al., 2012), which posits that enriching and stimulating environments induce experience-based neural changes that consequently provide resilience to neuropathological brain damage (Stern, 2002, 2009). Specifically, bilingualism carries broad appeal as a potential reserve variable because it is primarily influenced by environmental factors such as country of birth, emigration, or attendance of a second language immersion school (Bialystok & Craik, 2010). Cognitive reserve is not without controversy however, and is often confounded with a number of demographic variables including education and socioeconomic status (Tucker & Stern, 2011). Nevertheless, some promising findings from cognitive neuroscience concerning compensation may provide further insights into the mechanisms of compensation.

The influential HAROLD model (Hemispheric Asymmetry Reduction in OLder Adults) is based on findings that prefrontal brain activity during cognitive performance (perception, memory, and attention) show increases in bilateral processing with age (Cabeza, 2002). One possibility for this functional reorganization has been attributed to a compensatory adaptation to offset age-related neurocognitive declines. Evidence supporting this interpretation comes from neuroimaging studies of healthy older adults who have low performance on cognitive measures but recruit the same prefrontal cortex regions as young adults, whereas older adults who achieve high performance engage bilateral regions of prefrontal cortex (Cabeza, Anderson, Locantore, & McIntosh, 2002). Such results suggest that older adults may be using different strategies or cognitive processes to maintain representations over short time periods by recruiting additional neural regions (Grady, 1998, 2000, Grady et al., 1998). Such effects have been observed in a variety of tasks requiring controlled, effortful processes, including studies of verbal and spatial working memory (Reuter-Lorenz et al., 2000), verbal encoding (Anderson et al., 2000, Cabeza et al., 1997; Madden et al. 1999), and episodic retrieval (e.g., Bäckman et al., 1997; Cabeza et al., 1997; Schacter et al., 1996). For example, Cabeza et al. (1997) demonstrated that older adults showed less activity relative to young adults in some frontal regions but more activity in other temporal and insular regions. That is, older adults demonstrate additional non-selective recruitment of additional brain regions – and sometimes *over*-recruitment – in order to maintain task performance.

The CRUNCH (Compensation Related Utilization of Neural Circuits) model proposes a somewhat similar framework, in which additional neural circuitry is required at lower levels of task demands for aging individuals to meet task demands (Reuter-Lorenz & Cappell, 2008). According to CRUNCH, older adults reach their resource limits sooner than younger adults, leaving fewer resources for higher cognitive loads. However, in contrast to HAROLD, the model predicts both poorer performance for older adults than for younger adults on more complex tasks, as well as *under-recruitment* of dedicated neural regions in older adults relative to younger adults as tasks become more difficult. That is, according to the model, differences between older and younger adults increase as task load/difficulty becomes greater, and as older adults are less able to adapt to cognitively demanding task situations. Similar findings of neural under-recruitment in older adults have been observed across a number of other studies investigating cognitive decline, particularly with regard to attenuated activity in frontal regions (e.g., Anderson et al., 2000; Cabeza et al., 1997; Grady & Craik 2000; Grady et al., 1995; Grady et al., 1999; Reuter-Lorenz et al. 2000; Rypma & D'Esposito, 2000).

There is also evidence to suggest that brain regions may need to work ‘harder’ and thus become overactive because of age-related sensory declines (Payer, Marshuetz, Sutton, Hebrank, Welsh, & Park, 2006; Reuter-Lorenz & Lustig, 2005). For example, some researchers (Cabeza et al., 2004; Grady et al., 1994; Madden et al., 1996) have speculated that age-related increases in prefrontal cortex (PFC) activity compensate for decreased occipital activations. Grady et al.

(1994) suggested that during perception older adults might compensate for deficits in sensory processes mediated by occipital regions by recruiting strategic processes mediated by PFC regions. Similarly, Li and Lindenberger (2002) noted in a review that the results from a number of studies suggest that older adults may use cognitive processes to compensate for compromised sensory information.

From the discussion above, it is clear that the results represent a paradox in the findings of how compensation is represented in the aging brain. While a thorough discussion of the complex under-recruitment vs. over-recruitment perspectives is beyond the scope of this dissertation, there is good evidence to suggest that the two accounts may both be true under select circumstances (e.g., Logan et al., 2002; see Reuter-Lorenz et al., 2001, Reuter-Lorenz & Cappell, 2008, for reviews).

Within behavioral studies of cognitive aging however, there is far less evidence for compensation. As previously mentioned, many studies of spoken word identification have interpreted their results to support a compensatory account of how linguistic and contextual support can counteract the effects of sensory and cognitive declines (Dubno et al, 2000; Gordon-Salant & Fitzgibbons, 1997; Perry & Wingfield, 1994; Pichora-Fuller, 2008; Pichora-Fuller, Schneider, & Daneman, 1995; Silagi et al., 2015; Tun & Wingfield, 1994; Wingfield & Alexander, 1994; Wingfield & Tun, 2007; Wingfield et al, 2005) but few have obtained direct evidence for this (but see Sommers & Danielson, 1999). That is, the evidence for compensation has been a result of observing equivalent performance in younger and older adults in a certain condition, i.e., with high-predictability semantic context (Dubno et al., 2000; Gordon-Salant & Fitzgibbons, 1997; Perry & Wingfield., 1994; Pichora- Fuller, 2006; Pichora-Fuller et al., 1995; Wingfield et al., 2005). However, these studies claim evidence of compensation without having directly incorporated such a hypothesis into the experimental design. As such, the study of compensation has been confined to the factors that come into play at a descriptive level without specific, hypothesized experimental manipulations. Simply demonstrating age-equivalent performance is, in and of itself, not sufficient to make claims of compensation. An account of compensation requires that the experimental design reflects the hypothesized mechanisms of compensation. That is, without specifying how potential compensation is directly linked to varying task demands, claims of compensatory rebalancing between cognitive-linguistic and sensory factors are difficult to make.

There has also been a larger focus on the proposed compensatory effects of language on cognitive decline in improving speech under degraded listening conditions (e.g., Dubno, Ahlstrom, & Honwith, 2000; Pichora-Fuller, 2007, 2008; Pichora-Fuller et al., 1995; Wingfield, Aberdeen, & Stine, 1991; Wingfield, Tun, & McCoy, 2005). This degradation can be a result of either introducing background noise that masks the speech signal (e.g., Dubno, Ahlstrom, & Horwitz, 2000; Hutchinson, 1989; Pichora- Fuller, Schneider, & Daneman, 1995; Sommers & Danielson, 1999), or by temporally distorting the speech signal itself (i.e., jittering; Brown & Pichora-Fuller, 2000; Pichora-Fuller et al., 2007; Schneider, Daneman, & Pichora-Fuller, 2002). The relationship between sensory and cognitive processing has been a feature of several hypotheses of aging, including the *information-degradation hypothesis* (Baltes & Lindenberger, 1997; Lindenberger & Baltes, 1994, 1997). According to this hypothesis, one of the possible explanations for the strong correlations observed between auditory and cognitive aging is that impoverished auditory input stresses cognitive processing, exacerbating the apparent cognitive declines often observed in older listeners (e.g. McCoy et al., 2005; Pichora-Fuller, 2003, 2006, 2007; Pichora-Fuller et al., 1995; Wingfield et al., 1999). That is, older adults are faced with the difficult situation of being presented with degraded sensory input which must be encoded and processed with an impaired cognitive system. While it is difficult to critically assess the validity of this hypothesis due to limited longitudinal or experimental studies to provide evidence of causality (Arlinger, 2003; see Pichora-Fuller & Singh, 2006, for a review), it nevertheless implicates a strong association between sensory and cognitive processing that has been reported in several studies of speech processing and aging (e.g., Humes et al., 2013; Lunner, 2003; Schneider, Daneman, & Murphy, 2005; Wingfield, Tun, & McCoy, 2005). However, the potential for conflating cognitive and sensory factors using such an approach undermines the development of stronger mechanistic accounts of listening effort and cognitive factors in speech. Thus, although hearing loss is undoubtedly the most significant contributor to speech perception, examining differences in the ability to use linguistic knowledge to compensate for age-related deficits would be well-served by investigating such differences independently of sensory decline.

In sum, the general claim from previous studies is that support in the form of linguistic knowledge allows older adults to compensate for sensory and cognitive decline in speech perception tasks. What is lacking in previous research however, is placing the effects of crystallized linguistic factors purported to facilitate compensation, i.e., word knowledge and semantic context, directly in opposition to fluid factors such as WM and inhibitory function. That is, despite the research discussed above showing that these aforementioned factors are linked to speech performance, these variables have not been examined together within the same study. Doing so is critical in order to elucidate the nature of the fluid vs. crystallized asymmetry in speech and aging, and a mechanistic account of how these abilities interact in a way that allows individuals to compensate for difficult listening situations. Thus, the lack of specificity surrounding potential mechanisms of compensation in speech perception motivates the following major question: *How do fluid-crystallized interactions affect speech perception in aging?* From this starting point, I present the two empirical research questions which I address in the current dissertation.

1) How does working memory (WM) interact with semantic context and word frequency to affect speech perception? Specifically, how does age modulate the relationship between WM load and use of semantic context and word frequency during speech perception?
2) How does inhibitory function interact with semantic context and word frequency to affect speech perception? Specifically, how does age modulate the relationship between inhibitory demands and use of semantic context and word frequency during speech perception

CHAPTER 2: THE CURRENT STUDY

Overview of Experiments

To address the research questions presented in Chapter 1, I examined the contributions and potential interaction of crystallized and fluid abilities to speech perception in young and older adults, independently of age-related differences in hearing. In Experiment 1, I tested the potential compensatory effects of preserved linguistic knowledge on WM demands, while in Experiment 2 I tested preserved linguistic knowledge effects on inhibitory demands. Within each experiment, participants were instructed to identify key target words in speech stimuli. These key words were systematically varied either as a function of low and high semantic predictability (LP, HP), or low and high word frequency (LF, HF), so as to vary the level of available linguistic support. Concurrently, I systematically varied cognitive demands, i.e., WM load and inhibitory demands, by either introducing a secondary WM task or manipulating the lexical density of the target word, respectively.

In Experiment 1, I created conditions of low- and high-WM load. The high-WM load condition required participants to alternate between immediately identifying speech stimuli and performing a secondary task involving solving math equations and remembering target words for later recall. In the low-WM condition, no such equation-solving or recall demands were present.

In Experiment 2, I created conditions of low and high inhibitory demand by manipulating the lexical density of the target words. In the high inhibitory condition, target words had HD characteristics, i.e. they required greater inhibitory demands. In the low inhibitory condition, target words had LD characteristics, and therefore required relatively fewer inhibitory demands.

For both experiments, age (young, old) served as the between-subjects variable. All other factors, including stimulus type (single-words, sentences), semantic context (low predictability, high predictability), word frequency (low, high), WM load (low, high), and inhibitory demands (low, high) were within-subjects factors. In Experiment 1, WM load was crossed with semantic context and with word frequency separately. The same was true for Experiment 2, in which semantic context and word frequency were independently crossed with inhibitory demand.

Hypotheses

Given the many factors in the experimental design and the potential for complex interactions, there are many possible outcomes. The most critical hypotheses concern the possibility of compensation. Compensation, as I discussed in Chapter 1, refers to how older adults may overcome high demands on fluid abilities using preserved crystallized knowledge, i.e., use of semantic context and word frequency. In order to be considered evidence of compensation in the current study, it must be demonstrated that linguistic support, in the form of predictable semantic context and high word frequency, must be able to at least maintain levels of performance as the cognitive demands of the task increase. Moreover, linguistic knowledge ought to modulate older adults' performance more than younger adults. That is, a signature of compensation would show that older adults are able to disproportionately benefit from high linguistic support in comparison to younger adults, and that such benefits should be particularly evident in the high cognitive demand conditions. Specific hypotheses relating to the individual variable manipulations are described below.

1. Interaction of WM and linguistic support: There is good evidence to suggest that dual-task demands in speech disproportionately affect older more than younger adults (Tun, Wingfield, & Stine, 1991; Tun, McCoy, & Wingfield, 2009; Kemper et al., 2010). The critical question is whether semantic context and/or word-frequency knowledge, can mitigate these age effects. The major prediction here are that age (young, old) will modulate the interactions between WM Load (low-load vs. high-load), Stimulus Type (single-words vs. sentences) and each linguistic variable (Semantic Context (LP vs. HP), and Word Frequency (LF vs. HF)). For ease, hypotheses grouped by the individual manipulations are described below:

a) *WM Load x Semantic Context as a function of age:* While I predict overall main effects of WM load and semantic context, such that high-WM load is more detrimental to performance and HP context is beneficial to performance, I predict that these factors will moderate performance differentially for younger and older adults. Specifically, HP context is predicted to be disproportionately beneficial to older adults compared to younger adults in the high-WM load condition, while older adults may perform significantly worse than young in the high-WM load, LP context condition. That is to say, older adults will be able to use semantic context to their advantage in the high-WM load condition in a way that younger adults do not, suggesting that they may compensate for high WM demands by utilizing context more efficiently. This would be consistent with accounts finding that older adults' lifelong language experience and sometimes overreliance on linguistic expectations (e.g., false hearing, Rogers et al., 2012) produce benefits in which semantic context provides valid cues for speech understanding. In contrast, for LP context, WM deficits in older adults may become more apparent and subsequently impair accuracy without having the benefit of being able to use an intact crystallized ability, i.e., semantic context. Such results would support a compensation account of crystallized cognition counteracting the effects of impaired fluid abilities, particularly under cognitively demanding conditions.

b) *Semantic Context x Stimulus Type as a function of age*: Compensatory effects of HP context may enhance sentence performance more than single-word performance, as single words may not be sufficient to engage semantic context. Indeed, most evidence for possible compensatory mechanisms of context have emerged from studies examining sentences, or at least, final words of sentences (Hutchinson, 1989; Pichora-Fuller et al., 1995; Sommers & Danielson, 1999). Sentences provide more linguistic and syntactic information which affords older adults the opportunity to break up the sentence into smaller processing units (i.e., chunking; Miller & Stine-Morrow, 1998), providing multiple opportunities to encode linguistic context in a way that single-word stimuli with carrier phrases do not. On the other hand, sentences are naturally more linguistically complex and require more processing demands associated with encoding, storing, and recalling earlier parts of the sentence (Kemper et al., 2010) – for this reason, it may alternately be the case that older adults' accuracy may be impaired for such stimuli.

c) *WM Load x Frequency as a function of age*: Similar to the interaction of WM load and semantic context, I predict differential effects of WM Load x Frequency, such that HF words will allow older adults to compensate for high cognitive demands associated with the high-WM load condition. However, mixed findings with respect to age differences in the word frequency effect may also diminish any consistent benefits of HF information. Past research has shown inconsistent evidence of word frequency effects across age groups, in which some report an increasing frequency effect with age (e.g., Balota & Ferraro, 1993, 1996; Spieler & Balota, 2000; Rayner et al., 2006), whereas others report no interaction of frequency with age (e.g., Allen, Madden, & Crozier, 1991; Rayner et al., 2011; Whiting et al., 2006). Given this inconsistency in the literature, the effects of frequency may yield only moderate benefits in mitigating the effects of high cognitive demand.

2. Interaction of inhibition and linguistic support: As with WM, inhibitory demands, in the form of high lexical density, place an additional cognitive load on older adults. As such, these may have consequences for the degree to which they are able to benefit from preserved crystallized ability. Similarly, I predict that age will modulate the interactions between the manipulated factors of Inhibitory Demand (LD vs. HD), Semantic Context (LP vs. HP), Word Frequency (LF vs. HF), and Stimulus Type (single-words vs. sentences). As in the predictions for Question #1, key interactions are described below:

a) *Inhibitory Demand x Semantic Context as a function of age:* The inhibition manipulation is intended to target single words at the item level in isolation as well as within an entire sentence. Manipulation of lexical density is an effect of which participants are often unaware, but nevertheless produces powerful age effects (Luce & Pisoni, 1998; Sommers 1996; Sommers & Danielson, 1999; Taler et al., 2010). The primary prediction here is that older adults will show evidence of compensation for HD targets, but not for LD targets, i.e., HP context will allow older adults to sufficiently overcome the high inhibitory demands associated with HD targets. Analogous to high-WM load conditions, older adults will be disproportionately affected by HD items compared to younger adults due to greater inhibitory demands of such items. Previous work has found that older adults show significantly poorer accuracy compared to younger adults in identifying HD words in both single-word presentation and LP context (Sommers & Danielson, 1999). These age differences, however, disappeared in HP context. Such results suggest that age-related deficits in speech performance can be attenuated if sufficient semantic contextual support is available, thereby reducing inhibitory requirements of HD words and providing evidence for a compensatory account of preserved ability. When inhibitory demands are reduced however, i.e. when presented with LD words, there are no additional cognitive demands, and both age groups will perform equivalently.

b) *Inhibitory Demand x Frequency as a function of age:* The frequency manipulation in the inhibitory demand conditions presents a unique case, because of the fact that both frequency and density are item-level manipulations, in contrast to Experiment 1 in which the cognitive demands are extrinsic to the speech identification task. Moreover, frequency and density values tend to be highly correlated (Goldinger, Luce, & Pisoni, 1990; Luce & Pisoni, 1998; Sommers, 1996), such that HD words are also high in frequency, and LD words are also low in frequency. Despite this high correlation, it is possible to disentangle these effects and place them in opposition to examine whether word frequency can differentially mitigate density effects in younger and older adults. I predict that while HF words will be beneficial to both younger and older adults' performance, this benefit will depend on lexical density. That is, the word frequency effect will be similar for both age groups for LD, but may be exaggerated for HD words. Such results would suggest that despite reduced inhibitory function, older adults may be able to compensate for such deficits by utilizing their knowledge of word frequency information. However, due to the mixed effects with regard to age and the word frequency effect as mentioned above, it may also be the case that older adults do not benefit from HF information, but rather LF information. That is, given that older adults presumably have more language use than younger adults, cumulative frequency effects may be more likely to affect LF rather than

HF information. As such, compensatory effects of frequency for older adults may be found in performance for LF targets, rather than HF targets.

CHAPTER 3: GENERAL METHODS

The methodological protocol used in this study was approved by Washington University's Institutional Review Board and participants were treated in accordance with the ethical standards of the American Psychological Association (1992). Aspects common to Experiments 1 and 2 will be described in this chapter. Specific manipulations in Experiment 1 and 2 will described in separate chapters.

Participants

Based on a priori power analyses using G* Power (Faul et al., 2007) with desired power of .95 and a medium effect size (f = .5) for analyses of variance (ANOVA), the minimum required sample size reported was 54. I thus recruited 50 younger (34 women) and 50 older (31 women) participants for these experiments. Younger adults were recruited through the PSYC100 Subject Pool while older adults were recruited through the Volunteers for Health (VFH) database. Younger participants received one hour of course credit, while older adults received $10/hour of participation. Potential older adult participants were contacted by phone and, after the study was described, asked if they would like to participate. Upon initial contact, older adult participants were asked several short questions to help ensure the absence of medical conditions known to affect cognitive performance and were excluded if they reported having certain neurological problems (e.g., stroke, Parkinson's disease), injuries (e.g., recent concussion), or depression.

Prior to the experiments, all participants completed a questionnaire on basic demographic information (shown in Appendix A), reading habits (from Stanovich, West, and Harrison, 1995; shown in Appendix B), an audiogram assessing pure-tone thresholds for octave frequencies from

250 to 4000 Hz, the Shipley vocabulary test (Shipley, 1946), and a perceptual processing speed task (Chen, Myerson, & Hale, & Simon, 2000). The processing speed task presented participants with a computer display consisting of a central white dot flanked by a blue dot and a red dot. Their task was to respond as quickly as possible as to which of the colored dots was closer to the central dot by pressing the corresponding key on the keyboard. Both age groups were comparable in accuracy for the processing speed task, $t(98) = 1.21$, $p = .35$, but younger adults showed reliably faster reaction times than did older adults, $t(98) = 4.19$, $p < .001$.

Older adults had significantly higher vocabulary scores than did younger adults, $t(98) = 3.40$, $p = .001$; as well as more years of education, $t(98) = 7.72$, $p < .001$. In terms of reading habits, responses on the questionnaire were scored in the direction of higher scores reflecting more reading. Older adults generally reported higher overall levels of reading ($M = 4.54$, $SD = 1.07$), compared to younger adults ($M = 2.66$, $SD = 1.01$), $t(98) = 8.12$, $p < .001$; as well as more enjoyment of reading ($M_{older} = 3.23$, $SD_{older} = 0.83$; $M_{younger} = 2.61$, $SD_{younger} = 0.68$), $t(98) = 3.62$, $p < .001$). Hearing ability as measured by pure-tone average (PTA) thresholds was calculated across the 500, 1000, and 2000 Hz frequencies. As predicted, older adults demonstrated significantly higher pure-tone hearing thresholds compared to younger adults, $t(98) = 2.61$, $p = .01$, although both groups were well within clinically normal hearing ranges (< 20 dB hearing loss). Older adults also completed the Mini-Mental Status Examination (MMSE, Folstein & Folstein, 1975) to assess cognitive status, and scored within clinically normal ranges. This information is presented in Table 1.

Table 1.
Demographic Information for Younger and Older Adults

	N	Age (Mean, SD)	Shipley Vocabulary (score out of 40, SD)	Years of Education (SD)	Processing Speed RT (ms, SD)	Processing Speed ACC (%, SD)	MMSE (score out of 30, SD)	PTA (better ear dB, SD)
Young	50	19.86 (1.58)	30.85 (2.60)	13.30 (1.34)	687.98 (145.05)	97.77 (4.41)	---	5.06 (8.68)
Old	50	71.02 (4.07)	34.78 (4.79)	16.89 (2.46)	1156.42 (414.15)	99.78 (1.04)	28.87 (1.64)	13.94 (18.25)

Note. SD = standard deviation, ACC = accuracy, PTA = pure-tone average.

Apparatus

The experiments were conducted in a quiet testing room. All tasks, excluding the MMSE, audiogram, and questionnaires, were programmed and administered on a Windows-based computer using E-Prime 2.0 software (Psychology Software Tools, Inc., Pittsburgh, PA) with Sennheiser HD 518 headphones to hear the auditory stimuli. Responses were made on a standard keyboard. For the processing speed task, Shipley task, and some aspects of the WM task, participants entered their own responses. For all other portions of the study, the experimenter entered the participants' verbal responses.

Stimuli

Stimuli. All target words were monosyllabic nouns. The stimuli were recorded by a male native English speaker with a Midwestern dialect using a sampling rate of 44.1 kHz and a 16-bit A/D converter. They were presented in a background noise of 6-talker babble at a signal-to-noise ratio (SNR) of 0 dB to younger adults, and +3 dB to older adults to ensure roughly equivalent performance of 60% in a standard measure of speech identification across the age groups.

Single words. Single-word stimuli were those that consisted of a target word preceded by a carrier phrase (i.e. "Say the word _____"). I selected these stimuli from the English Lexicon Project (Balota et al., 2007).

In order to simulate HP and LP context for single-word stimuli for the semantic context conditions, I selected low- and high-association semantic primes which would be presented before each auditory stimulus. Note that low-association primes served a similar function to LP context for sentences, in which the preceding sentential context is not at all predictive of the final target word. Similarly, the low-association primes contained no contextual cues as to the target word, i.e., essentially unrelated primes. I selected these primes from the Semantic Priming Project (Hutchison et al., 2012), and matched the primes in frequency and length across LP and HP conditions, $p = .462$. For example, a high-association prime, i.e., HP context prime, might be "KNIFE" followed by the carrier phrase and target word "Say the word <u>FORK</u>", whereas a low-association prime, i.e., LP context prime, might be "GLOBE" followed by the carrier phrase and target word "Say the word <u>MILK</u>". All prime-target associations were based on forward associative strength (FAS) values. The mean FAS value for high-association pairs was 0.45 (*SD* = 0.05), while the mean value for low-association pairs was 0 (due to random repairing of prime-target pairs during the norming process, see Hutchison et al., 2010, for further details). The primes were presented in orthographic form on the screen before each auditory speech stimulus.

Sentences. Sentence stimuli were those that were syntactically correct, but varied in the degree of semantic support for the final target item. I selected these sentences from the Speech Perception in Noise (SPIN) test (Kalikow, Stevens, & Elliott, 1977; Bilger et al., 1984). These sentences consist of a final key word embedded within the context of a high-predictability (HP) sentence (e.g., "The crew swabbed the DECK") or a low-predictability (LP) sentence (e.g., "Miss Smith was looking for the BIB"). These sentences have been normed for key words alone as well as for all content words for form equivalence and lexical characteristics including phonetic class, number of syllables, and number of words (Kalikow et al., 1977).

Target words in both single-word and sentence stimuli were matched across all conditions for length, number of phonemes, number of orthographic neighbors, and average frequency of the phonological neighborhood, in addition to word frequency and lexical density in the conditions in which these aspects were not being directly manipulated. Number of phonological neighbors, while highly correlated with density (*r* = .86), was also controlled for in the conditions in which density was not actively being manipulated.

In order to designate low and high frequency (LF/HF) items and low and high density (LD/HD) targets, I dichotomized word frequency and lexical density values. Although this was done for the sake of ease in this dissertation, it is important to note that artificially dichotomized stimuli sets can be susceptible to a host of confounds and spurious correlations (e.g., Balota et al., 2004; Cohen & Cohen, 1983). HF words were those with a log frequency of 9 or above, while LF words had log frequency of 6 or below. Frequency norms were based on those from the Hyperspace Analogue to Language (HAL) log-transformed frequency norms (Lund & Burgess, 1996). HD words had a neighborhood density of 13 or more, while LD words were those which had a neighborhood density of 7 or less. These density values were based on the NAM conception of density values, in which targets and competitors differ by the addition, substitution, or deletion of a single phoneme, and were obtained using the Washington University Speech and Hearing Lab Neighborhood Database (Sommers, 2002).

Table 2 shows the mean lexical characteristics of the target stimuli across conditions. HF targets were significantly higher in frequency than LF targets, $p < .001$, and HD targets were significantly higher in lexical density than LD targets, $p < .001$. Highly related to lexical density was number of phonological neighbors, which was also significantly higher for HD targets than for LD targets, $p < .001$. None of the targets significantly differed on any of the other control characteristics, p's $> .654$. No target words were repeated across stimuli, resulting in 560 unique speech stimuli. A complete list of all the stimuli is presented in Appendix C.

Table 2.
Mean Lexical Characteristics of Target Words across Conditions and Condition Levels

	Experiment 1: Working Memory				Experiment 2: Inhibition							
	HP Context	LP Context	HF	LF	HP Context		LP Context		HF		LF	
					LD	HD	LD	HD	LD	HD	LD	HD
N	70	70	70	70	35	35	35	35	35	35	35	35
Length	4.28 (.31)	4.40 (.15)	4.51 (.16)	4.79 (.17)	4.75 (.45)	3.85 (.58)	4.90 (.71)	4.10 (.78)	4.00 (.53)	3.93 (.70)	4.66 (1.04)	4.33 (.81)
HAL Log Freq	9.09 (.23)	9.17 (.67)	10.29 (.43)	4.78 (.26)	9.29 (1.15)	10.01 (1.34)	9.63 (1.47)	9.73 (1.58)	9.18 (1.95)	10.17 (.87)	5.67 (1.33)	5.51 (.65)
Ortho_N	9.13 (3.73)	7.97 (1.52)	6.77 (2.36)	4.28 (.41)	3.40 (2.41)	14.85 (6.44)	4.55 (3.64)	13.20 (6.89)	4.33 (2.79)	10.66 (4.90)	3.00 (2.10)	8.00 (5.68)
Phono_N	18.64 (8.88)	18.50 (7.21)	14.37 (3.54)	12.05 (2.85)	8.25 (5.64)	24.65 (8.99)	10.1 (7.65)	26.90 (12.02)	7.06 (5.58)	19.26 (8.79)	4.73 (3.17)	18.41 (7.58)
N_Phon	3.50 (.46)	3.59 (.05)	3.60 (.10)	4.00 (.04)	3.15 (.98)	2.95 (.22)	4.10 (.55)	3.20 (.65)	3.66 (.48)	3.33 (.81)	3.93 (.70)	3.20 (.67)
Freq_N_P	7.01 (1.35)	7.21 (1.10)	6.91 (1.18)	7.13 (4.97)	7.09 (.98)	7.54 (.58)	6.94 (.87)	8.04 (.71)	7.73 (.66)	7.00 (1.13)	7.98 (.74)	7.23 (.89)
Density	7.54 (3.66)	6.37 (2.74)	6.33 (2.10)	6.89 (4.63)	4.95 (2.03)	24.55 (4.46)	5.90 (1.55)	21.65 (6.93)	4.86 (2.23)	20.13 (4.33)	5.00 (2.26)	18.00 (5.41)

Note. HP = high predictability, LP = low predictability; HF = high frequency, LF = low frequency; HD = high density, LD = low density. Values shown in parentheses represent the standard deviation from the mean.

Row Values: Ortho_N = # of orthographic neighbors, Phono_N = # of phonological neighbors, N_Phon = # of phonemes, Freq_N_P = average of the frequency of the phonological neighborhood of a particular word.

Methods

The order of Experiments 1 and 2 was counterbalanced across participants. All participants completed both experiments. Trials were blocked into single-word and sentence trials. Within each block, a black central fixation cross appeared for 500ms between each trial. Block order was randomized across participants, although trials within each block were pseudo-randomized prior to the experiment and presented in a fixed order to all participants. When speech stimuli were auditorily presented, the screen display consisted of "LISTEN" presented in red font. Participants were periodically reminded to keep their eyes on the computer screen at all times. A general schematic of the experimental procedures is shown in Figure 1 and 2, and more detailed examples of the trial sequences are described separately for each experiment in subsequent chapters.

The WM experiment lasted for approximately 1 hour, and the inhibition experiment lasted approximately 30 minutes. Participants were allowed a break mid-way through the WM experiment, and between Experiments 1 and 2. Combined with the screening materials and questionnaires, the entire experimental session lasted approximately 2 hours.

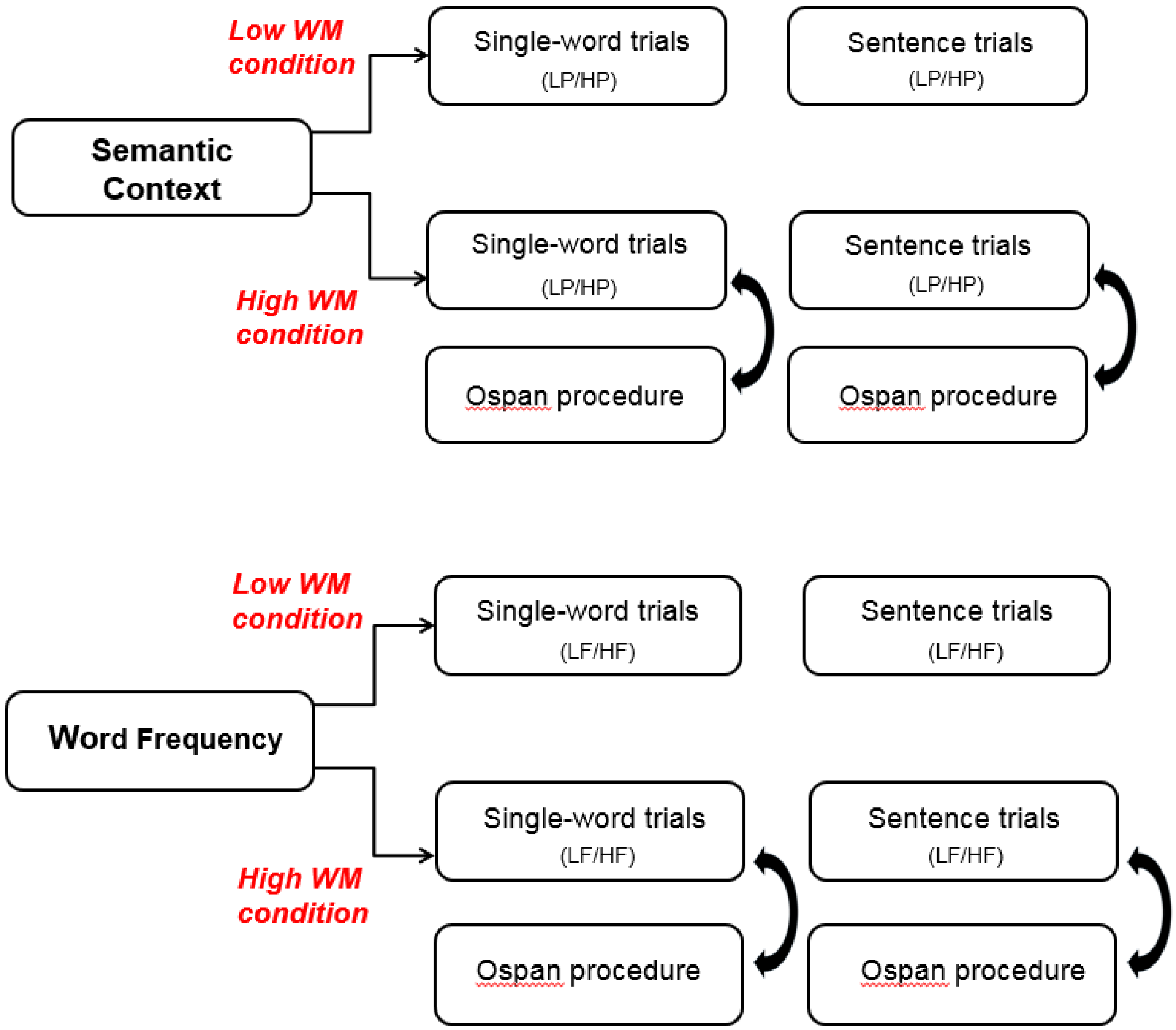


Figure 1. A schematic depiction of the components in the working memory (WM) manipulation conditions. For each crystallized ability manipulation (semantic context, word frequency) there was a low and high WM condition. Note LP = low predictability, HP = high predictability; LF = low frequency, HF = high frequency. Single-word trials and sentence trials were blocked separately, but presentation order was randomized.

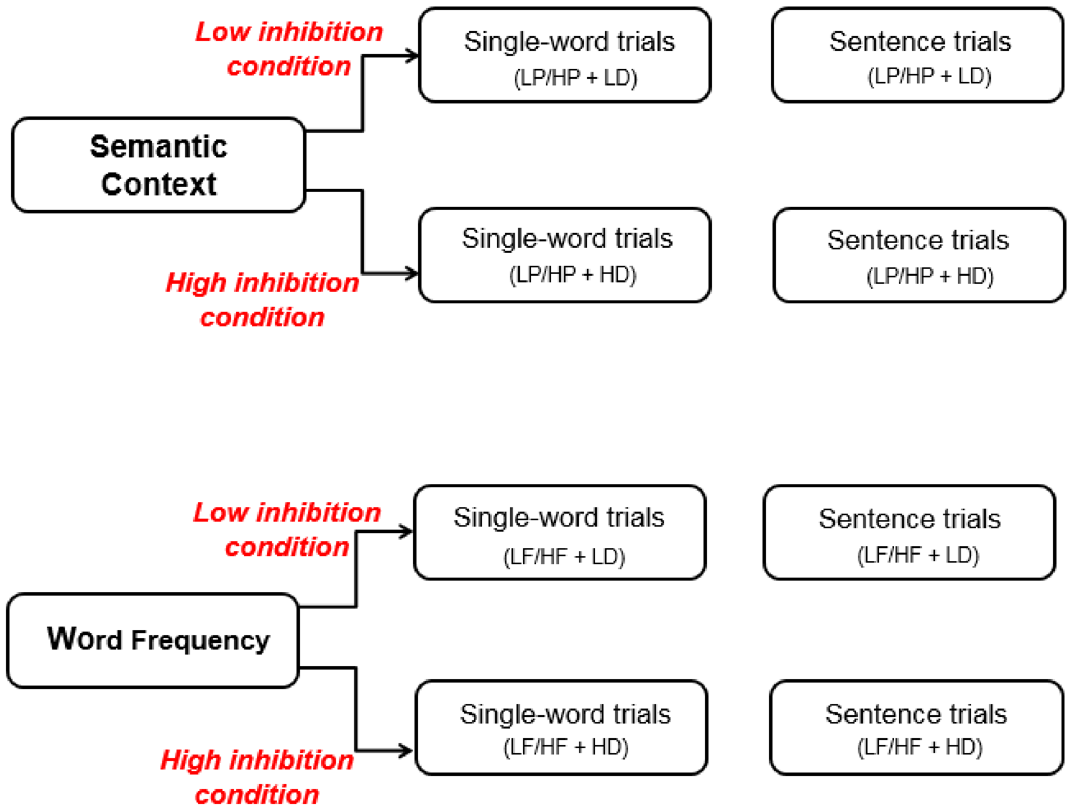


Figure 2. A schematic depiction of the components in the inhibition manipulation conditions. For each crystallized ability manipulation (semantic context, word frequency) there was a low and high inhibitory condition. Note LP = low predictability, HP = high predictability; LF = low frequency, HF = high frequency; LD = low density, HD = high density. Single-word trials and sentence trials were blocked separately, but presentation order was randomized.

CHAPTER 4: EXPERIMENT 1 – WORKING MEMORY

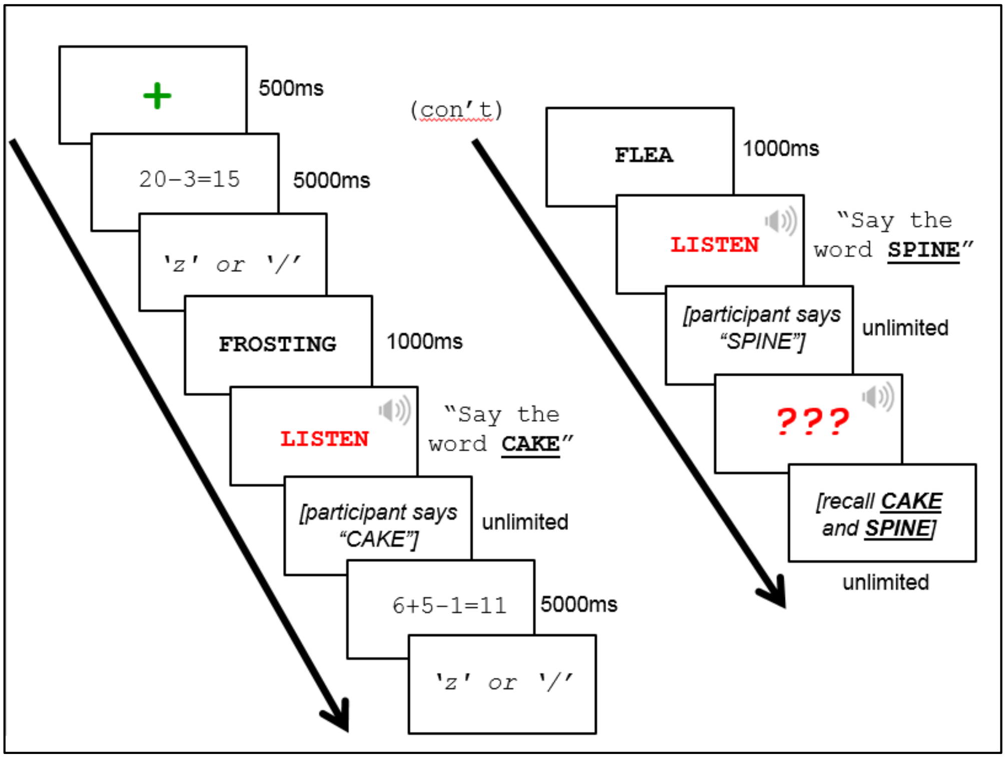
Methods

In Experiment 1, I examined the contributions and potential interaction of working memory (WM), semantic context and word frequency. Trials were blocked into high-WM load and low-WM load blocks. High-WM load trials placed additional cognitive demands on participants by intermixing regular speech identification trials with an O-Span (operation span) task (Turner & Engle, 1989). Within each block, there were separate sub-blocks of word frequency and semantic context manipulations. Recall that word frequency and semantic context were separately crossed with WM load, and not with each other. For frequency trials, the target word was either LF or HF. For semantic context trials, the target word was presented in either LP or HP context. Before beginning the experimental trials, participants were given three trials of high-WM load practice trials so that they could practice completing both the O-Span component and immediate speech identification concurrently.

High-WM load trials. The sequence of events that occurred for single-word and sentence trials during the high-WM load condition is depicted in Figures 3 and 4. In order to create a high-WM load for participants, speech identification trials were interleaved with O-Span sequences. Each sequence of a high-WM load trial began with a green central fixation cross presented for 500 ms. Following this cross, a math equation appeared on the screen (e.g., 20-3 = 15). Participants pressed the '/' key to indicate that the equation was correct and the 'z' key to indicate that it was incorrect. Participants were given 5000ms to make their response before the program automatically proceeded to the next screen. They were then auditorily presented with the speech stimulus, which they had to repeat the target (final) word out loud. For semantic single-word prime trials in the semantic context manipulation condition, the primes were presented orthographically on the screen prior to the target stimulus. Primes were presented in the center of the screen for 1000 ms before proceeding to the speech stimulus. Participants were informed that they would occasionally see a word presented onscreen before certain trials, and that it would be either related or unrelated to the word that they would have to repeat.

After a random number of equation-word pairings, a string of three red question marks and an auditory tone were presented, cueing the participants to recall the words that they had identified out loud in the preceding sequence. Serial order recall was encouraged, but not emphasized, as recall was not the primary dependent measure. Following recall, a new sequence began. Spans ranged from 2 to 7 items. Span sequences were randomized prior to the experiment, and then presented in a fixed order to all participants. Although trials were blocked by stimulus type, i.e. separate blocks of single-word stimuli and sentence stimuli; and by type of linguistic support, i.e., separate blocks of LF/HF trials and LP/HP trials, trials within each block were randomly intermixed.

Participants manually entered the correct responses for the math equations, and verbally provided their responses to the speech identification stimuli, which the experimenter entered on the keyboard. All target words were presented in noise (0 dB for young, +3 dB for old), while the remainder of the sentences/carrier phrases were presented in clear.



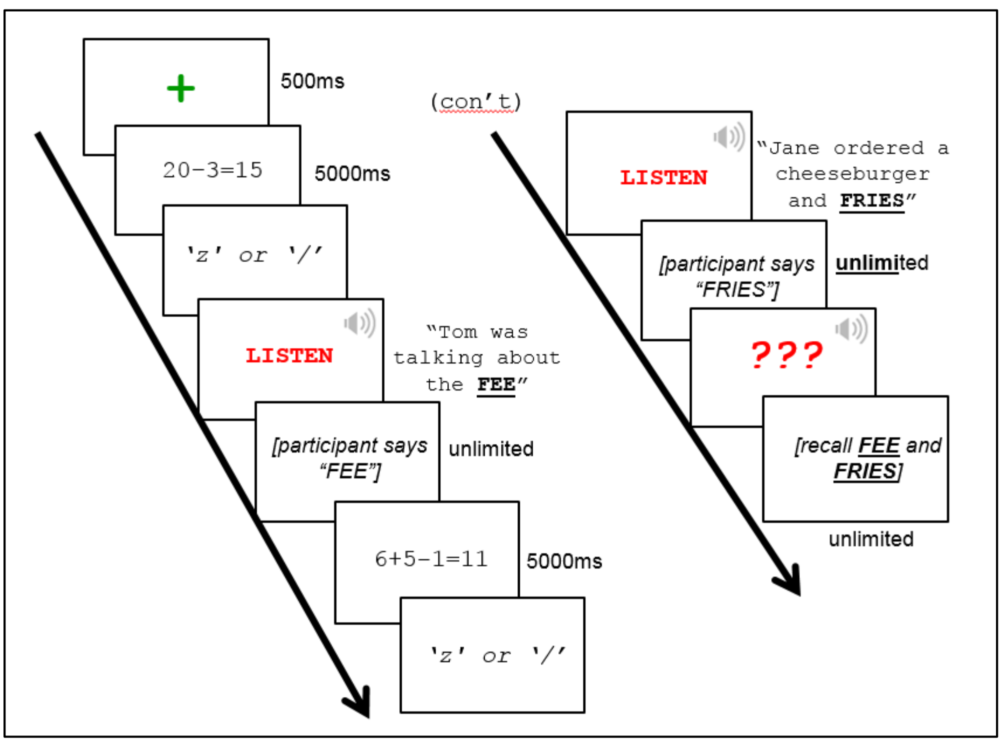


Figure 3. A schematic depiction of the typical trial for the single-word condition (top panel) and the sentence condition (bottom panel) in the high working memory (WM) load semantic context manipulation, shown with 2-span length. Note that low-predictability (LP) and high-predictability (HP) trials were pseudo-randomly intermixed and presented within each block.

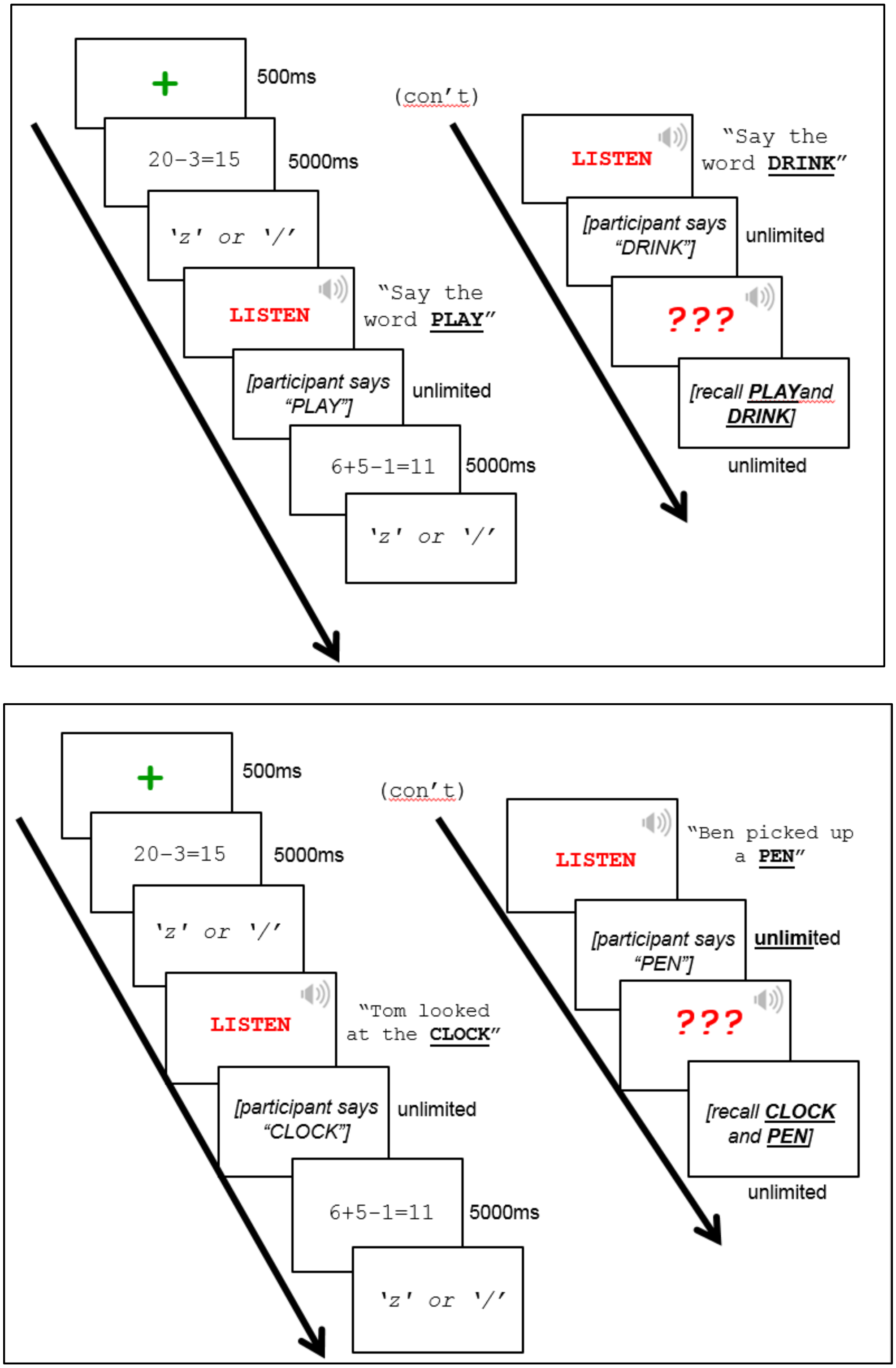


Figure 4. A schematic depiction of the typical trial for single-word (top panel) and sentences (bottom panel) in the high working memory (WM) word load frequency manipulation condition, shown with 2-span length. Note that low-frequency (LF) and high-frequency (HF) trials were pseudo-randomly intermixed and presented within each block.

Low-WM load trials. The sequence of events that occurred during the low-WM load condition is depicted in Figures 5 and 6. For low-WM load trials, there was no concurrent O-Span task in conjunction with identifying the speech stimuli. Participants were presented with speech stimulus trials and instructed to repeat the target word only.

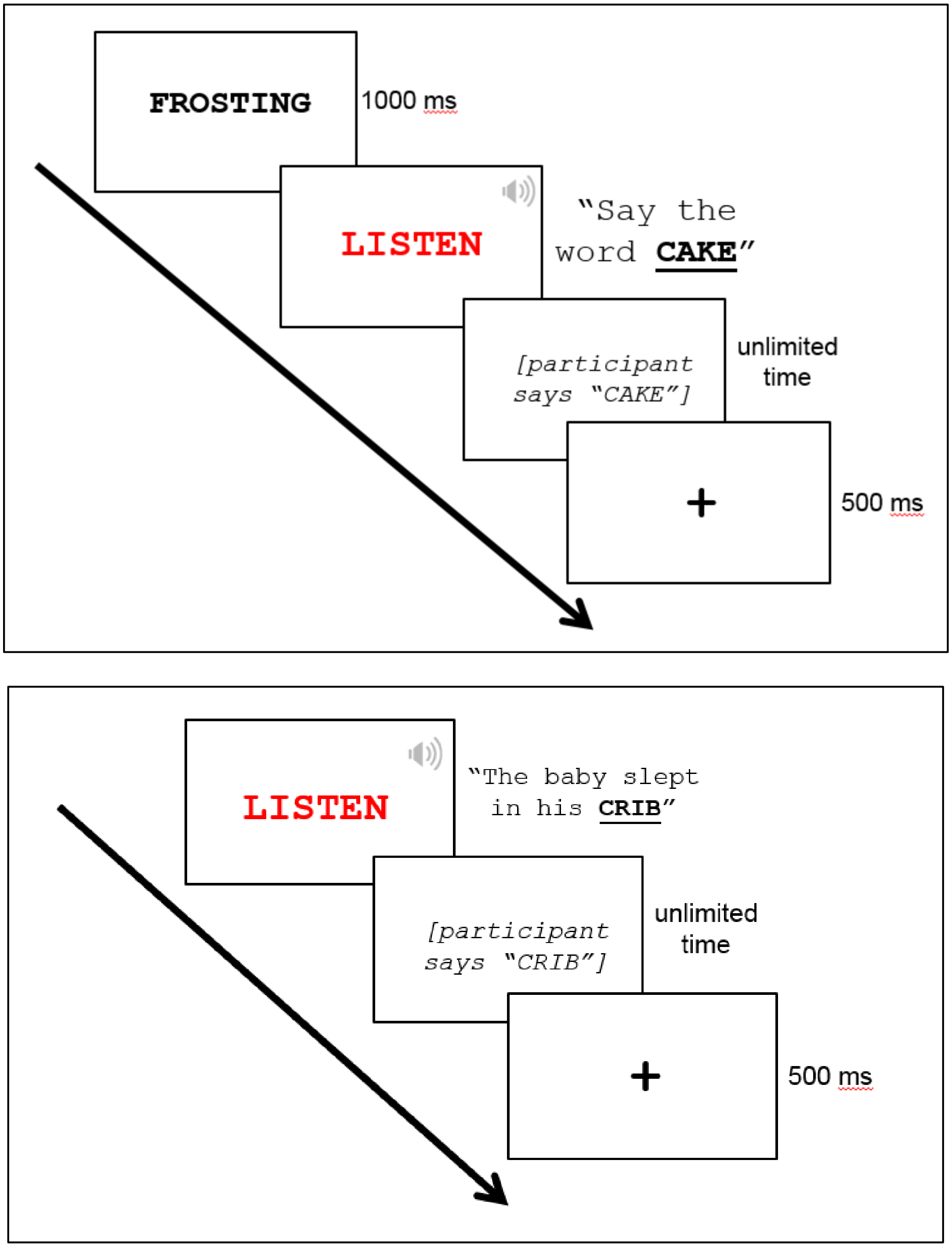


Figure 5. A schematic depiction of the typical trial for single-words (top panel) and sentences (bottom panel) in the low working memory (WM) load semantic context manipulation condition. Note that LP and HP stimuli were intermixed for each stimulus type block.

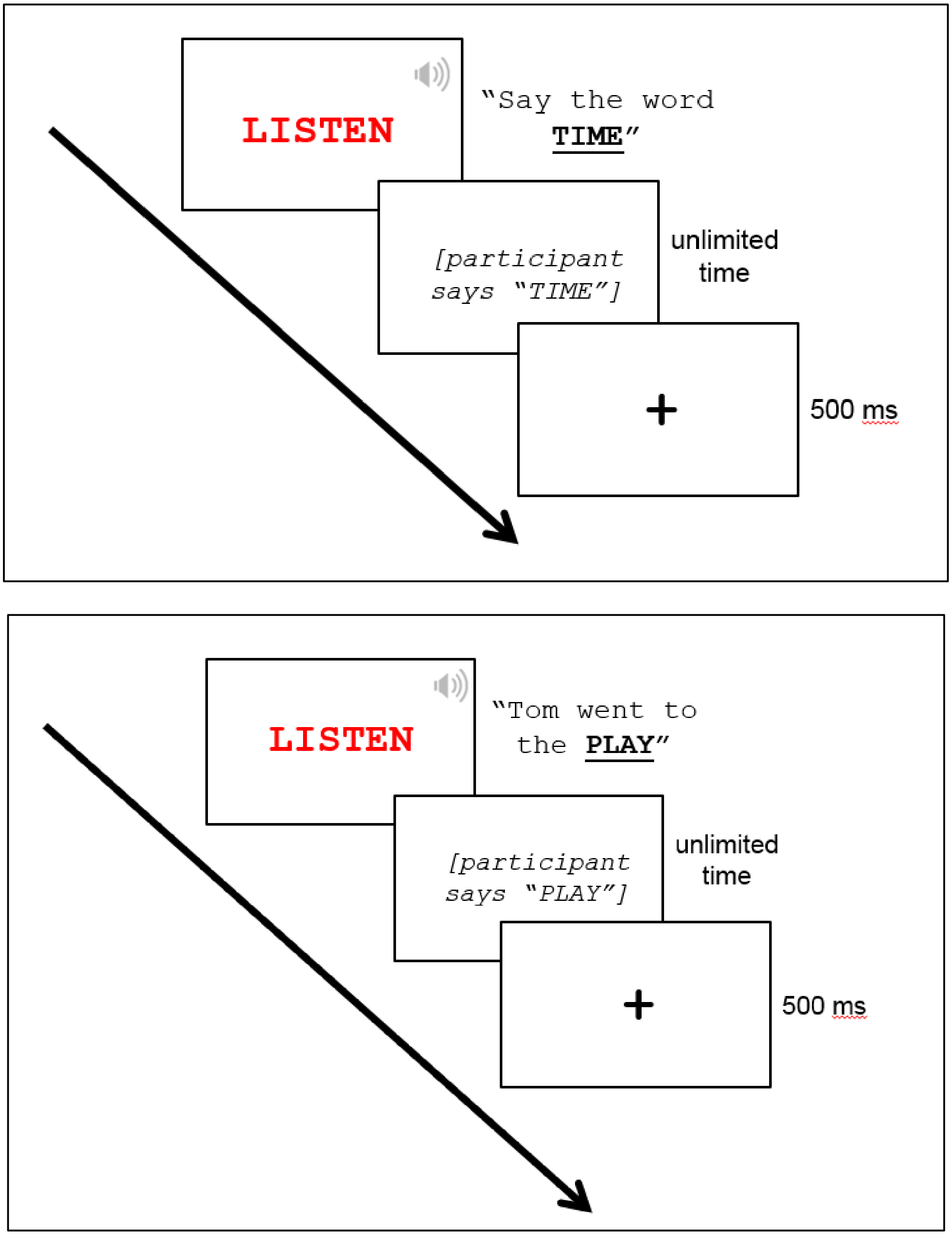


Figure 6. A schematic depiction of the typical trial for the single-words condition (top panel) and the sentences condition (bottom panel) in the low working memory (WM) load word frequency manipulation. Note that LF and HF stimuli were intermixed for each stimulus type block.

Results

Before proceeding to the identification results in Experiment 1, I first present the results of computing Pearson-moment correlations between PTA (pure-tone hearing thresholds), processing speed, Shipley vocabulary and accuracy across the conditions of WM Load-Semantic Context and WM Load-Frequency in Table 3. In computing scores for each of the two crystallized conditions, I collapsed identification scores across stimulus type (single-word, sentences) and word frequency and semantic context level (low, high) for each manipulation. The correlation matrix is presented in Table 3. As shown, the only significant correlation with speech identification performance was between Shipley vocabulary and WM Load-Frequency, $r(98) = .38$, $p = .016$, suggesting that higher vocabulary was associated with higher intelligibility of targets in the frequency condition. This significant correlation between vocabulary and frequency will be re-examined later in this chapter.

Table 3.
Correlations between Demographic Variables and Accuracy in Experiment 1

	1	2	3	4	5
1. Dot Task	—	.47**	.23	-.04	.08
2. PTA		—	-.24	-.27	-.18
3. Shipley			—	.18	.38*
4. WM Load – Semantic Context				—	.50**
5. WM Load – Frequency					—

WM = working memory.
p < .05, ***p* < .01.

The results of the WM load manipulations primarily focus on the interactions with semantic context and word frequency. Results of recall performance in the high-WM load conditions are presented at the end of this chapter[1].

Before proceeding to the identification accuracy results, it is important to point out that noise levels were selected to produce equivalent performance for both age groups at roughly 60%. Accordingly, there was no main effect of age for either the WM load manipulation experiments or the inhibition manipulation experiments, p's > .50. Therefore, all age differences which were observed in the following results are a function of the various within-subjects manipulations. Also present in both experiments were 1) main effects of semantic context, in which accuracy for HP items was greater than for LP items, p's < .001; and 2) main effects of word frequency, in which accuracy for HF items was higher than for LF items, p's < .001. Therefore, these comparisons will not be reported individually. All pairwise analyses were conducted with Bonferroni corrections for multiple comparisons.

Age, WM Load, Stimulus Type, and Semantic Context

Identification accuracy was entered into a 2 (Age: young, old) X 2 (Stimulus Type: single-word, sentence) X 2 (WM: low-load, high-load) X 2 (Semantic Context: low predictability, high predictability) mixed Analysis of Variance (ANOVA) in which Age was the between-subjects factor and Stimulus Type, WM Load, and Semantic Context were within-subjects factors. As expected, there was a main effect of WM load, $F(1, 98) = 27.04$, $p < .001$, partial $\eta^2 = .41$ – accuracy was higher when attention was full, i.e., no additional load from the concurrent O-Span task ($M = 63.22$, $SE = 1.30$) than when it was divided, i.e., concurrently

[1] Note that for the low WM load conditions, there was no word recall aspect.

performing the O-Span task (M = 54.04, SE = 1.43). There was also a significant main effect of stimulus, $F(1, 98) = 92.33$, $p < .001$, partial $\eta^2 = .70$, in which accuracy for sentence stimuli (M = 65.93, SE = 1.12) was higher than for single-word stimuli (M = 51.33, SE = 1.43).

There were a number of 2-way and 3-way interactions. First, there was a significant interaction of Age x Semantic Context as shown in Figure 7, $F(1, 98) = 14.12$, $p < .001$, partial $\eta^2 = .26$, in which older adults showed poorer performance than younger adults for the LP context condition, $p = .040$, but superior performance for the HP context condition, $p = .035$.

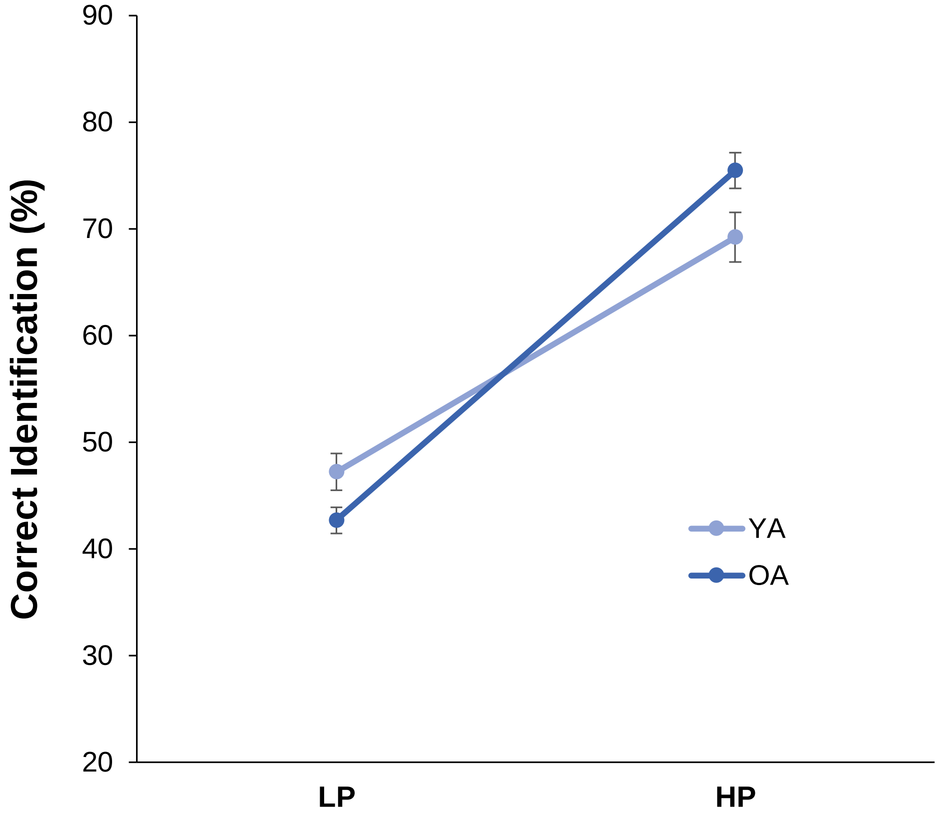


Figure 7. 2-way interaction showing mean percentage of targets correctly identified by young adults and older adults in the low-predictability (LP) and high-predictability (HP) context conditions collapsed across stimulus type and WM load conditions.
Note: YA = young adults, OA = older adults. Error bars represent standard errors of the mean.

There was also an interaction of Stimulus Type x Semantic Context, $F(1, 98) = 74.05$, $p < .001$, partial $\eta^2 = .65$, in which performance was equivalent for both single-word and sentence targets in the LP context condition, i.e., for targets with no preceding linguistic support (single-word: $M = 45.02$, $SE = 1.16$; sentences: $M = 44.85$, $SE = 1.51$), $p = .941$; but greater for sentences in the HP context condition with highly predictive semantic support, (single-word: $M = 57.64$, $SE = 2.15$; sentences: $M = 87.10$, $SE = 1.45$), $p < .001$. That is, target identification in context of sentences particularly benefitted from HP context.

I also observed an interaction of WM Load x Semantic Context, $F(1, 98) = 20.93$, $p < .001$, partial $\eta^2 = .35$, in which performance was significantly worse in high-WM load trials ($M = 36.31$, $SE = 1.53$) compared to low-WM load trials ($M = 53.57$, $SE = 1.75$) in the LP context condition, $p < .001$; but was equivalent in the HP context condition, (low load: $M = 72.88$, $SE = 1.93$; high load: $M = 71.76$, $SE = 1.85$), $p = .665$. Specifically, HP context eliminated the negative effects of high-WM load.

Importantly, there was a reliable interaction of Age x Stimulus Type x Semantic Context, $F(1, 98) = 6.43$, $p = .015$, partial $\eta^2 = .14$, which is shown in Figure 8. Follow-up comparisons revealed age differences only for sentence stimuli, in which older adults performed more poorly than younger adults in LP context conditions, $F(1, 98) = 4.74$, $p = .036$, partial $\eta^2 = .11$, whereas they performed significantly better than younger adults in HP context conditions, $F(1, 98) = 19.82$, $p < .001$, partial $\eta^2 = .34$. In contrast, there was no effect of semantic context on age differences for single-word stimuli, F's $< .60$, p's $> .44$.

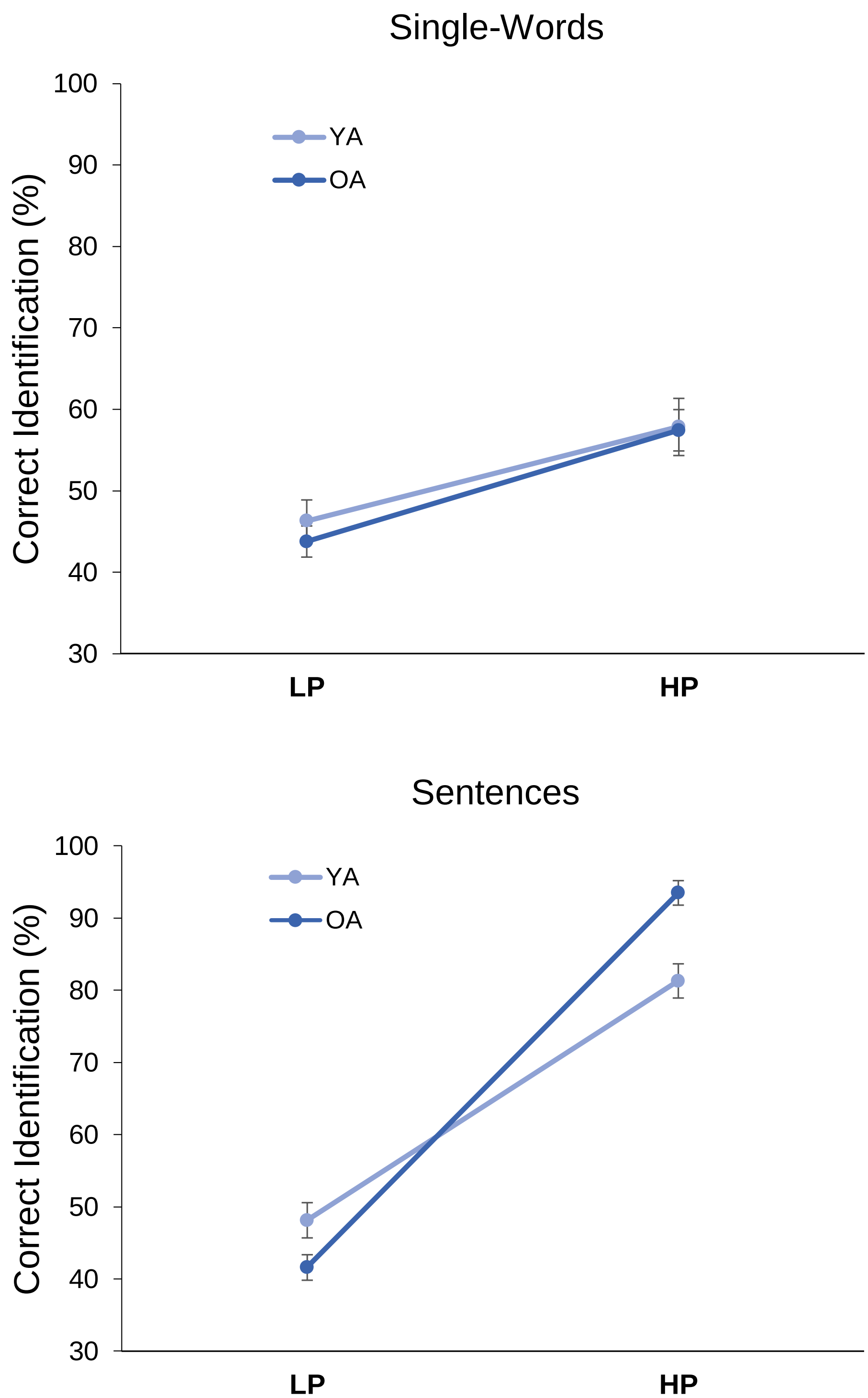


Figure 8. 3-way interaction showing mean percentage of targets correctly identified by young adults and older adults in the single-word condition (top panel) and sentence condition (bottom panel) as a function of semantic context and collapsed across low and high-WM load conditions. Note: YA = young adults, OA = older adults; LP = low predictability, HP = high predictability. Error bars represent standard errors of the mean.

Although there was no 4-way interaction of Age x WM Load x Stimulus Type x Semantic Context, planned pairwise comparisons showed that WM load moderated the 3-way interaction as shown in Figure 8. Figure 9 shows this higher-order interaction in separate panels as a function of low-WM load and high-WM load. The individual pairwise comparisons are reported below.

Single-words. There were no age differences in identification accuracy of single-word targets as a function of semantic context in the low-WM load condition, F's < .84, p's > .363. However, older adults did perform significantly worse than younger adults in the LP context (i.e. unrelated prime), high-WM load condition, $F(1, 98) = 6.27$, $p = .017$, partial $\eta^2 = .14$. This age difference subsequently disappeared with the addition of HP context in the high load condition, $F(1, 98) = .24$, $p = .626$, partial $\eta^2 = .006$.

Sentences. There was no age difference in performance in the LP context, low WM condition, $F(1, 98) = .50$, $p = .433$, partial $\eta^2 = .013$. However, older adults showed a significant advantage over younger adult for HP targets, $F(1, 98) = 15.58$, $p < .001$, partial $\eta^2 = .285$. Performance in the high WM condition showed a crossover interaction, in which older adults were disproportionately negatively affected by high WM demands in the LP context condition compared to younger adults, $F(1, 98) = 4.16$, $p = .048$, partial $\eta^2 = .09$, but showed superior performance in the HP context condition, $F(1, 98) = 14.46$, $p < .001$, partial $\eta^2 = .27$.

That is, the LP context condition in the high-WM load condition appeared to be most detrimental to older adults' performance, while HP context – regardless of WM load – appeared to be the most beneficial.

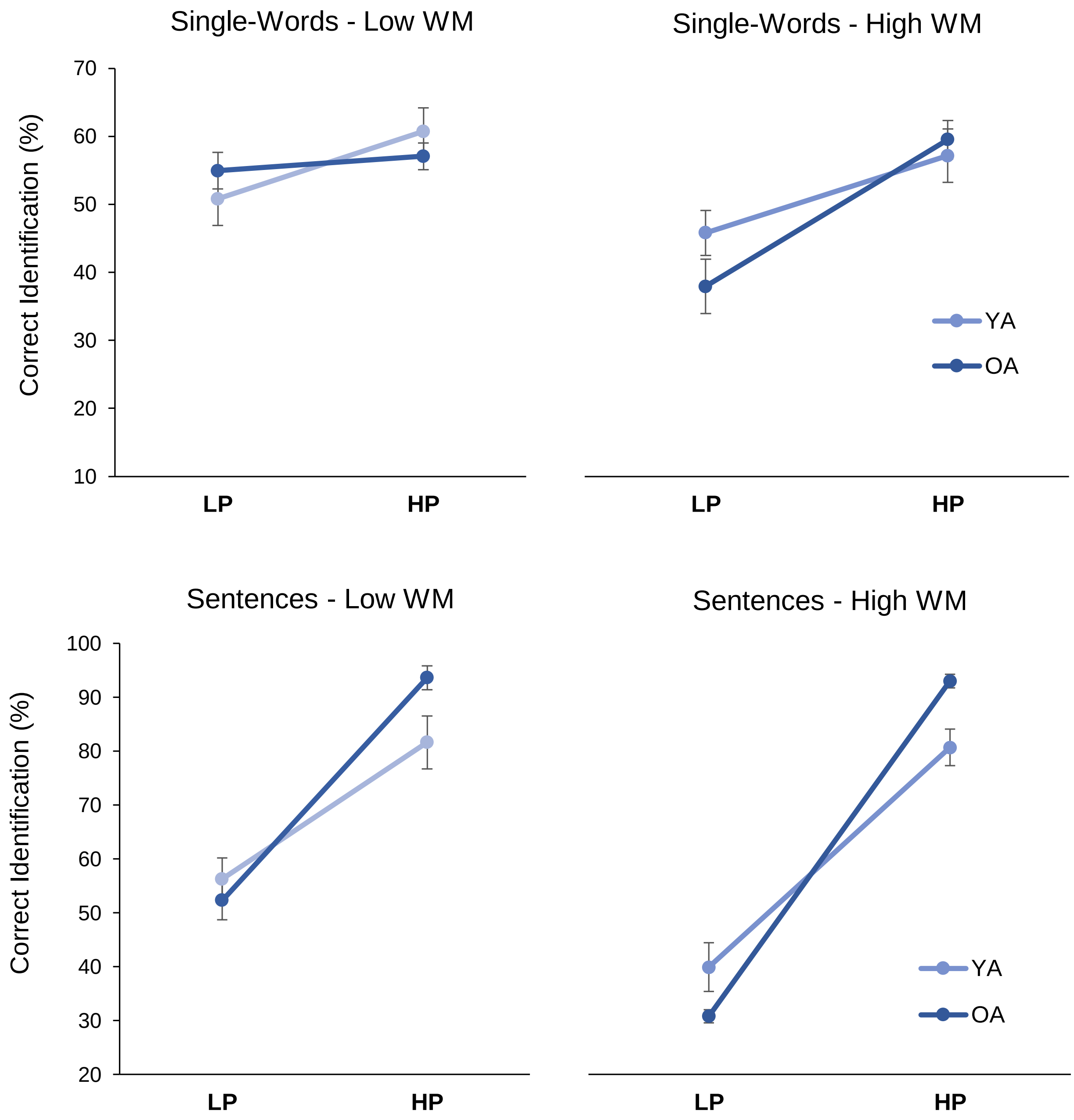


Figure 9. The 3-way interaction of Age x Stimulus Type x Semantic Context shown separately as a function of WM load for single-word trials (top panels) and sentence trials (bottom panels). Note: YA = young adults, OA = older adults; LP = low predictability, HP = high predictability; Low WM = low working memory load, High WM = high working memory load. Error bars represent standard errors of the mean.

Figure 10 replots the results from Figure 9, but directs depicts the compensatory effects of LP vs. HP context across WM load for each age group separately as a function of stimulus type. All pairwise comparisons are listed in Appendix D.

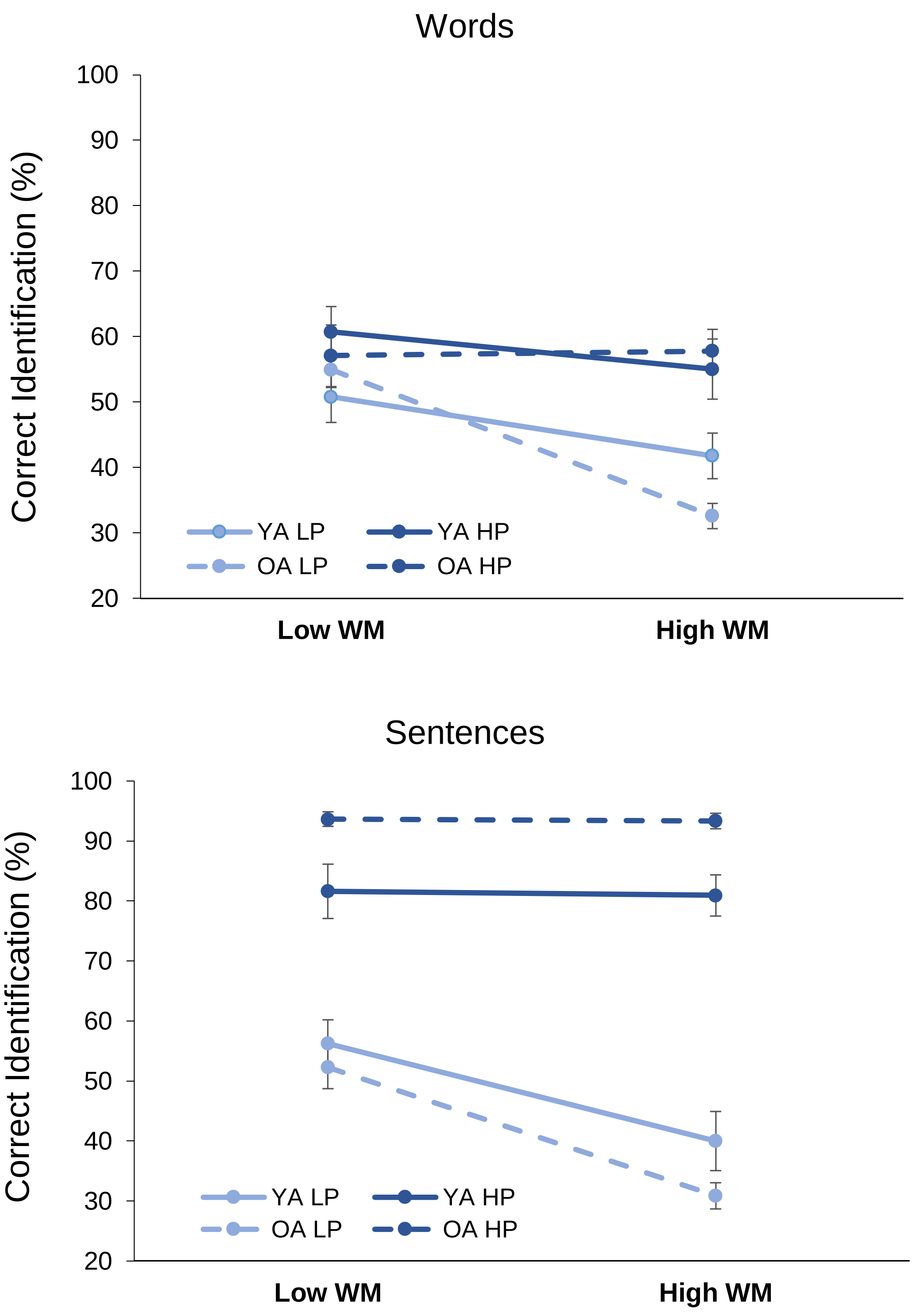


Figure 10. Mean percentage of targets correctly identified by young adults and older adults in single-word stimuli (top panel) and sentence stimuli (bottom panel) as a function of WM Load and Semantic Context.
Note: YA = young adults, OA = older adults; LP = low predictability, HP = high predictability; Low WM = low working memory load, High WM = high working memory load. Error bars represent standard errors of the mean.

Age, Stimulus Type, WM Load, and Word Frequency

The identification accuracy measure was entered into a 2 (Age: young, old) X 2 (Stimulus Type: single-word, sentence) X 2 (WM: low-load, high-load) X 2 (Word Frequency: low-frequency, high-frequency) mixed ANOVA in which Age was the between-subjects factor and Stimulus Type, WM Load, and Word Frequency were within-subjects factors. Again, there was an expected main effect of WM load, $F(1, 98) = 54.47$, $p < .001$, partial $\eta^2 = .58$ in which accuracy was higher for the low load condition ($M = 53.60$, $SE = 1.83$) compared to the high load condition ($M = 39.78$, $SE = 1.68$). There was also a main effect of stimulus type, $F(1, 98) = 7.05$, $p = .011$, partial $\eta^2 = .15$; in which accuracy was higher for sentence stimuli ($M = 49.27$, $SE = 1.85$) than for single-word stimuli ($M = 44.11$, $SE = 1.71$). Finally, there was an expected main effect of word frequency, $F(1, 98) = 61.18$, $p < .001$, partial $\eta^2 = .61$, in which accuracy was significantly higher for HF targets ($M = 54.03$, $SE = 1.24$) compared to LF targets ($M = 39.35$, $SE = 2.16$).

In addition to these main effects, there were a number of reliable interactions. First, there was a significant interaction of Age x Frequency, $F(1, 98) = 5.03$, $p = .031$, partial $\eta^2 = .11$, in which older adults showed superior identification of LF targets compared to younger adults ($M_{older} = 43.38$, $SE_{older} = 2.54$; $M_{younger} = 35.32$, $SE_{younger} = 3.51$), $p = .035$, but equivalent identification performance for HF targets ($M_{older} = 53.85$, $SE_{older} = 1.45$; $M_{younger} = 35.32$, $SE_{younger} = 3.50$), $p = .884$. That is, the word frequency effect was numerically smaller for older adults (diff $M = 10.46$, $SE = 2.19$) than it was for younger adults (diff $M = 18.89$, $SE = 3.05$).

There was also a significant interaction of Stimulus Type x WM Load, $F(1, 98) = 5.86$, $p = .02$, partial $\eta^2 = .13$, in which there was no difference in identification of single-word and sentence targets in the LF condition (single-word: $M = 38.49$, $SE = 2.28$; sentence: $M = 40.28$, *SE* = 3.01), *p* = .602, but better identification of HF sentence targets compared to HF single-word targets (single-word: *M* = 49.74, *SE* = 1.96; sentence: *M* = 58.32, *SE* = 1.57), *p* = .002.

Additionally, there was an interaction of WM Load x Frequency, $F(1, 98) = 5.86$, $p = .02$, partial $\eta^2 = .13$, in which there was a smaller word frequency effect (diff *M* = 11.98, *SE* = 2.35) in the low-WM load condition, $p < .001$, compared to the high-WM load condition (diff *M* = 17.37, *SE* = 2.34), $p < .001$.

Finally, there was an interaction between Stimulus Type x WM Load x Frequency, which is shown in Figure 11, $F(1,98) = 9.76$, $p = .003$, partial $\eta^2 = .20$. Follow-up comparisons revealed significant effects of word frequency on identification of single-word targets in the low- and high-WM load conditions, *F*'s > 10.70, *p*'s < .01. These differences were also present for sentence targets, but there was a significantly larger effect of word frequency in the high-WM load condition, $F(1,98) = 52.74$, $p < .001$, partial $\eta^2 = .57$, compared to the low-WM load condition, $F(1,98) = 7.92$, $p = .008$, partial $\eta^2 = .17$.

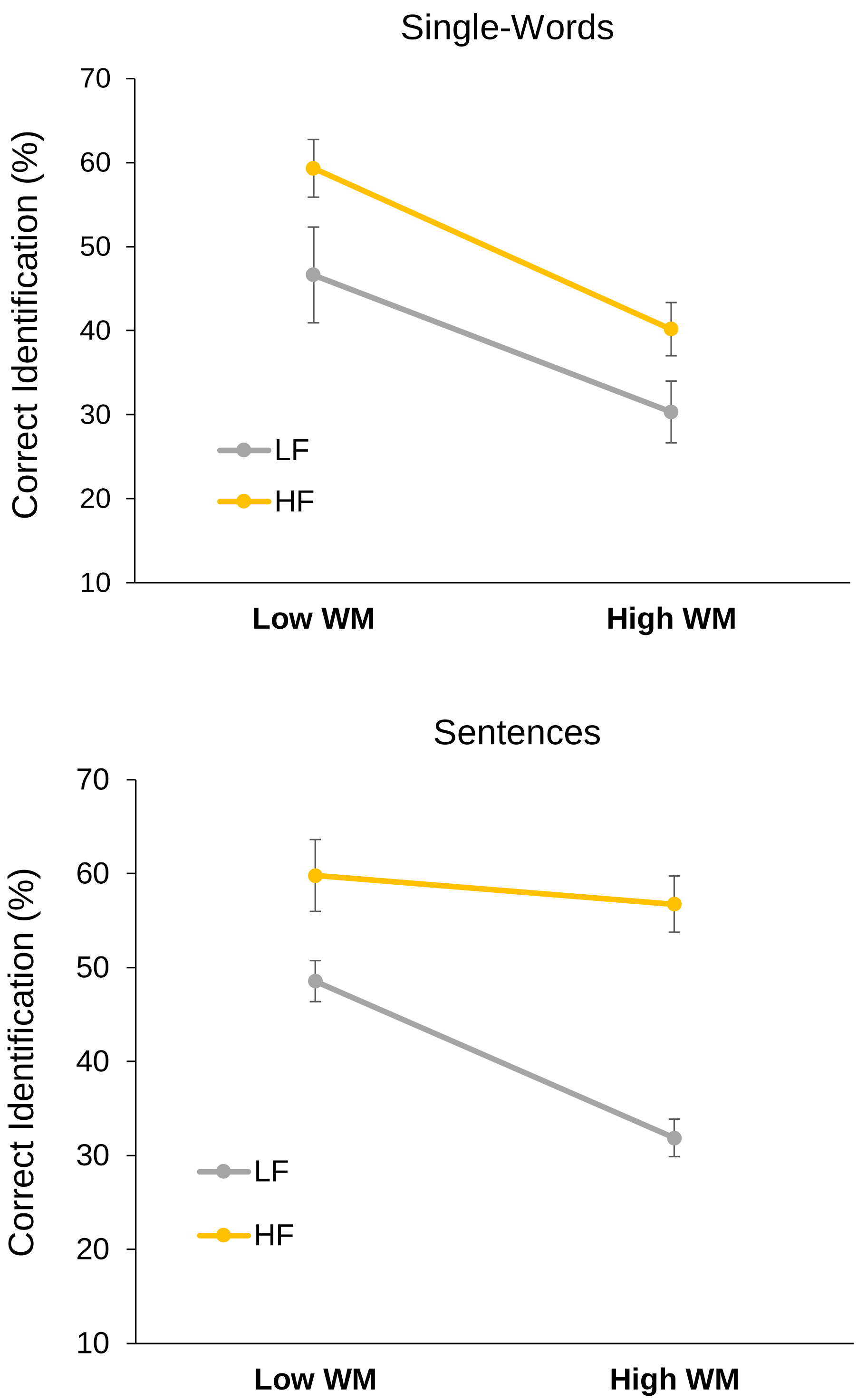


Figure 11. 3-way interaction showing mean percentage of targets correctly identified in the single-word condition (top panel) and the sentence condition (bottom panel) as a function of word frequency and working memory (WM) load.
Note: LF = low frequency, HF = high frequency. Error bars represent standard errors of the mean.

Similar to the interaction of WM Load x Semantic Context, an omnibus ANOVA did not reveal a significant 4-way interaction of Age x Stimulus x WM Load x Word Frequency, $F(1, 98) = .59$, $p = .44$, partial $\eta^2 = .02$. However, planned pairwise comparisons revealed significant differences with age as a moderating factor. Thus, the 3-way interaction from Figure 11 is replotted in Figure 12 separately for each age group, demonstrating how age modulates the interaction between WM Load, Stimulus Type, and Frequency. The pairwise comparisons are reported below.

Single-words. For younger adults, there were significant frequency effects under both low- and high-WM load conditions, F's > 8.43, p's < .006. However, older adults did not show significant effects of frequency in either the low- or high-WM load conditions, F's < 3.12, p's > .085.

Sentences. Similarly to the pattern of results for single-words, younger adults showed reliable effects of word frequency in both low- and high-WM load conditions, F's > 4.19, p's < .047. While older adults showed significant effects of frequency in the high-WM load condition, $F(1, 98) = 25.29$, $p < .001$, partial $\eta^2 = .39$, the difference in identifying LF vs. HF targets in the low-WM load condition was only marginally significant, $F(1, 98) = .3.88$, $p = .056$, partial $\eta^2 = .09$.

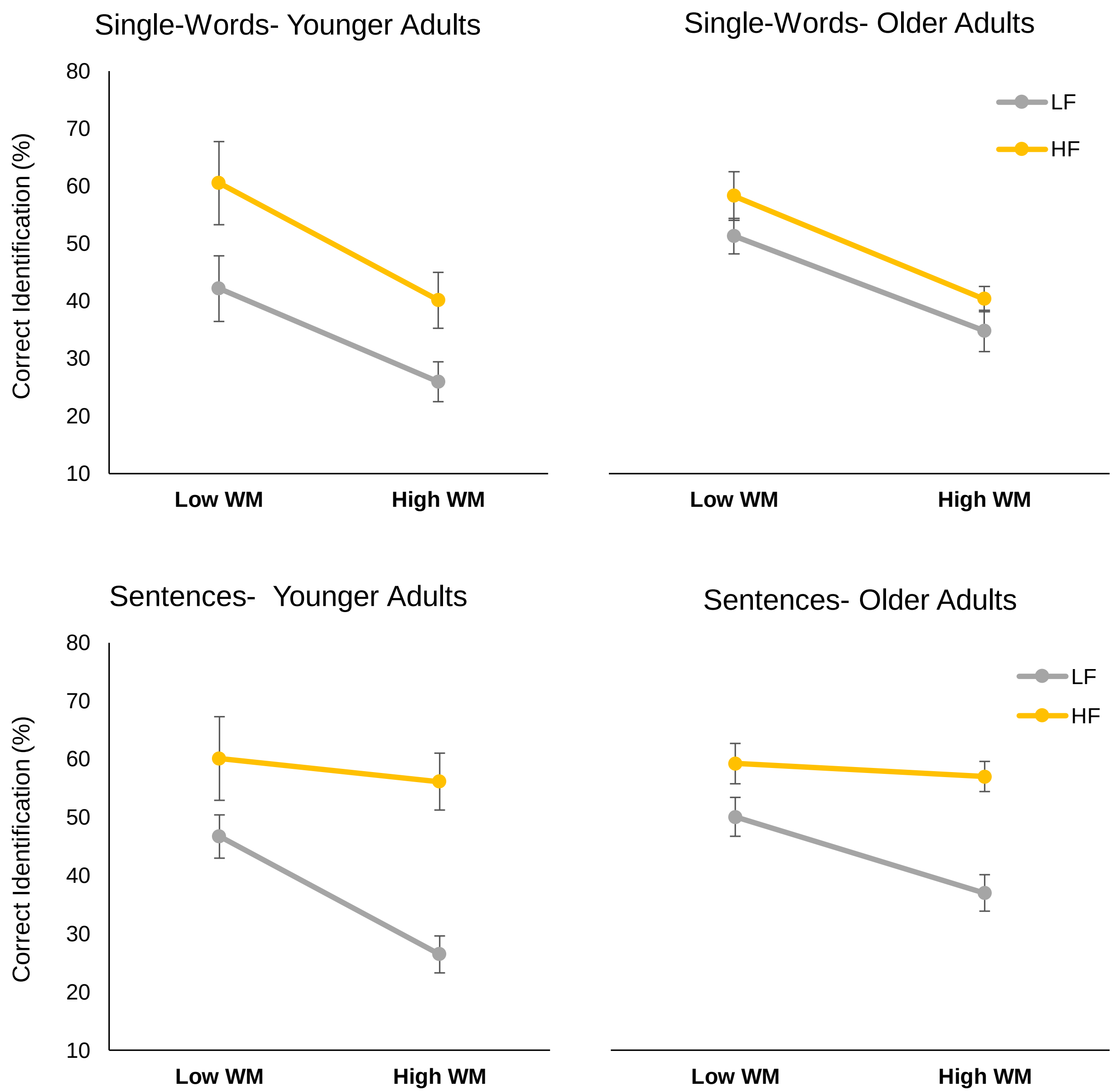


Figure 12. The 3-way interaction of Stimulus Type x WM Load x Frequency shown separately as a function of age for single-word targets (top panels) and sentence targets (bottom panels). Note: YA = young adults, OA = older adults; LF = low frequency, HF = high frequency; Low WM = low working memory load, High WM = high working memory load. Error bars represent standard errors of the mean.

Figure 13 displays a similar pattern of data, but directs depicts the compensatory effects of LF vs. HF targets across WM load for each age group separately as a function of stimulus type. In addition to the comparisons described previously, this figure also more clearly depicts an older adult advantage for LF targets in the high-WM load conditions for both single-word and sentence stimuli, *p*'s < .05. All other pairwise comparisons are listed in Appendix E.

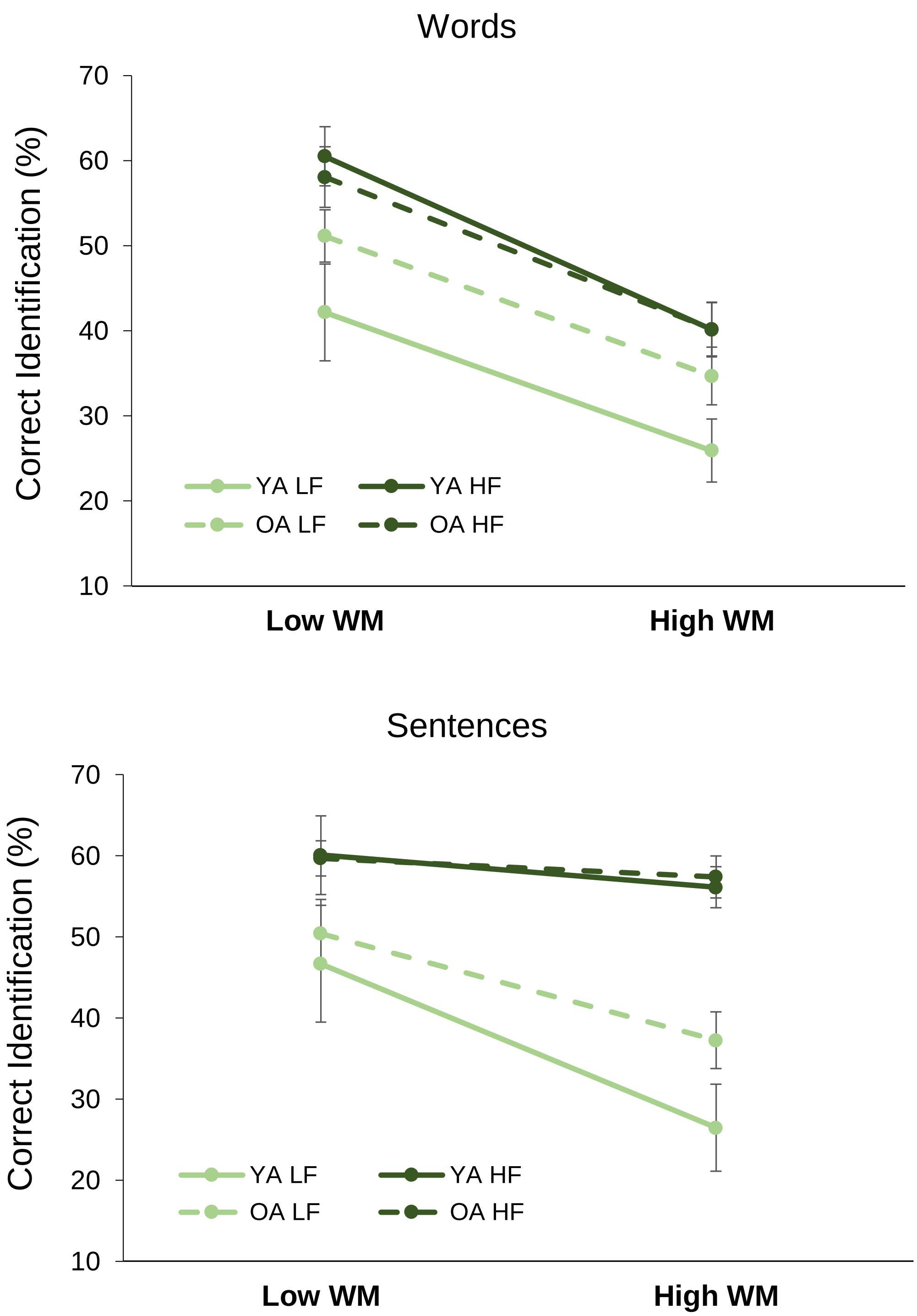


Figure 13. Mean percentage of targets correctly identified by young adults and older adults in single-word stimuli (top panel) and sentence stimuli (bottom panel) as a function of WM Load and Word Frequency.
Note: YA = young adults, OA = older adults; LF = low frequency, HF = high frequency; Low WM = low working memory load, High WM = high working memory load. Error bars represent standard errors of the mean.

Given the apparent older adult advantage for LF targets and its potential relationship with enhanced vocabulary knowledge based on prior research (e.g., Verhaeghen, 2003), I computed Pearson correlations between Shipley vocabulary scores with accuracy for LF targets collapsed across WM load conditions. The correlation was significant, $r(98) = .32$, $p = .037$, demonstrating that higher vocabulary scores were positively correlated with identification accuracy for LF targets in noise. Interestingly, when I examined this correlation separately for each age group, older adults showed stronger correlations between vocabulary scores and LF identification (r = .36) compared to younger adults (r = .03), although neither correlation was significant, p's > .14.

I then reanalyzed the data and entered Shipley scores as a covariate into an ANCOVA. The results are presented in Figure 14. While controlling for vocabulary reduced the overall strength of the omnibus ANOVA, $F(1, 98) = .11$, $p = .74$, partial $\eta^2 = .03$, the reliable Age x Frequency interaction was also eliminated, $F(1, 98) = 2.64$, $p = .111$, partial $\eta^2 = .06$. Further pairwise comparisons revealed that the previous advantage of older adults for LF targets in the high-WM load condition was eliminated for both single-word stimuli, $F(1, 98) = .98$, $p = .328$, partial $\eta^2 = .02$, and for sentence stimuli, $F(1, 98) = 1.74$, $p = .195$, partial $\eta^2 = .04$. That is, the word frequency effect became statistically equivalent across both age groups. Such results suggest that the compensatory effects of word frequency are entirely driven by superior vocabulary knowledge in older adults. Controlling for Shipley scores did not significantly affect any of the other interactions reported above.

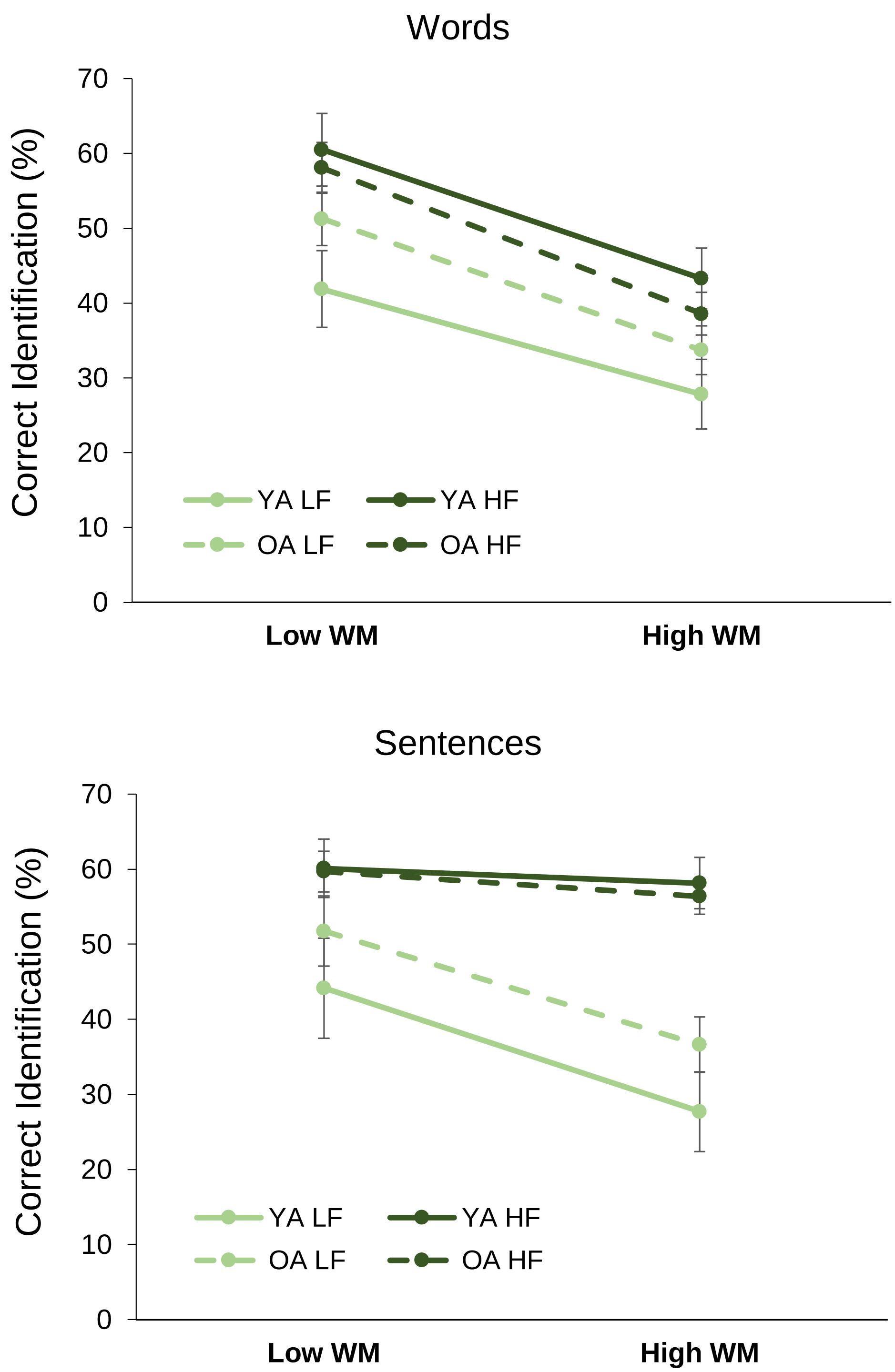


Figure 14. Mean percentage of targets correctly identified by young adults and older adults in single-word stimuli (top panel) and sentence stimuli (bottom panel) as a function of WM Load and Word Frequency, controlling for Shipley vocabulary scores.
Note: YA = young adults, OA = older adults; LF = low frequency, HF = high frequency; Low WM = low working memory load, High WM = high working memory load. Error bars represent standard errors of the mean.

Word Recall

Although identification was the primary dependent measure of analysis, I also analyzed the pattern of word recall to determine if recall was differentially affected by age or task demands. These analyses were conducted with the word recall responses of participants in the high-WM load condition, in which the O-Span task was completed alongside the identification task. Because recall was not the major focus of analyses, I will examine the data only as a function of a) Crystallized variable condition, i.e., semantic context and word frequency, b) Stimulus Type, and c) number of items in the span. It is also important to note that the results reported here are according to the criteria that responses are considered correct if they match the actual stimulus target, and not the participants' (potentially incorrect) responses during immediate identification. I analyzed the data using both criteria, and analysis of recall responses using participants' immediate responses produced roughly the same pattern of results as using the stimulus target as the correct response, although performance was reliably higher for both age groups when using immediate responses as the criterion for correct recall, $p = .026$. However, as there are potential complications of immediate generation differentially impacting later recall (e.g., Nairne, Riegler, & Serra, 1991; Burns, Curti, & Lavin, 1993); I therefore report the latter analyses of using the target as the basis for correct recall here.

First, accuracy in the math equations as a function of age and span length was examined to determine whether participants were sufficiently attending to the secondary task. Recall that O-Span sequences ranged between 2 to 7 items. There was no significant main effect of Age, $F(1,98) = .19$, $p = .723$, partial $\eta^2 = .003$; nor of Span Length, $F(5,93) = 1.9$, $p = .098$ partial $\eta^2 = .04$. There was also no interaction of Age x Span Length, $F(5,93) = 1.12$, $p = .368$, partial $\eta^2 =$

.14, indicating that both age groups were equally accurate in solving the equations across the span lengths. Table 4 shows mean accuracy across spans.

Table 4.
Mean Accuracy (%) for Correctly Solved Math Equations across Span Lengths

Span Length (#)	Younger Adults	Older Adults
2	89.88 (3.08)	92.59 (2.22)
3	92.85 (3.33)	91.05 (2.40)
4	91.99 (1.63)	90.23 (1.17)
5	93.57 (1.69)	94.69 (1.22)
6	91.07 (2.41)	95.98 (1.75)
7	90.13 (1.19)	88.62 (0.85)

Note. Values in parentheses indicate standard error of the mean.

I further analyzed recall as a function of age and span length. Results showed an expected main effect of Age, $F(1,98) = 4.86$, $p = .03$, partial $\eta^2 = .11$, in which younger adults showed superior recall of items overall. There was also a main effect of Span Length, $F(5,93) = 25.15$, $p < .001$, partial $\eta^2 = .78$, as shown in Table 5, showing poorer recall with longer span lengths. Finally, there was a significant interaction between Age x Span Length, $F(1,98) = 3.81$, $p = .007$, partial $\eta^2 = .78$, as depicted in Figure 15. Pairwise comparisons revealed that older and younger adults showed comparable item recall in the 2-, 3-, and 4-span (F's < 2.03, p's > .162), but that younger adults recalled significantly more items than did older adults in the 5-, 6- and 7-span lengths, F's < 4.01, p's < .025.

Finally, I examined whether *accuracy* for immediate identification of targets differed as a function of span length. While there was no overall effect of Age, $F(1,98) = .68$, $p = .419$, partial $\eta^2 = .017$, there was a significant main effect of Span Length, $F(1,98) = 16.65$, $p < .001$, partial $\eta^2 = .70$. Results of the follow-up pairwise comparisons are shown in Table 6 and 7, demonstrating a general trend of poorer accuracy when identifying words in a long span sequence. There was no significant interaction of Age x Span Length, $F(5,93) = 1.72$, $p = .156$, partial $\eta^2 = .19$; indicating that the effect of span length on identification accuracy did not differ as a function of age.

Table 5.
Mean Recall (%) of Items as a Function of Span Length

Span Length (#)	Recall (%)
2	60.59 (3.07)
3	42.65 (2.05)
4	41.01 (2.34)
5	36.07 (2.00)
6	32.27 (2.60)
7	32.05 (1.89)

Note. Values shown in parentheses represent standard error of the mean.

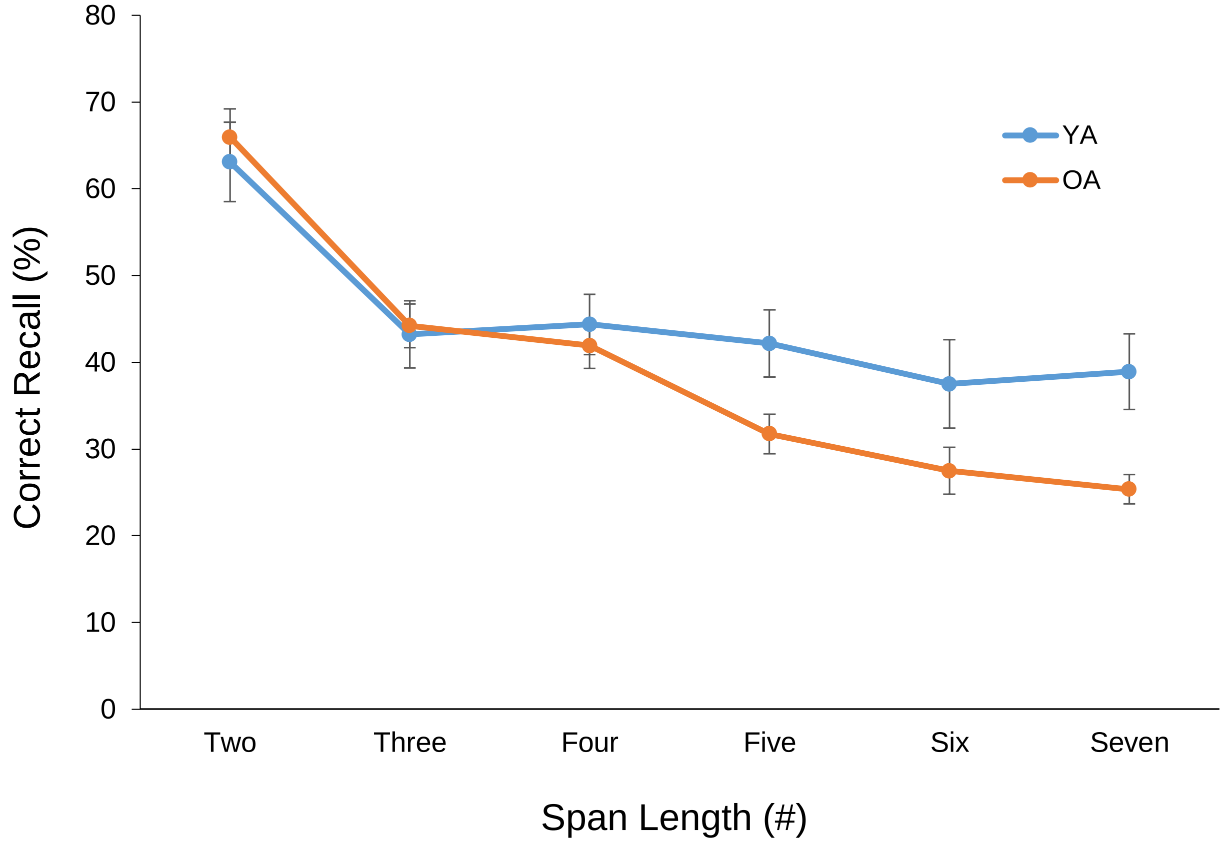


Figure 15. Mean percentage of correct item recall by young adults and older adults as a function of span length in items.

Note: YA = young adults, OA = older adults. Error bars represent standard errors of the mean.

Table 6.
Mean Accuracy for Target Identification as a Function of Span Length

Span Length (#)	Identification Accuracy (%)
2	55.41 (2.27)
3	47.51 (2.14)
4	45.89 (1.17)
5	43.83 (1.62)
6	37.41 (2.56)
7	33.27 (2.62)

Note. Values shown in parentheses represent standard error of the mean.

Table 7.
Mean Difference in Identification Accuracy as a Function of Span Length

Span Comparisons		Mean Difference
2 vs.	3	7.89 (2.85)
	4	9.52 (2.04)***
	5	11.57 (1.78)***
	6	18.00 (2.13)***
	7	22.13 (3.56)***
3 vs.	4	1.62 (2.49)
	5	3.68 (2.47)
	6	10.10 (2.86)**
	7	14.21 (3.14)***
4 vs.	5	2.05 (1.36)
	6	8.48 (2.41)*
	7	12.61 (3.35)**
5 vs.	6	6.42 (2.23)
	7	10.56 (2.90)*
6 vs.	7	4.13 (3.22)

Note. Values shown in parentheses represent standard error of the mean.
$^{*}p < .05$, $^{**}p < .01$, $^{***}p < .001$.

Interim Summary

In summary, the results of Experiment 1 show that high linguistic support, in the form of predictable semantic context and high word frequency, is able to maintain performance levels across increasing cognitive task demands. Specifically, it is clear that this high linguistic support is differentially beneficial to older adults compared to younger adults, and particularly in the high-WM load condition. For the semantic context manipulation, older adults performed expectedly equivalent to (and even poorer than) younger adults with LP context, but their performance far exceeded that of younger adults for HP context trials. Such a pattern of data is consistent with the compensatory effects of linguistic knowledge in older adults that is able to mitigate the negative effects of high cognitive load on task performance. Moreover, results of word recall performance suggested that older adults may be maintaining this high level of performance at the expense of poorer recall at the highest span lengths. Older adults also showed a benefit in identifying LF target words, which follow-up analyses demonstrated were due to their enhanced vocabulary knowledge.

Collectively, these results show promising evidence for cognitive-linguistic compensation in speech perception, and which will be discussed in further detail in Chapter 6.

CHAPTER 5: EXPERIMENT 2 – INHIBITION

Methods

Experiment 2 examined the contributions and potential interaction of inhibitory function, semantic context, and word frequency. Similar to Experiment 1, trials were blocked into high inhibitory demand trials and low inhibitory demand trials. High inhibition trials were those that alternated between trials of low density (LD) and high density (HD) targets, while low inhibition trials were those in which the key word were all low density (LD). Participants were given 5 practice trials of speech identification trials using words not used during the experimental trials. The experimental sequence for high and low inhibitory trials was identical, except for the target items; thus the schematic depictions of the trial sequences depicted in Figures 16 and 17 only show the difference between the semantic context manipulation and the word frequency manipulation.

High inhibition trials. Participants were presented with speech stimuli and instructed to repeat the target word. In the semantic context manipulation, key words varied in predictability of semantic context (LP, HP) and were all HD items. In the word frequency manipulation, key words varied in word frequency (LF, HF) and were all HD items.

Low inhibition trials. Similar to the high inhibition trials, participants were presented with speech stimuli and instructed to repeat the target word. In the semantic context manipulation, key words varied in predictability of semantic context (LP, HP) and were all LD items. In the word frequency manipulation, key words varied in predictability of word frequency (LF, HF) and were all LD items.

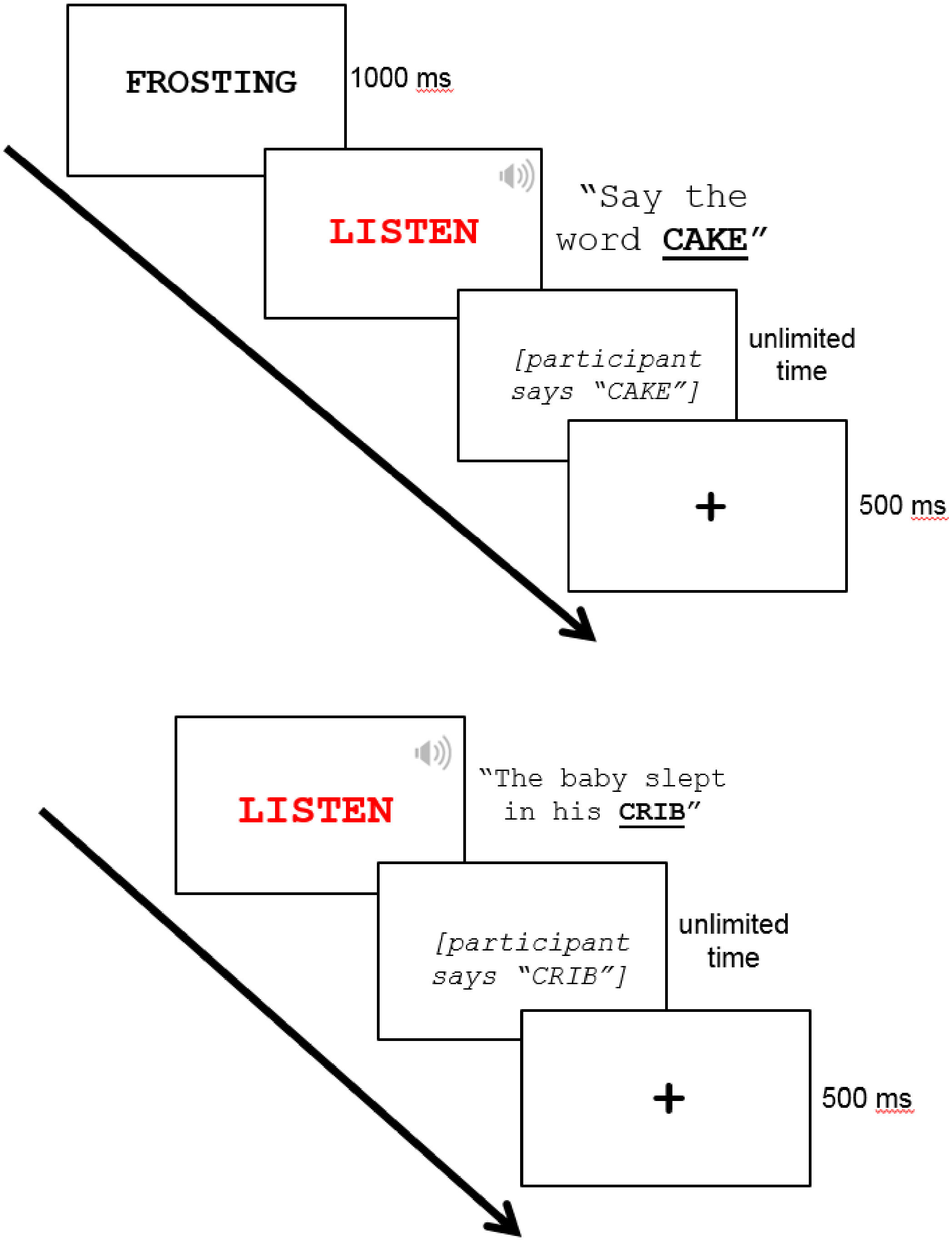


Figure 16. A schematic depiction of the typical trial for single-words (top panel) and sentences (bottom panel) in the inhibition semantic context manipulation condition. Given that inhibitory demand was manipulated as a function of the lexical density of the target word, the procedures in this figure is essentially identical for the low and high inhibitory demand conditions.

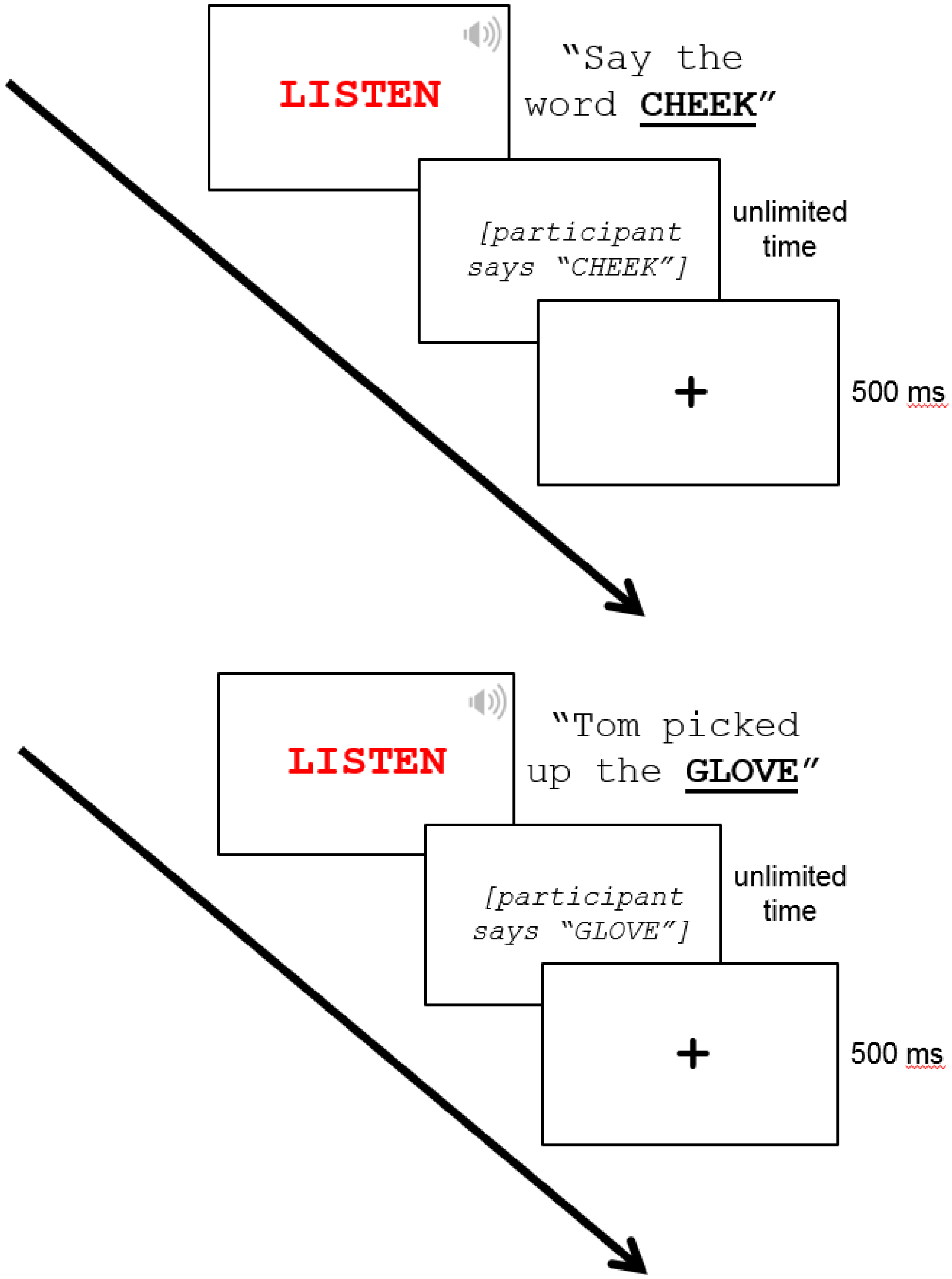


Figure 17. A schematic depiction of the typical trial for single-words (top panel) and sentences (bottom panel) in the inhibition word frequency manipulation condition. Given that inhibitory demand was manipulated as a function of the lexical density of the target word, the procedures in this figure is essentially identical for the low and high inhibition conditions.

Results

Before proceeding to the identification results in Experiment 2, I first present the results of computing Pearson-moment correlations between PTA, processing speed, Shipley vocabulary and accuracy across the conditions of Inhibition-Semantic Context and Inhibition-Word Frequency in Table 8. Similar to the computations in calculating performance in Experiment 1, I collapsed identification scores across stimulus type (single-word, sentences) and word frequency and semantic context level (low, high) for each manipulation. The correlation matrix is presented in Table 8. As shown, the only significant correlation with speech identification performance was between Shipley vocabulary and Inhibition-Frequency, $r(98) = .36$, $p = .039$. Again, I will return to the significance of this finding later in this chapter.

Table 8.
Correlations between Demographic Variables and Accuracy in Experiment 2

	1	2	3	4	5
1. Dot Task	—	.47**	.23	-.23	-.07
2. PTA		—	-.24	-.21	-.19
3. Shipley			—	-.24	.36*
4. Inhibition – Semantic Context				—	-.11
5. Inhibition – Frequency					—

*$p < .05$, **$p < .01$

Similar to Chapter 4 which detailed the results of the WM load manipulation, the results of the inhibitory demand manipulations are reported here. As in the previous chapter, the results are subdivided into the interactive effects with semantic context and word frequency, respectively.

Age, Stimulus Type, Inhibitory Demands (Lexical Density), and Semantic Context

The identification accuracy measure was entered into a 2 (Age: young, old) X 2 (Stimulus Type: word, sentence) X 2 (Density: high density, low density) X 2 (Semantic Context: high predictability, low predictability) mixed Analysis of Variance (ANOVA) in which Age was the between-subjects factor and Stimulus Type, Density, and Semantic Context were within-subjects factors. There was an expected main effect of Density, $F(1,98) = 69.88$, $p < .001$, partial $\eta^2 = .63$, such that accuracy was higher for LD words, i.e., fewer inhibitory demands (M = 76.65, SE = 1.48) than for HD words, i.e., greater inhibitory demands (M = 65.11, SE = 1.60).

There were a number of reliable interactions. First, there was a significant interaction of Age x Density, $F(1,98) = 4.62$, $p = .038$, partial $\eta^2 = .10$, in which both age groups showed equivalent performance for LD targets with fewer inhibitory demands (younger: M = 77.02, SE = 2.41; older: M = 76.28, SE = 1.70), $p = .803$; but significantly poorer performance for older adults (M = 61.77, SE = 1.84) compared to younger adults (M = 68.45, SE = 2.61) for HD targets with greater inhibitory demands, $p = .043$.

I also observed an interaction of Stimulus Type x Semantic Context, $F(1,98) = 7.55$, $p = .009$, partial $\eta^2 = .16$, in which there was no difference in performance for single-word (M = 54.89, SE = 2.55) or sentence targets (M = 59.64, SE = 1.69) in the LP condition, $p = .151$; but superior performance for sentence targets (M = 90.77, SE = 1.39) compared to single-word targets (M = 78.21, SE = 3.25) in the HP condition, $p = .001$.

I additionally observed an interaction of Density x Semantic Context, $F(1,98) = 5.80$, $p = .021$, partial $\eta^2 = .13$, in which there was a larger effect of lexical density (diff $M = 15.10$, $SE = 2.07$) in the LP condition, $p < .001$, compared to a smaller density effect (diff $M = 7.97$, $SE = 1.97$) in the HP condition, $p < .001$.

Finally, I obtained three reliable 3-way interactions: Age x Density x Context, $F(1,98) = 4.35$, $p = .043$, partial $\eta^2 = .09$; Age x Stimulus Type x Context, $F(1,98) = 5.04$, $p = .030$, partial $\eta^2 = .11$; and Stimulus Type x Density x Context, $F(1,98) = 5.88$, $p = .020$, partial $\eta^2 = .13$. These are individually examined below.

Age x Density x Semantic Context: This interaction is shown in Figure 18, revealing an Age x Semantic Context interaction in the HD condition, but not in the LD condition, F's < .27, p's > .60. Follow-up comparisons examining this interaction in the HD condition showed no age differences in performance in the HP context condition for HD targets, $F(1,98) = .17$, $p = .683$, partial $\eta^2 = .004$, but that older adults performed significantly worse in identifying HD targets in the LP context condition, $F(1,98) = 12.13$, $p = .001$, partial $\eta^2 = .23$. That is, age differences in performance only emerged under the most difficult conditions, i.e., lack of predictable semantic context and items requiring high inhibitory ability.

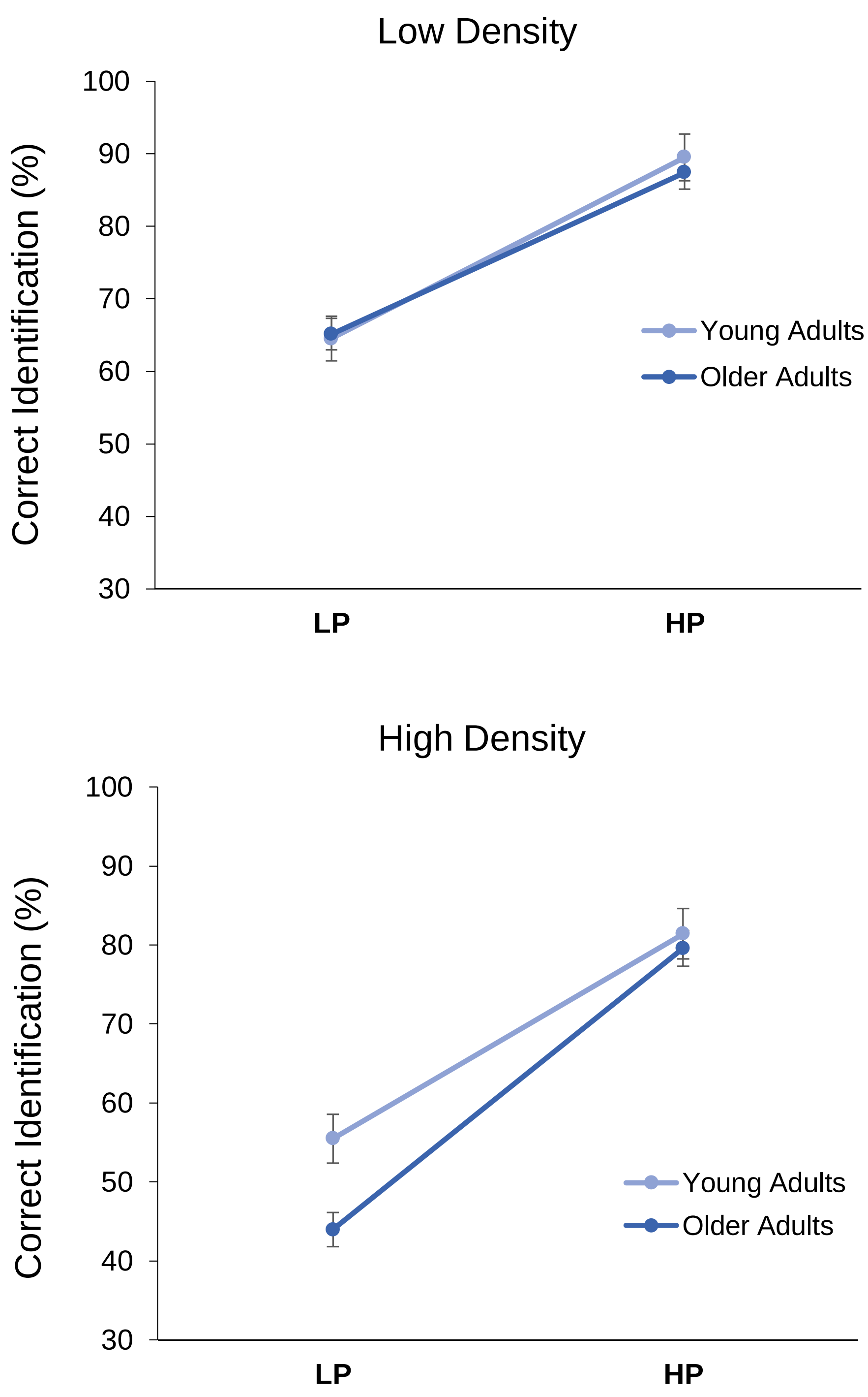


Figure 18. Mean percentage of targets correctly identified by young adults and older adults in the low-density condition (top panel) and high-density condition (bottom panel) as a function of semantic context.

Note: LP = low predictability, HP = high predictability. Error bars represent standard errors of the mean.

Stimulus Type x Density x Semantic Context: This interaction is shown in Figure 19. Follow-up comparisons revealed superior performance for sentence targets over single-word targets for both LP and HP context in the LD condition, F's > 4.43, p's < .042. However, there was no differential effect of LP context on single-word vs. sentence targets in the HD condition, $F(1,98) = .17$, $p = .68$, partial $\eta^2 = .004$, while sentence performance was again superior over that of single-word targets in the HP context condition, $F(1,98) = 17.53$, $p < .001$, partial $\eta^2 = .30$.

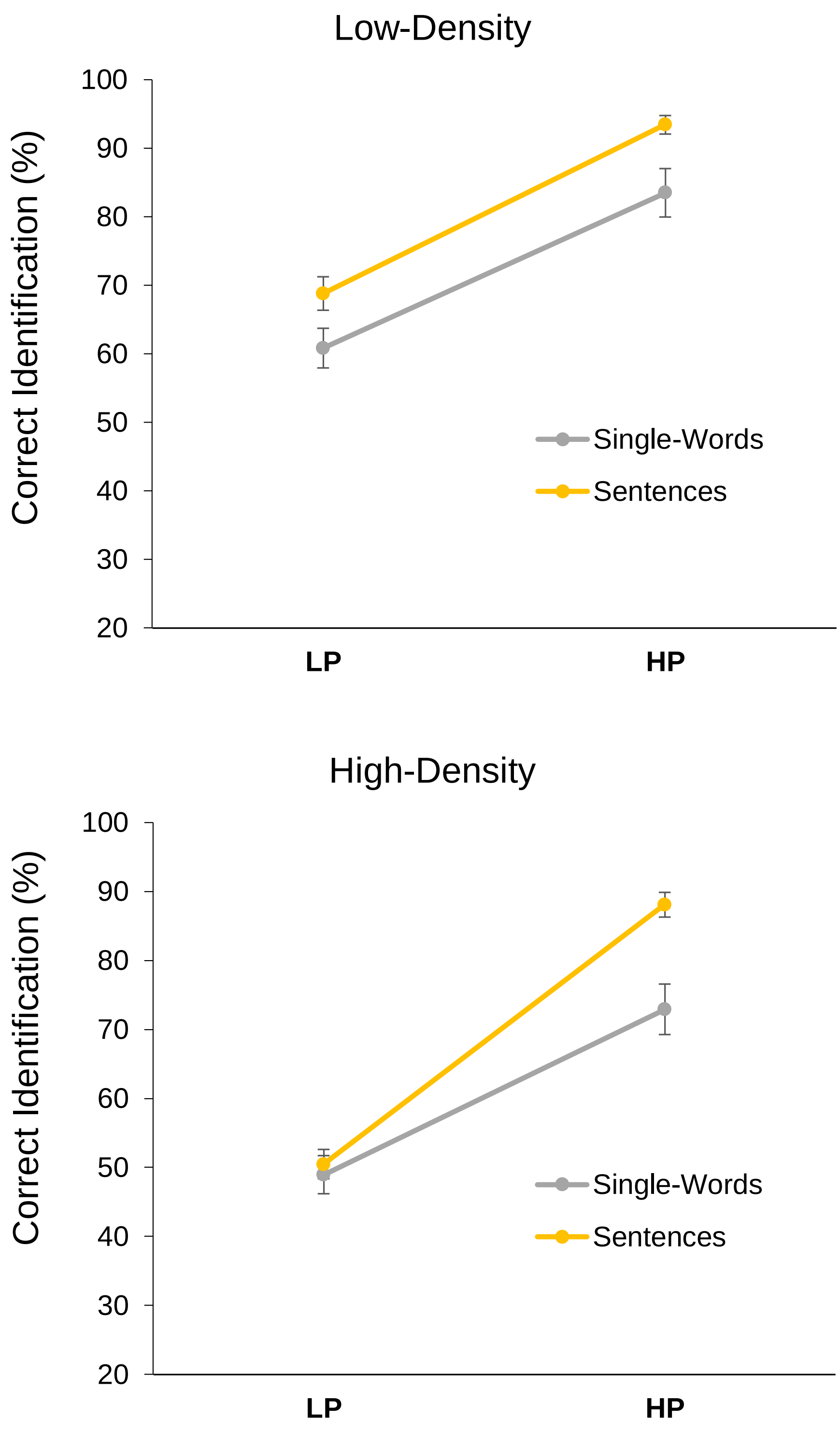


Figure 18. 3-way interaction showing mean percentage of targets correctly identified in the low density condition (top panel) and the high density condition (bottom panel) as a function of stimulus type and semantic context.
Note: LP = low predictability, HP = high predictability. Error bars represent standard errors of the mean.

Age x Stimulus Type x Semantic Context: This interaction is shown in Figure 19, showing an Age x Semantic Context interaction for sentences, but not for single-words. Pairwise comparisons showed no reliable age differences in the effects of semantic context for single-word targets, F's < 2.34, p's > .108. However, while there were also no age differences in performance in the LP context condition for sentence targets, $F(1,98) = .83$, $p = .368$, partial $\eta^2 = .02$, older adults did perform significantly better than younger adults in identifying sentence targets in the HP context condition, $F(1,98) = 5.96$, $p = .019$, partial $\eta^2 = .13$.

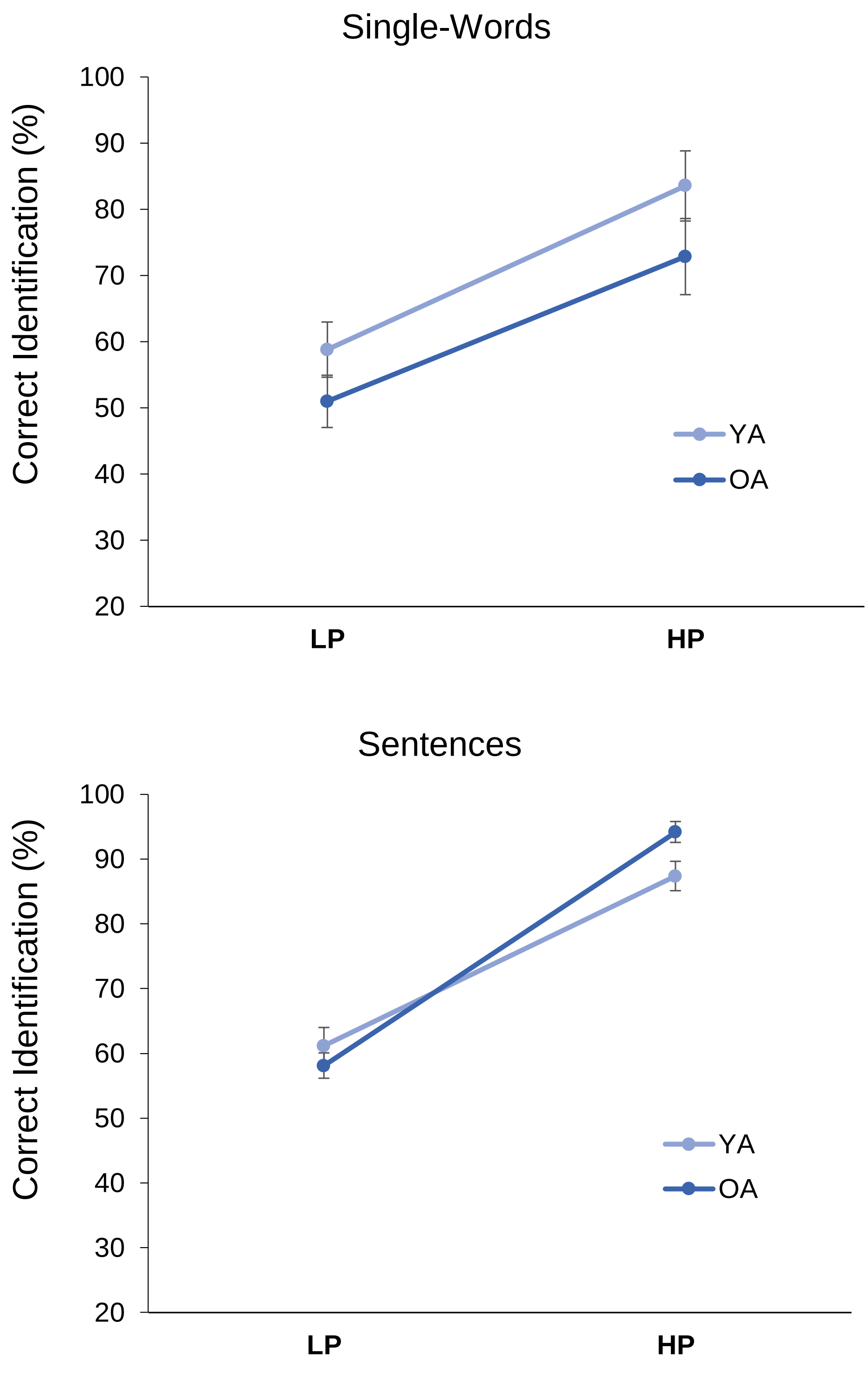


Figure 19. 3-way interaction showing mean percentage of targets correctly identified by young adults and older adults for single-word stimuli (top panel) and sentence stimuli (bottom panel) as a function of semantic context.
Note: YA = young adults, OA = older adults; LP = low predictability, HP = high predictability. Error bars represent standard errors of the mean.

Although there was no significant 4-way interaction of Age x Density x Stimulus Type x Semantic Context, Figure 20 replots the 3-way interaction from Figure 19 in separate panels as a function of density to demonstrate the moderating effects of low and high inhibitory demand. The individual pairwise comparisons are reported below.

Single-words. There were no age differences in the effects of semantic context on LD single-word identification, F's < 1.70, p's > .200. However, while there were no age differences in the effects of HP context in HD target identification, $F(1,98) = 2.71$, $p = .102$, partial $\eta^2 = .06$, older adults did perform significantly more poorly than younger adults in identifying HD, LP targets, $F(1,98) = 5.24$, $p = .027$, partial $\eta^2 = .12$. Mirroring the pattern of results from Experiment 1, the poorest performance for older adults were in identifying targets low in linguistic support, i.e., LP context, and in a highly demanding cognitive condition, i.e., HD.

Sentences. Similar to the results obtained for single-word targets, there were no age differences in the effects of context on LD target identification in sentence stimuli, F's < 3.39, p's > .073. There was, however, a crossover interaction in the HD condition, similar to what was obtained in Experiment 1: while older adults performed significantly worse than younger adults in identifying targets in the LP context, $F(1,98) = 5.91$, $p = .020$, partial $\eta^2 = .13$, they significantly *out*performed younger adults in identifying HD targets in HP context, $F(1,98) = 5.77$, $p = .021$, partial $\eta^2 = .13$.

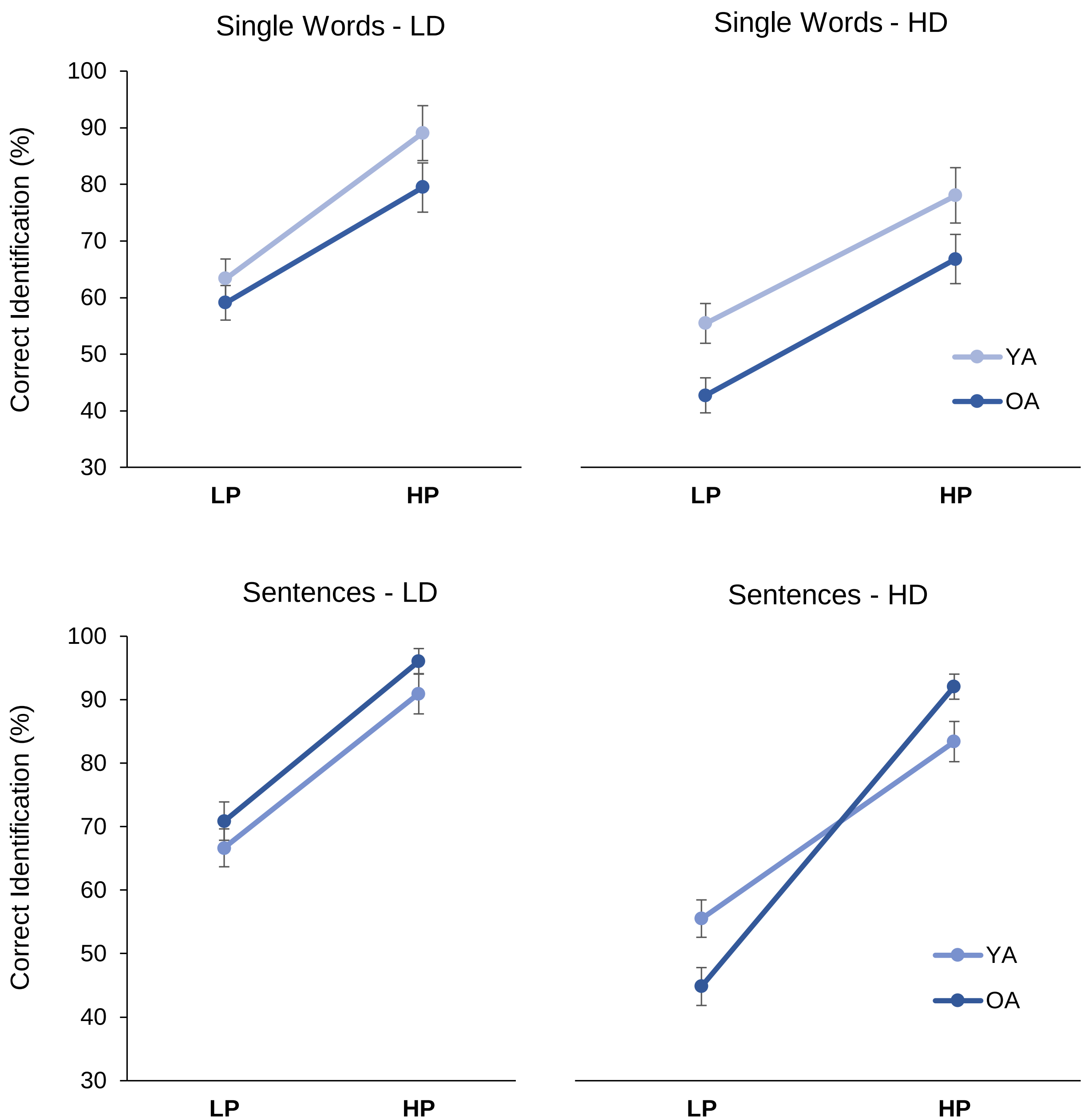
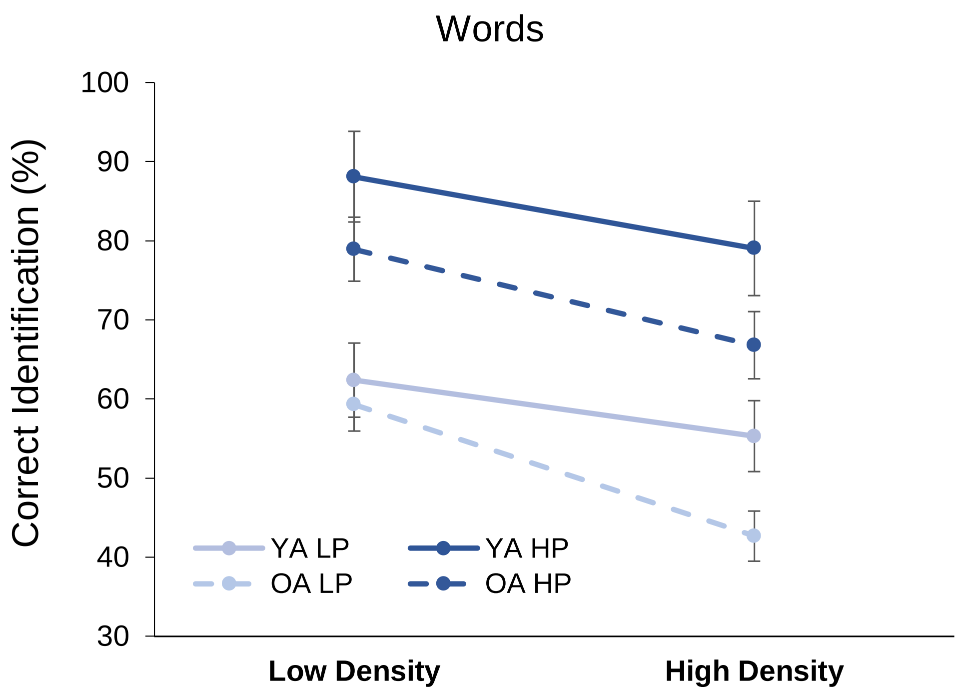


Figure 20. The 3-way interaction of Age x Stimulus Type x Semantic Context shown separately as a function of inhibitory demand, i.e., lexical density, for single-word trials (top panels) and sentence trials (bottom panels). Note: YA = young adults, OA = older adults; LP = low predictability, HP = high predictability; LD = low density, HD – high density. Error bars represent standard errors of the mean.

Figure 21 displays the same results from Figure 20, but directly depicts the compensatory effects of LP vs. HP context across inhibitory demand conditions for each age group separately as a function of stimulus type. All pairwise comparisons are listed in Appendix F.



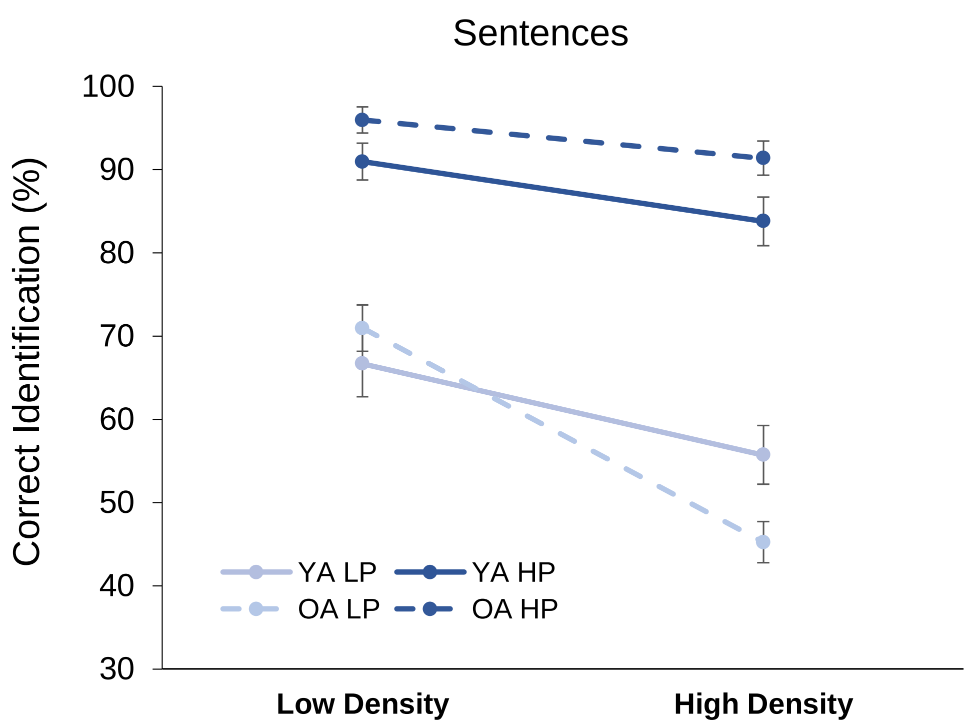


Figure 21. Mean percentage of targets correctly identified by young adults and older adults in single-word stimuli (top panel) and sentence stimuli (bottom panel) as a function of Inhibitory Demand (Density) and Semantic Context.
Note: YA = young adults, OA = older adults; LP = low predictability, HP = high predictability. Error bars represent standard errors of the mean.

The Interaction of Inhibition and Word Frequency.

The identification accuracy measure was entered into a 2 (Age: young, old) X 2 (Stimulus Type: word, sentence) X 2 (Density: low density, high density) X 2 (Word Frequency: high, low) mixed ANOVA in which Age was the between-subjects factor and Stimulus Type, Density, and Frequency were within-subjects factors. As in the previous results, there was an expected main effect of Density, $F(1, 98) = 194.54$, $p < .001$, partial $\eta^2 = .83$, in which LD targets ($M = 70.31$, $SE = 1.85$) were identified more accurately than HD targets ($M = 45.90$, $SE = 1.83$). Additionally, there was an expected main effect of Frequency, $F(1,98) = 128.52$, $p < .001$, partial $\eta^2 = .76$, in which accuracy was significantly higher for HF targets ($M = 68.99$, $SE = 2.05$) compared to LF targets ($M = 47.27$, $SE = 1.98$). In contrast to the previous manipulations however, there was no main effect of Stimulus, $F(1,98) = .33$, $p =.57$, partial $\eta^2 = .01$; such that target accuracy was statistically equivalent for both single-word and sentence stimuli.

First, I obtained a significant interaction of Age x Density, $F(1,98) = 7.30$, $p = .010$, partial $\eta^2 = .16$, as shown in Figure 22, in which both age groups showed equivalent performance for LD targets, $p = .378$; but significantly poorer performance for older adults compared to younger adults for HD targets, $p = .034$.

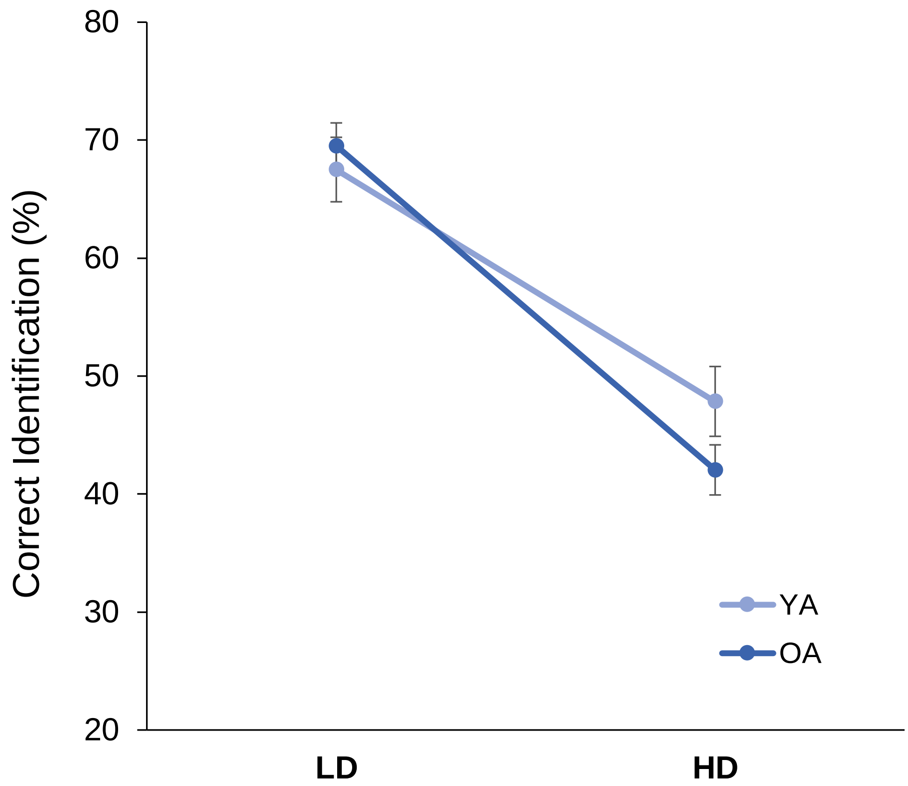


Figure 22. Mean percentage of targets correctly identified by young adults and older adults in the LD condition and HD condition.
Note: LD = low density, HD = high density. Error bars represent standard errors of the mean.

There was also an Age x Frequency interaction, $F(1,98) = 9.09$, $p = .004$, partial $\eta^2 = .19$, as shown in Figure 23, demonstrating an older adult advantage for LF targets compared to younger adults ($M_{older} = 50.62$, $SE_{old} = 1.98$, $M_{young} = 43.92$, $SE_{young} = 2.75$), $p = .046$; but no age differences in identification of HF targets ($M_{older} = 66.55$, $SE_{old} = 2.40$, $M_{young} = 71.43$, $SE_{young} = 3.34$), $p = .243$. In other words, older adults showed a similar word frequency effect than did younger adults. There were no significant 3-way interactions.

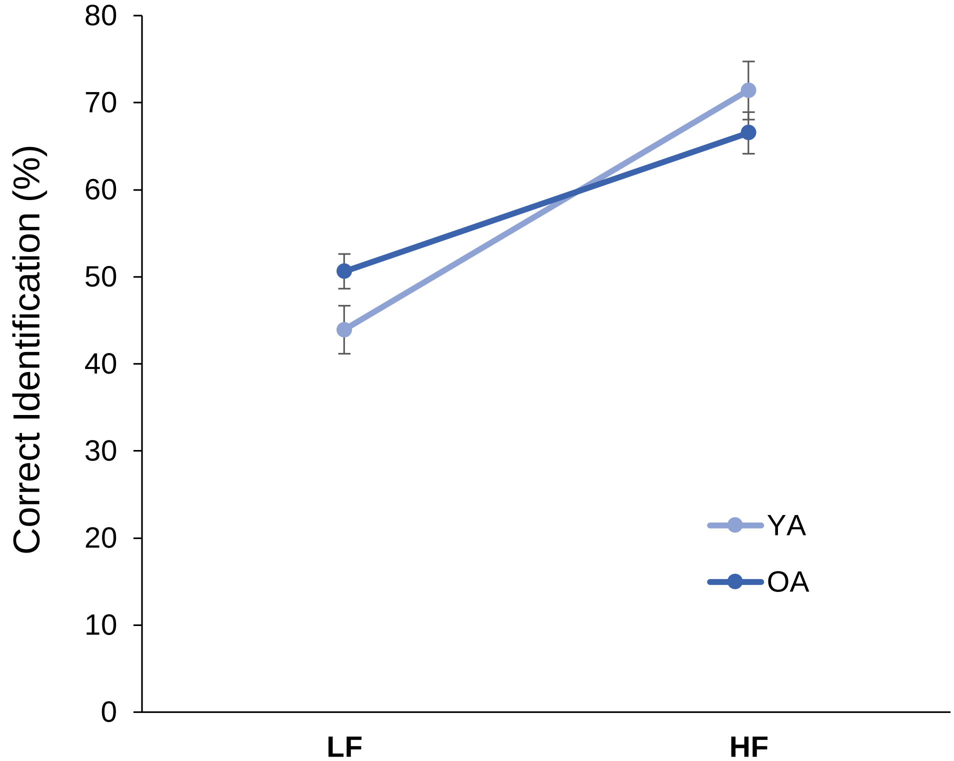


Figure 23. Mean percentage of low-frequency (LF) and high-frequency (HF) targets correctly identified by young adults and older adults. Error bars represent standard errors of the mean.

Although an omnibus ANOVA did not reveal a significant interaction of Age x Stimulus x Density x Frequency, $F(1,98) = .18$ $p = .67$, partial $\eta^2 = .01$, a series of planned follow-up analyses revealed a number of significant pairwise comparisons. Figure 24 shows these interactions separately by stimulus type.

Single-words. Accuracy for LF single-word targets was significantly lower in the HD compared to the LD condition for both age groups, F's > 6.27, p's < .017. Accuracy for HF single-word targets was also significantly lower in the HD compared to the LD condition for both age groups, F's > 16.30, p's < .001, but younger adults were more accurate for HF targets than older adults in the HD condition, $F(1, 98) = 3.68$, $p = .026$, partial $\eta^2 = .08$. That is, younger adults showed a larger word frequency effect in the HD condition.

Sentences. Accuracy for LF sentence targets was also worse in the HD condition compared to the LD condition for both age groups, F's > 13.79, p's < .001; however, older adults were more accurate for LF targets compared to younger adults in the LD condition, $F(1, 98) = 3.82$, $p = .048$, partial $\eta^2 = .09$; showing a smaller word frequency effect. Accuracy for HF targets was negatively affected as a function of high density for both age groups, F's > 16.99, p's < .001, but younger adults showed higher accuracy for HF targets than older adults in the HD condition, $F(1, 98) = 4.23$, $p = .046$, partial $\eta^2 = .09$. That is, similar to the pattern for single-word stimuli, younger adults again showed a larger word frequency effect for sentence targets than did older adults.

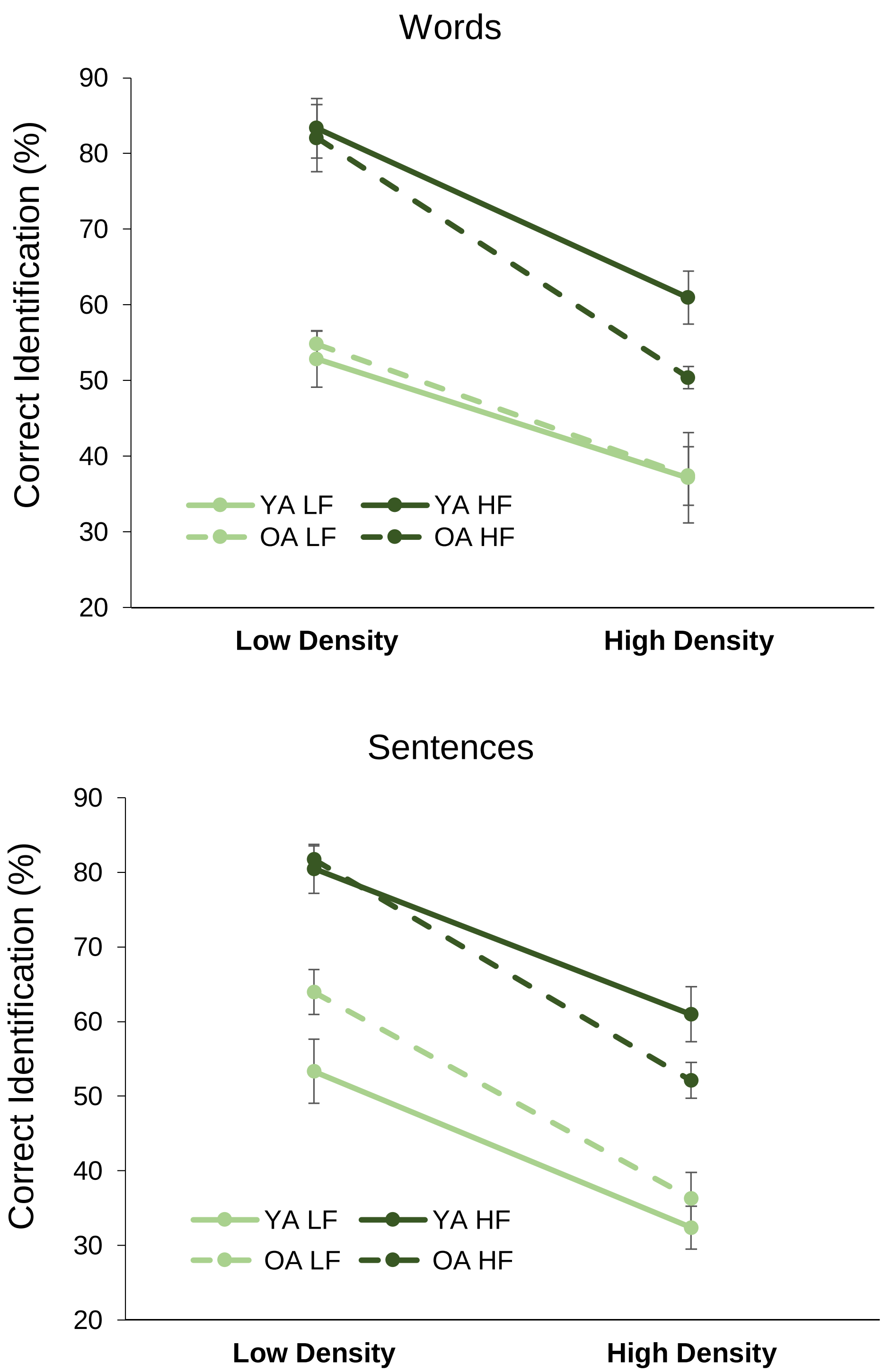


Figure 24. Mean percentage of targets correctly identified by young adults and older adults in single-word stimuli (top panel) and sentence stimuli (bottom panel) as a function of Inhibitory Demand (Density) and Semantic Context.
Note: YA = young adults, OA = older adults; LF = low frequency, HF = high frequency. Error bars represent standard errors of the mean.

As in the WM analyses, I also conducted a set of analyses using Shipley vocabulary scores as a covariate to examine the potential effects of vocabulary knowledge. First, the Pearson correlation between Shipley scores and accuracy for LF targets collapsed across inhibition conditions was significant, $r(98) = .31$, $p = .049$, demonstrating that higher vocabulary scores are positively correlated with identification accuracy for LF targets in noise. Older adults showed a significant correlation between vocabulary and LF identification, $r(98) = .53$, $p = .049$; while younger adults did not, $r(98) = .21$, $p = .29$.

Results of the ANCOVA controlling for vocabulary are presented in Figure 25. Controlling for vocabulary not only reduced the *F*-statistic of the omnibus ANOVA, $F(1, 98) = .064$, $p = .801$, partial $\eta^2 = .002$; but also eliminated the reliable Age x Frequency interaction, *p*'s > .164. Pairwise comparisons also revealed that the LF advantage for older adults in the LD condition for sentence stimuli was effectively eliminated, $F(1, 98) = 1.91$, $p = .174$, partial $\eta^2 = .05$, such that the size of the word frequency effect was statistically equivalent across both groups. Moreover, controlling for vocabulary also eliminated the significant younger adult advantage for HF targets in the HD condition for both single-word stimuli, $F(1, 98) = 2.71$, $p = .108$, partial $\eta^2 = .06$; and sentence stimuli, $F(1, 98) = 3.21$, $p = .081$, partial $\eta^2 = .08$. That is, controlling for vocabulary scores reduced word frequency effects across the age groups by both reducing older adults' LF advantage and younger adults' HF advantage.

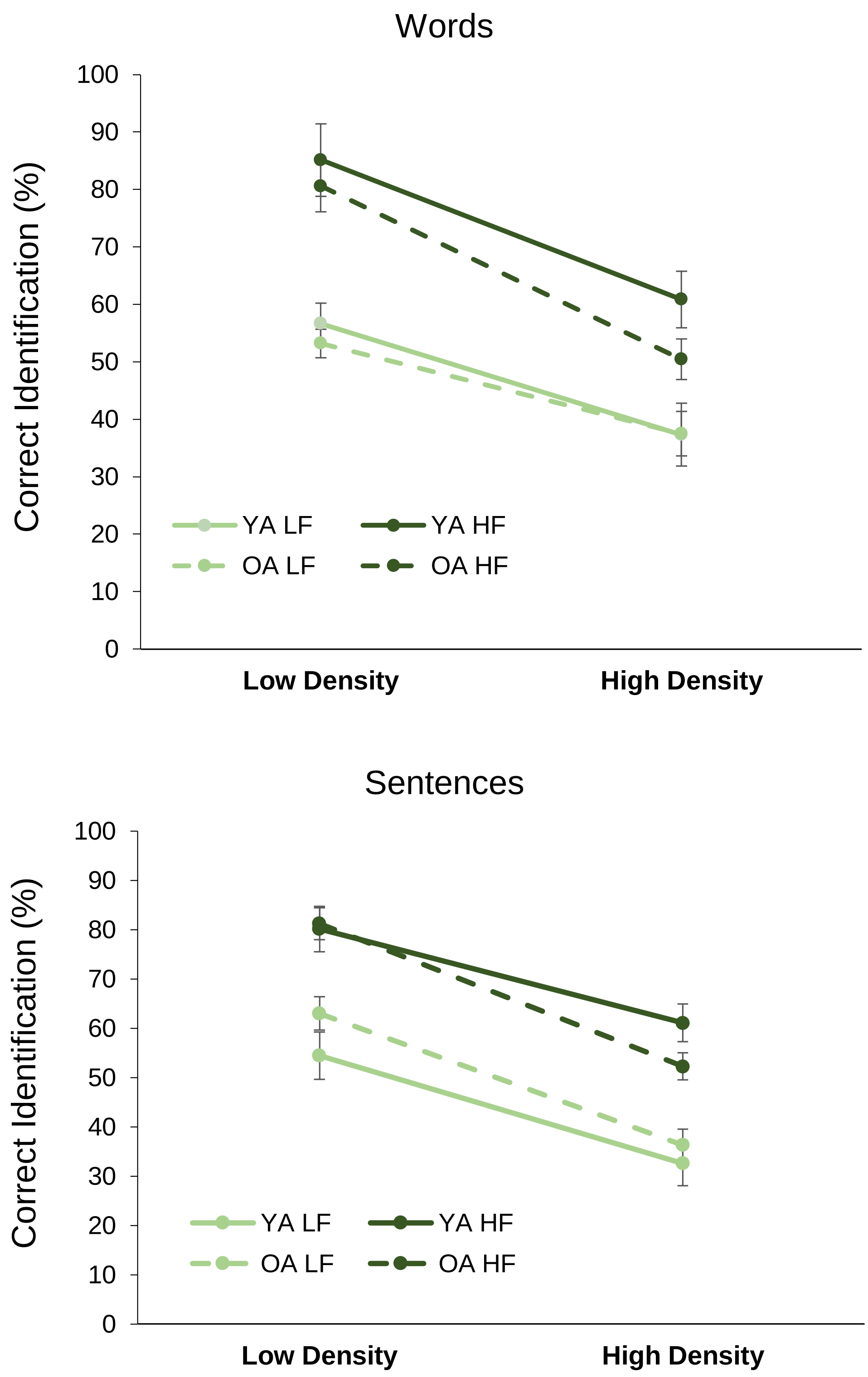


Figure 25. Mean percentage of targets correctly identified by young adults and older adults in single-word stimuli (top panel) and sentence stimuli (bottom panel) as a function of Inhibitory Demand (Density) and Semantic Context, controlling for Shipley vocabulary scores.
Note: YA = young adults, OA = older adults; LF = low frequency, HF = high frequency. Error bars represent standard errors of the mean.

CHAPTER 6: DISCUSSION

The goal of the current study was to examine the independent and interactive contributions of fluid and crystallized abilities in accounting for age differences in speech perception Specifically, the present investigation attempted to address the following research questions: 1) how do deficits in working memory (WM) interact with use of semantic context and word frequency, to impact speech processing; and 2) how do deficits in inhibitory ability interact with use of semantic context and word frequency to impact speech processing.

To examine these questions I experimentally manipulated and compared the effects of fluid demands (WM load and inhibitory demands, i.e., lexical density), and crystallized support (use of semantic context and word frequency). In Experiment 1 I examined the interaction of age, stimulus type, WM load, semantic context, and word frequency. I manipulated WM demands by creating a high-WM load condition which involved a concurrent O-Span task, and a low-WM load condition that did not involve a secondary task. In Experiment 2 I examined the interaction of age, stimulus type, inhibitory demand, semantic context, and word frequency. In the high inhibitory demand condition, I manipulated inhibitory demands as a function of high or low lexical density, thus necessitating greater or fewer inhibitory demands. The outcomes of both experiments implicated complex conditions under which crystallized and fluid ability differentially interact and contribute to speech perception. That is, linguistic support, in the form of semantic context and word frequency, appeared to moderate age differences in the effects of high cognitive load during speech identification.

The interaction of Age, WM load, and linguistic support

In the current study, I obtained reliable evidence that older adults compensate for increased WM demands by making use of semantic context and word frequency knowledge. Recall the conditions presented in Chapter 2 which were necessary to meet in order to make such claims of compensation: 1) conditions of low cognitive demand, i.e., low WM and low inhibitory demands, should produce age-equivalent performance to serve as a baseline for performance, and 2) high linguistic support should be able to maintain levels of identification accuracy as the cognitive demands of the task increase, with a particular focus on older adults demonstrating a greater benefit of high linguistic support compared to younger adults. The results of the experiments generally support these conditions, which are discussed below.

Age, WM Load, and Semantic Context. First, there were no age differences in identification accuracy for targets in the LP condition under low-WM load conditions. Older adults performed significantly worse than younger adults, however, in identifying targets in the LP condition under high-WM load conditions. The addition of HP context had minimal effects on younger adults, but had a significantly beneficial effect on older adults, elevating them to near ceiling levels of performance. This was also true for targets in the low-WM load condition.

To my knowledge, these results are the first to directly demonstrate that older adults use predictable semantic context to compensate for increased WM demands. The absence of predictable context in the LP condition essentially acts as a baseline for performance to which manipulations in other task demands can be compared. Introducing high WM demands in the form of a concurrent O-Span task had a significant negative impact on older adults' performance in the LP condition compared to younger adults as would be expected, but this age difference was dramatically reversed with the addition of HP context. The results as demonstrated in Figure

10 clearly demonstrate the compensatory power of HP context for older adults' identification accuracy, as a high level of accuracy is maintained moving from low to high load conditions. Younger adults also demonstrated this, but at a reduced level.

This work contributes to an existing body of literature which demonstrates the disproportionately large benefits of predictable semantic context on speech perception, particularly for older adults (e.g., Cohen & Faulkner, 1983; Hutchinson, 1989; Lieberman, 1963; Madden, 1988; Nittrouer & Boothroyd, 1990, Wingfield, Aberdeeen, & Stine, 1991; Sommers & Danielson, 1999). However, there is considerable debate in the cognitive literature with respect to the mechanisms of such effects. Although most models of auditory word recognition share the assumptions that (a) multiple candidates from the mental lexicon are activated early on as the acoustic input unfolds in time, and (b) the acoustic input is matched against a stored representation of the phonological structure of the word, it is unclear how context operates on these processes. For example, context may only come into play relatively late after lexical candidates have already been activated (as argued in "modular" models) or early in conjunction with lexical activation (as argued in "interactive" models; for a review, see Lively, Pisoni, & Goldinger, 1994). Regardless of the time course, however, the explanation in the cognitive aging literature for older adults' greater reliance on – and greater benefit from – context is that the activation of lexical candidates by the context enables older adults to "fill in" the gaps created in the auditory input by an impoverished sensory signal (cf. Holtzman et al., 1986; Pichora-Fuller et al., 1995; Wingfield et al., 1991).

It is interesting that both younger and older adults maintained high levels of accuracy in HP context conditions under both levels of WM load. Related to the discussion above and as briefly discussed in Chapter 1, such findings raise the point of determining the mechanisms of using such contextual support in cognitively demanding situations. Given that high-WM load did not negatively affect the benefits of predictable semantic context, it can be hypothesized that the availability of context bypasses the need to direct attention towards the processing of such linguistic information, and can be directed elsewhere. This is not to say that attention is not at all involved in employing use of semantic context, but that the presence of predictable context acts to rapidly constrain the possibilities for sensory input to lead the perceiver towards the final target word that minimizes the need for cognitive processing of such input.

Moreover, the finding that older adults have higher accuracy for HP context targets suggests that this pathway to activation is even more automatic, made so by years of linguistic experience. Support for automaticity involved in the benefits of HP context, particularly in older adults, is consistent with prior literature (e.g., Craik & Jennings, 1992; Hasher & Zacks, 1979; Light, 1991; Roediger, Balota, & Watson, 2001) which has demonstrated that organized strategies and knowledge can speed the automaticity of certain encoding processes. In the case of the present study, it appears that older adults' reliance on context supersedes the need to use cognitive processing, even when perceiving speech under demanding cognitive conditions. The concept of automaticity is also a property of the ELU model (e.g., Rönnberg, Rudner, Foo, & Lunner, 2008; Stenfelt & Rönnberg, 2009) as discussed in Chapter 1, albeit in in the context of specific interactions with sensory acuity. Nevertheless, the relatively preserved automaticity of language use seems to be a key process in compensating for challenging listening situations.

In addition to a priming mechanism account for the benefits of context, a biased responding account (Rogers et al., 2012) may also be relevant. Indeed, the mechanisms by which a predictable context may benefit speech perception may be a combination of biased responding, in addition to implicit activation: older adults may be initially more biased to rely on context due to lifelong experience with it, and this initial bias prompts an automatic activation pathway leading to successful identification of the target. In a 2006 review paper on false memory, Jacoby and Rhodes described false memory findings in terms of a dual-process model of memory that distinguishes between recollection and accessibility bias. Whereas recollection can be considered a consciously controlled, effortful basis for responding, accessibility bias can be considered a less effortful and more automatic basis for responding that reflects potential effects of prior experience, e.g., habits and context. Thus, age differences in the effects of context may be attributed to a decline in effortful recollection and an increase in experience-driven bias. In the context of the current findings, use of linguistic knowledge represents an aspect of cognition that is more automatic and therefore less sensitive to age-related decline in other domains.

Further evidence of this distinction between controlled cognitive processing and automatic linguistic knowledge use comes from research examining semantic priming in patients with Alzheimer's disease (DAT) (Nebes, Boiler & Holland, 1986) in which DAT individuals show faster recognition and response production in response to highly semantically constrained sentences than to sentences without such constraints. As has been consistently demonstrated, DAT patients are characterized by significant progressive cognitive impairment, particularly in the domain of memory and attention (e.g., 2007; Belleville, Chertkow, & Gauthier; Bäckman et al., 2005; Celone et al., 2006; see Nelson et al., 2012, for a review). Given the markedly negative effects of Alzheimer's disease on such abilities, DAT patients' demonstrated benefits from constrained linguistic context – to a similar degree as non-DAT individuals – further supports the hypothesis of an automatized linguistic pathway that is separate from more effortful cognitive processing that is adversely affected by (ab)normal cognitive aging. That is, automatic mechanisms for linguistic support due to years of experience circumvent the necessities for controlled processing associated with increased cognitive demands.

In the vast majority of studies examining the effects of semantic context, however, the proposed form of compensation was in overcoming a degraded sensory signal and/or an impoverished auditory system. A common manipulation is to vary the degree of signal degradation and compare speech recognition across low and high semantic context. A recurring finding has been that older adults are more vulnerable than younger adults to reductions in the quality of the signal, but that less age-related differences are observed when sufficient supportive sentential context is available (e.g., Dubno et al., 2000; Gordon-Salant & Fitzgibbons, 1997;Perry & Wingfield, 1994; Pichora- Fuller, 2006; Pichora-Fuller et al., 1995; Wingfield et al., 2005). This is purported to be due to the fact that older adults have developed expertise by frequently listening in everyday situations where the SNR is more challenging for them than it is for younger adults. While such findings are not disputed here, it is important to note that sensory processing may be invariably linked to cognitive processing. The effortfulness hypothesis (McCoy et al., 2005) posits that additional effort must be expended in challenging listening situations (particularly for older adults), depleting cognitive resources that would otherwise be available for various kinds of information processing. Multiple studies have observed that encoding speech content and memory suffers under conditions of hearing loss/high signal degradation (e.g., McCoy et al, 2005; Murphy et al., 2001;Rabbit, 1968, 1991), showing that added perceptual is effort required for successful recognition, coming at a cost of poorer performance in other aspects of the task. The current findings, while not able to directly test the effortfulness hypothesis, do tease apart the effects of sensory and cognitive processing and set the stage for future studies to more closely investigate the concept of effortfulness. That is, if the claim for the effortfulness hypothesis is that more cognitive processing is required to overcome acoustically challenging listening situations, then placing cognitive and sensory demands in opposition, i.e., manipulating low vs. high cognitive load against low vs. high levels of background noise, will allow us to determine the mechanisms underlying the underspecified construct of listening effort.

The results further showed that accuracy in the absence of predictable context was consistently worse under conditions of high WM demand for both younger and older adults. That is, when no compensatory linguistic information was present, high cognitive load negatively impacted performance. This is consistent with findings from Gordon-Salant and Fitzgibbons (1997), who observed that increasing memory load by asking participants to recall full sentences, in addition to immediate recognition, differentially affected older adults to a greater extent than younger adults. Similarly, Tun and Wingfield (1994) varied the processing load of a speech memory task by presenting passages that ranged from high to low in predictability, as indexed empirically by cloze ratings. For all passages, participants' recall was highest for HP information and poorest for LP information, but the pattern of older adults' recall was disproportionately more affected by passage difficulty. Indeed, for the most difficult passages, older adults showed a sharper drop over levels of cloze values. Collectively, these results in combination with those from the present study suggest that the added demands of memory are particularly prominent in the absence of contextual cues, whereas the addition of such cues provide an alternative means of achieving the same level of identification as young adults.

The presence of the secondary word recall task in the high-WM load condition had a significantly negative effect on immediate identification performance for both younger and older adults. One possible mechanism for this pattern is that rehearsal of to-be-recalled items interferes with immediate identification. Rehearsal refers to the process or strategy of repeating information over and over in order to keep it active in working memory. The rehearsal of verbal information is performed through articulation, either overtly or covertly (e.g., Awh, Jonides, & Reuter-Lorenz, 1998; Baddeley, 1986; Geng, Ruff, & Driver, 2008; Tremblay, Saint-Aubin, & Jalbert, 2006). Participants in the present study were aware that they would have to remember and recall items in the future, but they did not know when they would be cued for recall. Thus, they may have employed rehearsal strategies to remember these targets, and in doing so, interfered with their ability to immediately identify ongoing targets. However, there is mixed evidence as to whether older adults differentially attended to the secondary task in order to maintain high levels of performance during immediate identification. While accuracy for the math equations was equally high for both age groups, the pattern of recall was differentially affected by age, in which long spans resulted in poorer recall performance for older adults. However, identification accuracy did not differ as a function of span length between the age groups. That is, despite overall poorer performance in recall, older adults did not differ from younger adults in identification accuracy of targets as a function of span. Such a finding suggests that older adults may have achieved their demonstrated level of identification accuracy at the expense of differentially poorer rehearsal of items for the longer spans. Demonstrating this trade-off is crucial in understanding how older adults use predictable semantic context to compensate for increased cognitive load, and which has been conspicuously absent in prior research.

There is one final point to be made about compensatory effects for targets in single-word vs. sentence stimuli. As the pattern of results demonstrate, the beneficial effects of HP context were more exaggerated in sentence stimuli, and the negative effects of LP context were more exaggerated for single-word stimuli. Moreover, there were no age differences in the effects of context for single-word stimuli. Although these findings cannot be directly compared because context strength was not equated across single words and sentences, these findings are generally consistent with the initial hypotheses, supporting the view that sentences provide more linguistic and syntactic information of which older adults can better take advantage compared to younger adults.

Previous work examining age differences in visual reading and discourse processing have suggested that micro-level processes which enable access to word meanings, i.e., the activation of letter and lexical codes, become more automatic with practice (LaBerge & Samuels, 1974; Stine, 1990), and such automaticity would be naturally more rehearsed in older adults with more linguistic and reading experience. Accordingly, older adults may process sentences in a more automatic fashion compared to younger adults, allowing them to extract meaning more quickly and in a more efficient way that allows them to take advantage of the linguistic complexity of sentences. Similarly, situations involving HP context in the real world may be more likely to occur in the form of sentences and longer forms of linguistic discourse as opposed to single words, therefore the benefit of sentences may be more ecologically valid and provide more opportunities for older adults to approximate everyday listening situations.

Age, WM Load, and Frequency. Consistent with the initial hypotheses, participants appeared to compensate for high WM demands by making use of HF information – however, this was only true for sentence stimuli and there were no age differences in the use of such information.

Surprisingly, HF information was only beneficial for sentence stimuli across low and high-WM load conditions; in contrast, accuracy for single-word stimuli was consistently lower, regardless of linguistic support. As there are no studies – to my knowledge – that have compared the effects of word frequency across single-word and sentence auditory presentation, I can only hypothesize as to the possible mechanisms. Similar to the sentential benefit of context, frequency effects appear to be strongest when there is sufficient linguistic content present. Sentences naturally provide more linguistic complexity than single-word presentation, and as such, it may be more engaging for a listener to attend to. Accordingly, listeners may be more inclined to attend to more complex linguistic stimuli, i.e., sentences, as opposed to single words. This was especially apparent in the high WM conditions, in which the combination of HF targets and syntactically interesting sentence stimuli were sufficient to compensate for high WM demands. This is in contrast to single-word presentation that lacked linguistic complexity, and in which it appears that HF targets were not sufficient to compensate for high WM demands. Given that the single-word and sentence stimuli were not equated for strength however (to be discussed shortly), a comparison of these effects is only speculative.

The lack of consistent support from HF information for older adults may stem from a further interesting finding to emerge, which was that older adults showed a LF advantage compared to younger adults. This is consistent with previous findings of higher recognition for LF compared to HF items (e.g., Glanzer & Bowles, 1976; Gorman, 1961; Jacoby & Dallas, 1981; Kinsbourne & George, 1974; Mandler, Goodman, & Wilkes-Gibbs, 1982; Rao & Proctor, 1984), as well as an age-related advantage for LF items and smaller word frequency effect than younger adults (e.g., Almond, 2013; Gomez, 2002; Spieler & Balota, 2000; Tainturier, Tremblay, & Lecours, 1989). The age differences in particular have been attributed to subtle changes in word processing across the life span that arise from continued exposure to old words and slow acquisition of new words. Any increase in the number of items in the lexicon is likely to be accompanied by an increase in the variety and richness of semantic representations associated with these additional words. Tainturier et al. (1989) suggested that the LF advantage may be a result of HF words reaching an asymptote at some point, making it less likely that further exposure to HF words will have any impact. In contrast, LF words are more sensitive to increased exposure, and more likely to vary as a function of age. Moreover, the additional reading experience that is likely to accrue over time may also influence the representation of lexical knowledge. Indeed, older adults in the current sample showed more frequent reading behaviors than did younger adults, and as such may result in comparatively subtle changes which may exert an influence on word processing. There is further evidence of this from the finding that controlling for vocabulary levels effectively eliminated the age difference in frequency effects. That is, the compensatory effects of frequency in older adults appear to be due to higher levels of word, i.e., vocabulary, knowledge. This is also consistent with older adults demonstrating higher performance on the Shipley vocabulary task than younger adults, as well as the correlations between vocabulary and LF target intelligibility. The enhancing effects of word knowledge for older adults have been shown extensively in past research (e.g., Alwin, 1991; Botwinick, 1967; Gold et al., 1995; Salthouse, 1993; Schaie, 1996; Verhaeghen, 2003), demonstrating that age-related advantages in education and linguistic experience may impact task performance. Moreover, similar to the effects of context, older adults' life experience may compel them to rely more on gist knowledge which can serve as an implicit, faster alternative route to the meaning of the word, reinforcing the notion of an automatic mechanism for linguistic processing in older adults (dual-representation theory of knowledge; Brainerd & Reyna, 1992; McGinnis & Zelinski, 2003).

Age, inhibitory demands, and linguistic support

Inhibition and semantic context. In examining the interaction of inhibitory demands and semantic context, there was a generally similar pattern of results compared to the interaction of WM and context. However, there were some key differences. While HP context was significantly more beneficial for accuracy in both the low and high inhibitory conditions, it allowed older adults to maintain a high level of accuracy only for sentence targets. Thus, it appears that inhibitory demands associated with HD words may be too challenging for older adult to sufficiently use HP context in single-word presentation.

The negative effects of HD targets have been reliably obtained in prior research (e.g., Dey & Sommers, 2015; Luce & Pisoni, 1998; Sommers & Danielson, 1999; Sommers, 1996; Taler et al., 2010), showing that the increased inhibitory demands associated with HD words disproportionately affect older adults' identification of such words in comparison to younger adults. Indeed, the pattern of results for the LP condition replicate previous findings of equivalent age performance for LD words but exaggerated differences for HD words. In the WM condition, older adults were able to overcome high-WM load to effectively use HP context, but were not able to overcome high inhibitory demands with HP context. Furthermore, the difference obtained between single-word and sentence stimuli suggest that HP context is more effective with targets embedded in meaningful sentences as opposed to carrier phrases associated with single-word presentation. Again, this is consistent with the results reported earlier in which the greatest benefits for identification – with and without context – is found for sentence stimuli with more linguistic context from which to draw. However, younger adults achieved comparable accuracy for HP targets in both single-word and sentence presentation, suggesting equivalent effects of context for them, regardless of the linguistic complexity of the stimuli. In contrast, older adults benefit more from the more varied linguistic content, as is present in sentences.

Why were older adults able to overcome high WM demands but not inhibitory demands? One reason may be that the nature of the additional cognitive task was different for the two experiments. In the case of the WM manipulation, the WM load was extrinsic to the identification task itself, i.e., alternating trials of O-Span equations, immediate identification, and recall. In the manipulation of inhibitory demands, the inhibitory demand was inherent to the lexical target itself, i.e., words with fewer or more neighbors which were also embedded within LP or HP contexts. This endogenous manipulation at the item-level may have made it harder for older adults to properly use context. In contrast, the secondary task in the WM load manipulation acted as an exogenous task demand, and this may have generated a level of strategy of when and how to attend to the target information.

Age, Inhibition, and Frequency. Although older adults were able to benefit from linguistic information in sentence stimuli in the semantic context manipulation, they were not able to do so in the word frequency manipulation. In fact, in addition to the negative effects of HD targets on accuracy, they were not able to benefit from HF information as well as younger adults.

One reason for this may have been the way in which the stimuli were assigned lexical parameter values. In assigning low and high frequency and density values, I did so by selecting relatively arbitrary cut-off points. Although these values produced reliable frequency and density effects individually, obtaining interactions between frequency and density may be undermined by the fact that the two variables generally show moderate to high correlations with each other, such that LD items are also high in frequency, and HD items are often low in frequency (Luce & Pisoni, 1998). Moreover, even though both phonological and orthographic neighborhood characteristics were controlled for across conditions, there are numerous other potential characteristics, such as neighborhood frequency, which were not examined and which may have influenced the current results. That is, the current set of stimuli parameters may not have been sufficient to demonstrate conditions under which the benefits of HF information can overcome high inhibitory demands.

As with the WM x Frequency manipulation, controlling for vocabulary skills eliminated the LF advantage for older adults in the LD sentence condition and reduced younger adults' advantage for HF targets, resulting in equivalent word frequency effects across age groups. This pattern of results demonstrates a reliable contribution of word knowledge to identification accuracy, and provides further support for the density-frequency dichotomy in the NAM. Without the necessity for inhibitory demands required to suppress competitors, frequency biases are reliably apparent in the LD condition. Such frequency effects disappear, however, when greater inhibitory suppression is required in the HD condition, negatively affecting older adults' accuracy.

Other considerations. It is interesting to note that there were no significant correlations between hearing ability (PTA) or processing speed and identification accuracy in any of the conditions. Even though audibility was equated by choosing different SNRs for each age group, the negligible contribution of hearing ability to speech performance may reflect an unusually highly-educated sample of older adults who may employ more efficient 'everyday' forms of compensation in their daily lives when listening to challenging speech (Pichora-Fuller, 2008).

The contributions of general slowing has been posited as a major contributor to age-related cognitive decline (e.g., Myerson et al., 1992; Salthouse, 1992, 1994, 1996; see Salthouse, 2000 for a review). With regard to speech perception, there has been less consistent evidence for a role in age differences. Evidence for the role of processing speed has been primarily observed in studies examining rate-altered speech (e.g., Gordon-Salant & Fitzgibbons, 2004; Hargrave et al., 1994; Wingfield & Ducharme, 1999), in which speaking rates are temporally manipulated. Results have demonstrated that listening performance is often predicted by speed of processing, and that age-related decreases in performance are associated with greater contributions of processing speed (e.g., Pichora-Fuller, 2003; Tun, 1998; Tun & Wingfield, 1999). For example, Schneider and colleagues (e.g., Schneider & Pichora-Fuller, 2001; Schneider et al., 2005) have reported that older adults show significantly poorer word recognition than do younger adults when the speech is speeded in a way that deletes segments, shortens vowel duration, and pauses between words. Thus, while processing speed may appear to be a significant contributor to speech that is temporally distorted, no such contributions have been observed for non-altered speech. That is, speed of processing may only play a role when the speech signal is time-altered in a way that reduces richness and encoding time in the acoustic signal.

Limitations

Although the experiments described here provide a crucial first step to understanding how cognitive abilities interact with linguistic knowledge, there are a number of caveats that limit definitive statements about the nature of fluid-crystallized interactions in speech.

As mentioned previously, I dichotomized several continuous variables, including age, word frequency, and lexical density. Although this was done as a first step in exploring the research questions, false dichotomies made to continuous variables may pose a number of problematic issues for interpretation. Spuriously high correlations may arise as a result of false dichotomies, in addition to misleading effect sizes and oversimplified conclusions (MacCallum, 2002). Moreover, arbitrarily chosen cut-off points may not reflect the latent classes of variables, nor empirical validity. As discussed in the previous section, I selected arbitrary cut-off boundaries for low- and high- frequency and density words, and it is possible that choosing different values may differentially exaggerate or minimize the pattern of findings. Despite this, dichotomizing frequency and density were necessary in this study in order to have sufficiently powered cells for analysis and manipulation. Future investigations of the questions explored in this study may wish to exclude one of the crystallized or fluid manipulations in order to gather a larger set of stimuli with a wide range of lexical characteristics for analyses. In doing so, it would be prudent to use linear regression analyses rather than ANOVAs, which allow for more nuanced interpretations of data. In addition to regression, another method of analysis which has recently been favored by speech and language researchers is the use of logit mixed models (e.g., Baayen et al., 2008; Jaeger, 2008; Quené & Van den Bergh, 2008). Analysis of speech intelligibility data has begun to favor the use of mixed-model regression to examine binary outcomes (i.e., correct or incorrect) as an alternative to ANOVA models, as such analyses allow for not only the advantages of logit models, but also to account for random subject and item effects (see Cunnings, 2012 for a review).

Another possible limitation may be that only two aspects of fluid cognition – WM and inhibition – were assessed. As discussed in the introduction, fluid cognition encompasses a wide range of abilities, including episodic memory and reasoning, among others (e.g., Salthouse & Atkinson, 2003; Verhaeghen & Salthouse, 1997). In addition to multiple cognitive constructs, there are additionally multiple associated tasks to assess such latent constructs. It is likely that different tasks and different latent constructs may elicit a different pattern of results than what is reported here. Indeed, the O-Span task and high lexical density manipulations are not "process-pure" and may likely reflect more than just WM and inhibitory control, respectively. As such, it is important to develop mediated or shared influence models to examine multiple potential contributing factors simultaneously (as discussed in Salthouse & Ferrer-Caja, 2003). The benefit of such an approach is that shared influence models do not assume that any particular variable or construct has a privileged status as a contributor, but instead they postulate that the age-related effects on many variables are at least partially a reflection of age-related effects on whatever is common to them all.

Future Directions

In addition to the limitations proposed above, the results of this study raise several questions that could be addressed by much-needed further investigation.

Longitudinal studies. The data presented in Park et al. (1996) show a longitudinal outcome of cognitive performance across the lifespan in the same individuals. As this was the framework adopted for the current studies, it will be important to examine whether the obtained pattern of data is true in a longitudinal sample. The claim being made here is that older adults acquire linguistic knowledge over a lifetime of experience in using it; to further support this hypothesis, it is necessary to demonstrate the intra-individual changes in dynamics between crystallized and fluid ability and their contributions to maintaining speech performance. Such an approach would also rectify the issue of dichotomizing age, as following individuals through middle-age through to older age would allow for observing potential non-linear trends in cognitive-linguistic interactions that were unable to be captured in the current study. Longitudinal research is also required to examine the intra-individual changes in fluid and crystallized abilities, as many studies have reported that cross-sectional examinations of cognition and knowledge may be subject to cohort effects (e.g., Verhaeghen, 2003). Accordingly, it may be the case that compensatory effects of linguistic knowledge are not maintained across the lifespan within individuals.

Interactions with sensory/acoustic factors. Although the current study focused on non-sensory contributions, it is axiomatic that age-related changes in speech perception requires a thorough understanding of sensory factors such as hearing loss. Previous studies have examined the issue of compensation with respect to a degraded acoustic signal and/or varying degrees of hearing loss (e.g., Gordon-Salant & Fitzgibbons, 1997; Perry & Wingfield, 1994; Pichora-Fuller, 2008; Pichora-Fuller et al, 1995). Compared to younger adults, older adults benefit more from context, and their maximum benefit is obtained in conditions of less severe signal degradation (Pichora-Fuller et al, 1995). Similar results have also been found when the sentences have been unnaturally distorted by jittering (Pichora- Fuller et al, 2007), or by noise-vocoding (Sheldon et al, 2008) to hamper the processing of temporal speech cues. Indeed, across the majority of studies, the compensatory rebalancing of cognitive-linguistic and sensory processing is greater for older adults than for younger adults. Given that the current study has found promising results speaking to the independent contributions of those processes which rely more greatly on cognitive processing and those which rely more greatly on lexical-linguistic processing, comprehensive approaches to examining the various factors that affect age-related speech perception require the inclusion of sensory factors as well. For instance, observing perception at different SNRs offers a systematic way in which to observe potential compensation at varying levels of signal degradation, and which is likely to differ between younger and older adults. For instance, given that in the current study I found a consistent benefit of HP context irrespective of cognitive load, it would be interesting to observe whether the compounded effects of severe signal degradation amd high cognitive load are still overcome by use of semantic context.

Neural compensation. The compensation hypothesis, with its origins in brain imaging studies, argues that the additional brain regions activated during task performance in older adults reflect recruitment in response to age-related reductions in neural resources. Unilateral activation during cognitive-task performance by young adults, for example, may be supplemented by recruitment of homologous regions in the contralateral hemisphere in older adults (Cabeza et al., 2002). Moreover, when performing tasks that are primarily sensory in nature, older adults show recruitment of frontal cortex not activated by younger adults (Cabeza et al., 2004). Because frontal brain regions are associated with executive functions but not sensory functions, this can be interpreted as older adults employing higher-level activation to compensate for sensory decline. However, the current study uniquely demonstrates an interaction of primarily top-down factors in impacting speech perception independent of sensory factors, and the key question is whether such findings would be consistent with imaging studies in which differential activation occurs in the brain of older adults during task performance by older adults and which does not appear when younger adults perform the same task. A test of such an account may involve using an event-related imaging design comparing BOLD activity for successful test trials across age groups. Another method would be to compare BOLD activity between those who are successful on particular trials and those who are not, focusing on the pattern of neural differences that arises between the two groups. If compensation is demonstrable at the neural level, this would likely involve frontal areas such as inferior frontal gyrus and prefrontal cortex, as previous groups have observed (Cabeza, Anderson, Locantore, & McIntosh, 2002; Langenecker, Nielson, & Rao, 2004; Morcom, Good, Frackowiak, & Rugg, 2003), in additional to language – specifically semantic-based – regions (Shafto et al., 2012; see Wingfield & Grossman, 2006 for a review). A key condition on which to focus would be trials with HP context – given older adults' superior performance in trials with HP context, it will be interesting to compare such trials with that of 1) younger adults, and 2) LP context. Accordingly, a cognitive neuroscience approach to replicating the current results is required for a comprehensive assessment of cognitive-linguistic compensation in older adults during speech perception.

Clinical Applications

The current study provides information on the nature of age-related changes in cognition that impact speech perception. As such, it adds to a growing body of literature (e.g., Sommers, 1996; Wingfield, 1996; Wingfield & Tun, 2007) that highlights the role of cognitive declines as a causal locus for age-related declines in speech perception which may exist independently of, but interact with age-related sensory declines. The primary, traditional approach to reducing age-related speech perception declines has been to address issues of sensory loss via signal amplification (i.e., hearing aids). While this approach has met with moderate success (CHABA, 1988), the results of the current study and others suggests that such an approach is necessarily limited. Clearly, a more comprehensive approach in which *both* cognitive and sensory issues are addressed, i.e., cognitive training, is likely to meet with greater success than one which is focused on sensory loss alone. Moreover, these experiments highlight the fact that "cognition" is not a unified construct, and can be divided into those which independently contribute to speech processing. The beneficial effects of semantic context on older adults' performance provide a unique starting point from which to develop individualized clinical training programs. Such programs would ideally incorporate aspects of familiarity and predictability into training sessions, including – but not limited to – semantic context. Moreover, the interactive effects of fluid and crystallized abilities provide a useful individual differences approach to training programs, in which an individuals' unique cognitive profile (based on working memory/inhibitory abilities and linguistic experience) can inform the direction of training.

Concluding Remarks

Investigations of factors that affect age-related changes in speech perception have primarily focused on sensory interactions with top-down processing. Claims of compensation have often been made with respect to mitigating the effects of sensory degradation, but without adequate baseline and control conditions, it is unclear as to how compensation occurs at the cognitive-linguistic level. The results of the present study are the first to provide direct evidence that older adults use intact preserved knowledge to compensate for cognitively demanding situations. In revisiting the conditions required to adequately demonstrate compensation as presented in Chapter 2, it is clear that the conditions were generally met – there was a strong compensatory effect of HP context on both younger and older adult performance that was able to maintain identification accuracy even as ask demands increased, but this was particularly true for older adults. While the beneficial effects of HF information was equivalent for both age groups, older adults appeared to benefit more from LF information than did younger adults. That is, linguistic support appeared to significantly modulate performance to a greater degree for older adults, the strongest effects of which were observed in the high cognitive demand conditions.

Thus, the findings of this study highlight the specific conditions in which the interaction of cognitive-linguistic factors yield differential patterns of performance across age groups. These findings should serve as a useful guide for clarifying current theorizing – and expanding future theorizing – about the nature of age-related changes in speech perception, and how the dynamic interaction of fluid and crystallized abilities contributes to speech processing.

References

Allen, P. A., Madden, D. J., & Crozier, L. C. (1991). Adult age differences in letter-level and word-level processing. *Psychology and Aging*, *6*(2), 261.

Amichetti, N. M., Stanley, R. S., White, A. G., & Wingfield, A. (2013). Monitoring the capacity of working memory: Executive control and effects of listening effort. *Memory & Cognition*, *41*(6), 839-849.

Anderson, N. D., Idaka, T., Cabeza, R., Kapur, S., McIntosh, A. R., & Craik, F. I. (2000). The effects of divided attention on encoding-and retrieval-related brain activity: A PET study of younger and older adults. *Journal of Cognitive Neuroscience*, *12*(5), 775-792.

Arbuckle, T.Y., Cooney, R., Milne, J., & Melchior, A. (1994). Memory for spatial layouts in relation to age and schema typicality. *Psychology and Aging*, *9*, 467–480. doi.org/10.1037//0882-7974.9.3.467

Arlinger, S. (2003). Negative consequences of uncorrected hearing loss-a review. *International Journal of Audiology*, *42*, 2S17-2S20.

Atkinson, R.C., & Shiffrin, R.M. (1968). Human memory: A proposed system and its control processes. In: Spence, KW.; Spence, JT. (Eds). *The Psychology of Learning and Motivation: Advances in Research and Theory* (pg 89-195). New York, NY: Academic Press

Bäckman, L., Almkvist, O., Andersson, J., Nordberg, A., Winblad, B., Reineck, R., & Långström, B. (1997). Brain activation in young and older adults during implicit and explicit retrieval. *Journal of Cognitive Neuroscience, 9*(3), 378-391.

Bäckman, L., Jones, S., Berger, A. K., Laukka, E. J., & Small, B. J. (2005). Cognitive impairment in preclinical Alzheimer's disease: a meta-analysis. *Neuropsychology*, *19*(4), 520.

Baddeley, A. (2000). The episodic buffer: a new component of working memory? *Trends in Cognitive Sciences*, *4*(11):417–423. doi.org/10.1016/s1364-6613(00)01538-2

Balota, D. A., & Ferraro, F. R. (1993). A dissociation of frequency and regularity effects in pronunciation performance across young-adults, older adults, and individuals with senile dementia of the Alzheimer-type. *Journal of Memory and Language*, *32*(5), 573-592.

Balota, D. A., & Ferraro, F. R. (1996). Lexical, sublexical, and implicit memory processes in healthy young and healthy older adults and in individuals with dementia of the Alzheimer type. *Neuropsychology*, *10*(1), 82. doi.org/10.1037//0894-4105.10.1.82

Balota, D. A., Cortese, M. J., Sergent-Marshall, S. D., Spieler, D. H., & Yap, M. (2004). Visual word recognition of single-syllable words. *Journal of Experimental Psychology: General*, *133*(2), 283.

Belleville, S., Chertkow, H., & Gauthier, S. (2007). Working memory and control of attention in persons with Alzheimer's disease and mild cognitive impairment. *Neuropsychology, 21*(4), 458.

Benichov, J., Cox, L. C., Tun, P. A., & Wingfield, A. (2013). Word recognition within a linguistic context: Effects of age, hearing acuity, verbal ability and cognitive function. *Ear and Hearing*, *32*(2), 250–256. doi:10.1097/AUD.0b013e31822f680f

Bialystok, E., Craik, F. I. M., & Ruocco, A. C. (2006). Dual-modality monitoring in a classification task: the effects of bilingualism and ageing. *Quarterly Journal of Experimental Psychology (2006)*, *59*(11), 1968–83. doi:10.1080/17470210500482955

Bialystok, E., Craik, F. I. M., Klein, R., & Viswanathan, M. (2004). Bilingualism, aging, and cognitive control: evidence from the Simon task. *Psychology and Aging*, *19*(2), 290–303. doi:10.1037/0882-7974.19.2.290

Bialystok, E., Craik, F.I.M., & Freedman, M. (2007). Bilingualism as a protection against the onset of symptoms of dementia. *Neuropsychologia*, *45*(2), 459–64. doi:10.1016/j.neuropsychologia.2006.10.009

Bialystok, E., Craik, F.I.M., Binns, M.A, Ossher, L., & Freedman, M. (2013). Effects of bilingualism on the age of onset and progression of MCI and AD: Evidence from executive function tests. *Neuropsychology*. doi:10.1037/neu0000023

Bilger, R. C, Nuetzel, J. M., Rabinowitz, W. M., & Rzeczkowski, C. (1984). Standardization of a test of speech perception in noise. *Journal of Speech and Hearing Research*, *27,* 32-48. doi.org/10.1044/jshr.2701.32

Botwinick, J., & Storandt, M. (1980). Recall and recognition of old information in relation to age and sex. *Journal of Gerontology*, *35*, 70–76. doi.org/10.1093/geronj/35.1.70

Brébion, G. (2003). Working memory, language comprehension, and aging: four experiments to understand the deficit. *Experimental Aging Research*, *29*(3), 269–301. doi:10.1080/03610730303725

Brown, S., & Pichera-Fuller, M. K. (2000). Temporal jitter mimics the effects of aging on word identification and word recall in noise. *Canadian Acoustics*, *28*(3), 126- 128.

Burke, D. M. (1997). Language, aging, and inhibitory deficits: Evaluation of a theory. *Journals of Gerontology: Series B: Psychological Sciences & Social Sciences*, *52B*, 254-264. doi.org/10.1093/geronb/52b.6.p254

Burke, D. M., & Shafto, M. A. (2008). Language and aging. In F.I.M. Craik, T.A. Salthouse (Eds.) *The Handbook of Aging and Cognition, 3rd Edition* (pg 373-443). New York, NY: Psychology Press.

Burke, D. M., MacKay, D. G., & James, L. E. (2000). Theoretical approaches to language and aging. In T. Perfect & E. Maylor (Eds.), *Models of Cognitive Aging* (pp. 204 – 237). Oxford, UK: Oxford University Press.

Burns, D. J., Curti, E. T., & Lavin, J. C. (1993). The effects of generation on item and order retention in immediate and delayed recall. *Memory & Cognition*, *21*(6), 846-852.

Cabeza, R. (2002). Hemispheric asymmetry reduction in older adults: The HAROLD model. *Psychology and Aging*, *17*, 85-100. doi.org/10.1037//0882-7974.17.1.85

Cabeza, R., Anderson, N. D., Locantore, J. K., & McIntosh, A. R. (2002). Aging gracefully: compensatory brain activity in high-performing older adults. *NeuroImage*, *17*(3), 1394–1402. doi:S1053811902912802

Cabeza, R., Grady, C. L., Nyberg, L., McIntosh, A. R., Tulving, E., Kapur, S., ... & Craik, F. I. (1997). Age-related differences in neural activity during memory encoding and retrieval: a positron emission tomography study. *The Journal of Neuroscience*, *17*(1), 391-400.

Caplan, D., Hildebrandt, N. & Waters, G. S. (1994) Interaction of verb selectional restrictions, noun animacy and syntactic form in sentence processing. *Language and Cognitive Processes*, *9*, 549–85. doi.org/10.1080/01690969408402131

Carhart, R., & Nicholls, S. (1971). Perceptual masking in elderly women. *American Speech and Hearing Association*, 13, 535.

Carhart, R., & Tillman, T. W. (1970). Interaction of competing speech signals with hearing loss. *Archives of Otolaryngology*, *91*, 273-279. doi.org/10.1001/archotol.1970.00770040379010

Carlson, S. M., & Meltzoff, A. N. (2008). Bilingual experience and executive functioning in young children. *Developmental Science*, *11*(2), 282-298.

Carter, A. S., & Wilson, R. H. (2001). Lexical effects on dichotic word recognition in young and elderly listeners. *Journal of the American Academy of Audiology*, *12*, 86–100.

Castel, A. D. (2005). Memory for grocery prices in younger and older adults: The role of schematic support. *Psychology and Aging*, *20*, 718–721. doi.org/10.1037/0882-7974.20.4.718

Cattell, R. B. (1998). Where is intelligence? Some answers from the triadic theory. In J. J. McArdle & R. W. Woodcock (Eds.), *Human cognitive abilities in theory and practice* (pp. 29–38). Mahwah, NJ: Erlbaum.

Celone, K. A., Calhoun, V. D., Dickerson, B. C., Atri, A., Chua, E. F., Miller, S. L., ... & Albert, M. S. (2006). Alterations in memory networks in mild cognitive impairment and Alzheimer's disease: an independent component analysis. *The Journal of Neuroscience*, *26*(40), 10222-10231.

Cervera, T. C., Soler, M. J., Dasi, C., & Ruiz, J. C. (2009). Speech recognition and working memory capacity in young-elderly listeners: effects of hearing sensitivity. *Canadian Journal of Experimental Psychology*, *63*(3), 216–26. doi:10.1037/a0014321

Charness N, & Bosman EA. (1990). Expertise and aging: life in the lab. In T.H. Hess (Ed). *Aging and Cognition: Knowledge Organization and Utilization*, pp. 343–85. Amsterdam: Elsevier.

Cohen G, & Faulkner D. (1983). Word recognition: Age differences in contextual facilitation effects. *British Journal of Psychology*, *74*, 239–251. doi.org/10.1111/j.2044-8295.1983.tb01860.x

Committee on Hearing and Bioacoustics, Working Group on Speech Understanding and Aging. (1998). Speech understanding and aging. *Journal of the Acoustical Society of America*, *83*, 859–895. doi.org/10.1121/1.395965

Cowan, N. (1999). An embedded-processes model of working memory. In A. Miyake & P. Shah, (Eds.), *Models of working memory: Mechanisms of active maintenance and executive control* (pp. 62-101) New York, NY: Cambridge University Press

Craik, F. I. (1986). A functional account of age differences in memory. *Human memory and cognitive capabilities: Mechanisms and performances*, 409-422.

Craik, F. I. M., & Jennings, J. M. (1992). Human memory. In F. I. M. Craik & T. A. Salthouse (Eds.), *The handbook of aging and cognition* (pp. 51–110). Hillsdale, NJ: Erlbaum.

Craik, F. I. M., Bialystok, E., & Freedman, M. (2010). Delaying the onset of Alzheimer disease: bilingualism as a form of cognitive reserve. *Neurology*, *75*(19), 1726–9. doi:10.1212/WNL.0b013e3181fc2a1c

Craik, F.I.M. (2007). The role of cognition in age-related hearing loss. *Journal of the American Academy of Audiology*, *18*, 539-547. doi.org/10.3766/jaaa.18.7.2

Daneman M. & Merikle P.M. (1996). Working memory and language comprehension: A meta-analysis. *Psychonomic Bulletin and Review*, *3*, 422-433. doi.org/10.3758/bf03214546

Daneman, M., & Carpenter, P. A. (1980). Individual differences in working memory and reading. *Journal of Verbal Learning and Verbal Behavior*, *466*, 450–466. doi.org/10.1016/s0022-5371(80)90312-6

Davis, H.P., Cohen, A., Gandy, M., Colombo, P., Van Dusseldorp, G., Simolke, N., & Romano, J. (1990). Lexical priming as a function of age. *Behavioral Neuroscience*, *104*, *288-297. doi.org/10.1037//0735-7044.104.2.288*

Davis, M. H., & Johnsrude, I. S. (2007). Hearing speech sounds: top-down influences on the interface between audition and speech perception. *Hearing Research*, *229*(1-2), 132–47. doi:10.1016/j.heares.2007.01.014

Dede, G., Caplan, D., Kemtes, K. A., & Waters, G. (2004). The relationship between age, verbal working memory, and language comprehension. *Psychology and Aging*, *19*(4), 601-616. doi.org/10.1037/0882-7974.19.4.601

Dey, A., & Sommers, M. S. (2015). Age-related differences in inhibitory control predict audiovisual speech perception. *Psychology and Aging*, *30*(3), 634.

Dixon R. & Bäckman L. (Eds.), 1995. *Compensating for Psychological Deficits and Declines: Managing Losses and Promoting Gains*. Mahwah, NJ: Lawrence Erlbaum Associates.

Donders, F. C. (1969). On the speed of mental processes. *Acta Psychologica*, *30*, 412-431. doi.org/10.1016/0001-6918(69)90065-1

Downs, D. W. (1982). Effects of hearing aid use on speech discrimination and listening effort. *Journal of Speech and Hearing Disorders*, *47*(2), 189-193.

Dubno, J. R., Dirks, D. D., & Morgan, D. E. (1984). Effects of age and mild hearing loss on speech recognition in noise. *Journal of the Acoustical Society of America*, *76*, 87–96. doi.org/10.1121/1.391011

Dubno, J.R., Ahlstrom, J.B., & Horwitz, AR. (2000). Use of context by young and aged adults with normal hearing. *Journal of the Acoustical Society of America*. *107*, 538–546. doi.org/10.1121/1.428322

Duquesnoy, A. J. (1983). The intelligibilityof sentences in quiet and in noise in aged listeners. *Journal of the Acoustical Society of America*, *74*, 1136-1144. doi.org/10.1121/1.390037

Engle, R. W., & Kane, K. A. (2004). Executive attention, working memory capacity, and a two-factor theory of cognitive control. In B. H. Ross (Ed.), *The psychology of learning and motivation*, (pp. 145-199). Amsterdam: Elsevier.

Ericsson, K.A. & Charness, N. 1994. Expert performance: Its structure and acquisition. *American Psychologist*, *49*, 725-747. doi.org/10.1037//0003-066x.49.8.725

Fallon, M., Peelle, J. E., & Wingfield, A. (2006). Spoken sentence processing in young and older adults modulated by task demands: evidence from self-paced listening. *The Journals of Gerontology Series B: Psychological Sciences and Social Sciences*, *61*(1), 10-17. doi.org/10.1093/geronb/61.1.p10

Ferreira, F., Henderson, J. M., Anes, M. D., Weeks, P. A., Jr. & McFarlane, D. K. (1996). Effects of lexical frequency and syntactic complexity in spoken language comprehension: Evidence from the auditory moving window technique. *Journal of Experimental Psychology: Learning, Memory and Cognition*, *22*, 324–35. doi.org/10.1037//0278-7393.22.2.324

Feuerstein, J. F. (1992). Monaural versus binaural hearing: ease of listening, word recognition, and attentional effort. *Ear and Hearing*, *13*(2), 80-86.

Folstein, M. F., Folstein, S. E., & McHugh, P. R. (1975). "Mini-mental state": a practical method for grading the cognitive state of patients for the clinician. *Journal of Psychiatric Research*, *12*(3), 189-198.

Foo, C., Rudner, M., Rönnberg, J., and Lunner, T. (2007). Recognition of speech in noise with new hearing instrument compression release set- tings requires explicit cognitive storage and processing capacity. *Journal of the American Academy of Audiology*, *18*, 553–566. doi.org/10.3766/jaaa.18.7.8

Ford, M. (1983) A method for obtaining measures of local parsing complexity throughout sentences. *Journal of Verbal Learning and Verbal Behavior, 22,* 203–18. doi.org/10.1016/s0022-5371(83)90156-1

Fraser, S., Gagné, J.P., Alepins, M., & Dubois, P. (2010) Evaluating the effort expended to understand speech in noise using a dual-task paradigm: the effects of providing visual speech cues. *Journal of Speech, Language, and Hearing Research*, *53*(1), 18–33.

Frazier, L. & Rayner, K. (1982) Making and correcting errors during sentence comprehension: Eye movements in the analysis of structurally ambiguous sentences. *Cognitive Psychology, 143,* 178–210. doi.org/10.1016/0010-0285(82)90008-1

Gelfand, S.A., Piper, N., & Silman, S. (1986). Consonant recognition in quiet and in noise with aging among normal hearing listeners. *Journal of the Acoustical Society of America*, *80*, 1589–1598. doi.org/10.1121/1.392888

Gernsbacher, M.A. (1989). Mechanisms that improve referential access. *Cognition*, *32*, 99-156. doi.org/10.1016/0010-0277(89)90001-2

Gernsbacher, M.A. (1990). Language comprehension as structure building. Hillsdale, NJ: Erlbaum.

Gold, B. T., Johnson, N. F., & Powell, D. K. (2013). Lifelong bilingualism contributes to cognitive reserve against white matter integrity declines in aging. *Neuropsychologia*, *51*(13), 2841-2846.

Goldinger, S., Luce, P.A., & Pisoni, D.B. (1989). Priming lexical neighbors of spoken words: effects of competition and inhibition. *Journal of Memory and Language*, *28*, 501–518. doi.org/10.1016/0749-596x(89)90009-0

Gollan, T. H., Montoya, R. I., Cera, C., & Sandoval, T. C. (2008). More use almost always means a smaller frequency effect: Aging, bilingualism, and the weaker links hypothesis. *Journal of Memory and Language*, *58*(3), 787-814. doi.org/10.1016/j.jml.2007.07.001

Gomez, R. (2002). Word frequency effects in priming performance in young and older adults. *The Journals of Gerontology Series B: Psychological Sciences and Social Sciences*, *57*(3), 233-240. doi.org/10.1093/geronb/57.3.p233

Gordon-Salant, S., & Fitzgibbons, P.J. (1993). Temporal factors and speech recognition performance in young and elderly listeners. *Journal of Speech, Language, and Hearing Research*, *36*, 1276–1285. doi.org/10.1044/jshr.3606.1276

Gordon-Salant, S., & Fitzgibbons, P.J. (1997). Selected cognitive factors and speech recognition performance among young and elderly listeners. *Journal of Speech, Language and Hearing Research*, *40*, 423–431. doi.org/10.1044/jslhr.4002.423

Gordon-Salant, S., & Fitzgibbons, P.J. (2001). Sources of age-related recognition difficulty for time-compressed speech. *Journal of Speech, Language, & Hearing Research*, 44, 709–719. doi.org/10.1044/1092-4388(2001/056)

Gosselin, P. A., & Gagné, J. P. (2011). Older adults expend more listening effort than young adults recognizing speech in noise. *Journal of Speech, Language, and Hearing Research*, *54*(3), 944-958. doi.org/10.1044/1092-4388(2010/10-0069)

Grady, C. L., & Craik, F. I. (2000). Changes in memory processing with age. *Current Opinion in Neurobiology*, *10*(2), 224-231.

Grady, C. L., McIntosh, A. R., Bookstein, F., Horwitz, B., Rapoport, S. I., & Haxby, J. V. (1998). Age-related changes in regional cerebral blood flow during working memory for faces. *Neuroimage*, *8*(4), 409-425. doi.org/10.1006/nimg.1998.0376

Grady, C. L., McIntosh, A. R., Horwitz, B., Maisog, J. M., Ungerleider, L. G., Mentis, M. J., ... & Haxby, J. V. (1995). Age-related reductions in human recognition memory due to impaired encoding. *Science*, *269*(5221), 218-221.

Grady, C.L. (1998). Brain imaging and age-related changes in cognition. *Experimental Gerontology*, *33*, 661-673. doi.org/10.1016/s0531-5565(98)00022-9

Grady, C.L. (2000). Functional brain imaging and age-related changes in cognition. *Biological Psychology*, *54*, 259-281. doi.org/10.1016/s0301-0511(00)00059-4

Hällgren, M., Larsby, B., Lyxell, B., & Arlinger, S. (2005). Speech understanding in quiet and noise, with and without hearing aids. *International Journal of Audiology*, *44*, 574-583. doi.org/10.1080/14992020500190011

Hamm, V. P., & Hasher, L. (1992). Age and the availability of inferences. *Psychology and Aging*, *7*, 56- 64. doi.org/10.1037//0882-7974.7.1.56

Hasher, L., & Zacks, R. T. (1979). Automatic and effortless processes in memory. *Journal of Experimental Psychology: General*, *108*, 356–388.

Hasher, L., & Zacks, R. T. (1988). Working memory, comprehension, and aging: A review and a new view. In G. H. Bower (Ed.), *The psychology of learning and motivation* (Vol. 22, pp. 193–226). New York: Academic Books Ltd

Hasher, L., Zacks, R. T., & May, C. P. (1998). Inhibitory control, circadian arousal, and age. In D. Gopher & A. Koriat (Eds.), *Attention and performance XVII: Cognitive regulation of performance. Interaction of theory and application*, (pp. 653–675). Cambridge, MA: MIT Press.

Heitz, R.P., Schrock, J.C., Payne, T.W., & Engle, R.W. (2008). Effects of incentive on working memory capacity: behavioral and pupillometric data. *Psychophysiology*, *45*, 119–129. doi.org/10.1111/j.1469-8986.2007.00605.x

Helfer, K. S., & Wilber, L. A. (1990). Hearing loss, aging, and speech perception in reverberation and noise. Journal of *Speech, Language, and Hearing Research*, *33*, 149–155. doi.org/10.1044/jshr.3301.149

Hess, T. M. (1990). Chapter Three: Aging and Schematic Influences on Memory. *Advances in Psychology*, *71*, 93-160.

Hess, T. M. (2005). Memory and aging in context. *Psychological Bulletin*, *131*(3), 383.

Hicks, C. B., & Tharpe, A. M. (2002). Listening effort and fatigue in school-age children with and without hearing loss. *Journal of Speech, Language, and Hearing Research*, *45*(3), 573-584.

Horn, J. L., & Cattell, R. B. (1967). Age differences in fluid and crystallized intelligence. *Acta Psychologica*, *26*, 107–129. doi.org/10.1016/0001-6918(67)90011-x

Humes, L. E. (1996). Speech understanding in the elderly. *Journal of the American Academy of Audiology*, *7*, 161-167.

Humes, L. E. (2002). Factors underlying the speech- recognition performance of elderly hearing-aid wearers. *Journal of the Acoustical Society of America*, *112*, 1112–1132. doi.org/10.1121/1.1499132

Humes, L. E. (2007). The contributions of audibility and cognitive factors to the benefit provided by amplified speech to older adults. *Journal of the American Academy of Audiology, 18*, 590–603. doi: 10.3766/ jaaa.18.7.6

Humes, L. E., & Christopherson, L. (1991). Speech identification difficulties of hearing-impaired elderly persons: The contribution of auditory processing deficits. *Journal of Speech and Hearing Research*, *34*, 686– 693. doi.org/10.1044/jshr.3403.686

Humes, L. E., & Roberts, L. (1990). Speech-recognition difficulties of the hearing-impaired elderly: The contributions of audibility. *Journal of Speech and Hearing Research, 33*, 726–735. doi.org/10.1044/jshr.3304.726

Humes, L. E., Busey, T. A., Craig, J., & Kewley-Port, D. (2013). Are age-related changes in cognitive function driven by age-related changes in sensory processing?. *Attention, Perception, & Psychophysics*, *75*(3), 508-524.

Humes, L. E., Christensen, L., Thomas, T., Bess, F. H., Hedley-Williams, A., & Bentler, R. (1999). A comparison of the aided performance and benefit provided by a linear and a two-channel wide dynamic range compression hearing aid. *Journal of Speech, Language, and Hearing Research*, *42*(1), 65-79.

Humes, L. E., Coughlin, M., & Talley, L. (1996). Evaluation of the use of a new compact disc for auditory perceptual assessment in the elderly. *Journal of the Acoustical Society of America*, 7, 419–427.

Humes, L. E., Watson, B. U., Christensen, L. A., Cokely, C. G., Halling, D. C., & Lee, L. (1994). Factors associated with individual differences in clinical measures of speech recognition among the elderly. *Journal of Speech, Language, and Hearing Research, 37*(2), 465-474. .doi.org/10.1044/jshr.3702.465

Humes, L.E., & Dubno, J.R. (2010). Factors affecting speech understanding in older adults. In S. Gordon-Salant, R. D. Frisina, A. N. Popper, & R. R. Fay (Eds.), *The Aging Auditory System* (Vol. 34, pp. 167–210). New York, NY: Springer New York. doi:10.1007/978-1-4419-0993-0

Hutchinson, K. M. (1989). Influence of sentence context on speech perception in young and older adults. *Journal of Gerontology*, *44*(2), 36–44. doi:10.1093/geronj/44.2.P36

Jacoby, L. L., & Rhodes, M. G. (2006). False remembering in the aged. *Current Directions in Psychological Science*, *15*, 49–53. doi:10.1111/ j.0963-7214.2006.00405.x

Jerger J., Jerger S. & Pirozzolo F. (1991). Correlational analysis of speech audiometric scores, hearing loss, age, and cognitive abilities in the elderly. *Ear & Hearing*, *12*, 103-109. doi.org/10.1097/00003446-199104000-00004

Kalikow, D. N., Stevens, K. N., & Elliott, L. L. (1977). Development of a test of speech intelligibility in noise using sentence materials with controlled word predictability. *The Journal of the Acoustical Society of America*, *61*(5), 1337-1351. doi.org/10.1121/1.381436

Kemper, S. 1992. Language and aging. In F.I.M. Craik & T.A. Salthouse (eds.) *The Handbook of Aging and Cognition*, (pp. 213-270). Hillsdale, NJ: Lawrence Erlbaum Associates.

Kemper, S., & Herman, R. E. (2006). Age differences in memory-load interference effects in syntactic processing. *The Journals of Gerontology Series B: Psychological Sciences and Social Sciences*, *61*(6), 327-332. doi.org/10.1093/geronb/61.6.p327

Kemper, S., Crow, A., & Kemtes, K. (2004). Eye fixation patterns of high and low span young and older adults: Down the garden path and back again. *Psychology and Aging*, *19*, 157-170. doi.org/10.1037/0882-7974.19.1.157

King, J. & Just, M. A. (1991). Individual differences in syntactic processing: The role of working memory. *Journal of Memory and Language*, *30*, 580–602. doi.org/10.1016/0749-596x(91)90027-h

Kintsch, W. (1988). The role of knowledge in discourse comprehension: A construction-integration model. *Psychological Review*, *95*, 163–182. doi.org/10.1037/0033-295x.95.2.163

Koutstaal, W., Reddy, C., Jackson, E. M., Prince, S., Cendan, D. L., & Schacter, D. L. (2003). False recognition of abstract versus common objects in older and younger adults: Testing the semantic categorization account. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *29*, 499–510. doi.org/10.1037/0278-7393.29.4.499

Kramer, S. E., Kapteyn, T. S. & Houtgast, T. (2006). Occupational performance: Comparing normally-hearing and hearing-impaired employees using the Amsterdam Checklist for Hearing and Work. *International Journal of Audiology*, *45*(9), 503–512. doi.org/10.1080/14992020600754583

Kwong See, S. T., & Ryan, E. B. (1995). Cognitive mediation of adult age differences in language performance. *Psychology and Aging*, *10*(3), 458–468. doi:10.1037//0882-7974.10.3.458

Lewellen, M. J., Goldinger, S. D., Pisoni, D. B., & Greene, B. G. (1993). Lexical familiarity and processing efficiency: Individual differences in naming, lexical decision, and semantic categorization. *Journal of Experimental Psychology: General*, *122*, 316–330. doi: 10.1037/0096- 3445.122.3.316

Li, K. Z., & Lindenberger, U. (2002). Relations between aging sensory/sensorimotor and cognitive functions. *Neuroscience & Biobehavioral Reviews*, *26*(7), 777-783.

Li, L., Daneman, M., Qi, J. & Schneider, B.A. (2004). Does the information content of an irrelevant source differentially affect speech recognition in younger and older adults? *Journal* of *Experimental Psychology*: *Human Perception and Performance*, *30*, 1077-1091. doi.org/10.1037/0096-1523.30.6.1077

Lieberman, P. (1963). Some effects of semantic and grammatical context on the production and perception of speech. *Language and Speech*, *6*(3), 172–187.

Light, L. L. (1991). Memory and aging: Four hypotheses in search of data. *Annual Review Psychology*, *42*, 333–376. doi.org/10.1146/annurev.ps.42.020191.002001

Logan, J. M., Sanders, A. L., Snyder, A. Z., Morris, J. C., & Buckner, R. L. (2002). Under-recruitment and nonselective recruitment: dissociable neural mechanisms associated with aging. *Neuron*, *33*(5), 827-840.

Luce, P. & Pisoni, D. (1998). Recognizing spoken words: The neighborhood activation model. *Ear & Hearing*, *19*, 1-36. doi.org/10.1097/00003446-199802000-00001

Lund, K., & Burgess, C. (1996). Producing high-dimensional semantic spaces from lexical co-occurrence. *Behavior Research Methods, Instruments, & Computers*, *28*(2), 203-208.

Lunner, T. (2003). Cognitive function in relation to hearing aid use. *International journal of audiology*, *42*, S49-S58.

MacDonald, M. C. (1997). Language and cognitive processes. *Special Issue on Lexical Representations and Sentence Processing*, *12*, 121-399. doi.org/10.1080/016909697386709

MacDonald, M. C., & Christiansen, M. H. (2002). Reassessing working memory: Comment on Just and Carpenter (1992) and Waters and Caplan (1996). *Psychological Review, 109*, 35–54. doi: 10.1037/0033- 295X.109.1.35

MacKay, D. G., & Abrams, L. (1998). Age-linked declines in retrieving orthographic knowledge: empirical, practical, and theoretical implications. *Psychology and Aging, 13*(4), 647. doi.org/10.1037//0882-7974.13.4.647

Madden, D. J., Gottlob, L. R., Denny, L. L., Turkington, T. G., Provenzale, J. M., Hawk, T. C., & Coleman, R. E. (1999). Aging and recognition memory: Changes in regional cerebral blood flow associated with components of reaction time distributions. *Journal of Cognitive Neuroscience*, *11*(5), 511-520.

Madden, D.J. (1988). Adult age differences in the effects of sentence context and stimulus degradation during visual word recognition. *Psychology of Aging*, 3:167–172. doi.org/10.1037//0882-7974.3.2.167

Marsh, E. J., Balota, D. A., & Roediger, H. L., III. (2005). Learning facts from fiction: Effects of healthy aging and early-stage dementia of the Alzheimer type. *Neuropsychology*, *19*, 115– 129. doi.org/10.1037/0894-4105.19.1.115

Marslen-Wilson, W. D. (1987). Functional parallelism in spoken word-recognition. *Cognition*, *25*(1-2), 71–102. doi:10.1016/0010-0277(87)90005-9

Martin, M., Ewert, O., & Schwanenflugel, P. J. (1994). The role of verbal ability in the processing of complex verbal information. *Psychological Research*, *56*, 301–309. doi: 10.1007/ BF00419660

Martin-Rhee, M. M., & Bialystok, E. (2008). The development of two types of inhibitory control in monolingual and bilingual children. *Bilingualism: Language and Cognition*, *11*(01), 81-93.

Matzen, L. E., & Benjamin, A. S. (2013). Older and wiser: Older adults' episodic word memory benefits from sentence study contexts. *Psychology and Aging*, *28*(3), 754. doi.org/10.1037/a0032945

Mcclelland, J. L., & Elman, J. L. (1986). The TRACE model of speech. *Cognitive Psychology*, *18*, 1–86. doi.org/10.1016/0010-0285(86)90015-0

McCoy, S. L., Tun, P.A, Cox, L.C., Colangelo, M., Stewart, R.A, & Wingfield, A. (2005). Hearing loss and perceptual effort: downstream effects on older adults' memory for speech. *The Quarterly Journal of Experimental Psychology. A, Human Experimental Psychology*, *58*(1), 22–33. doi:10.1080/02724980443000151

McGinnis, D., & Zelinski, E. M. (2000). Understanding unfamiliar words: the influence of processing resources, vocabulary knowledge, and age. *Psychology and Aging*, *15*(2), 335. doi.org/10.1037//0882-7974.15.2.335

Miller, L. M. S., & Stine-Morrow, E. A. (1998). Aging and the effects of knowledge on on-line reading strategies. *The Journals of Gerontology Series B: Psychological Sciences and Social Sciences*, *53*(4), 223-233. doi.org/10.1093/geronb/53b.4.p223

Morton J. (1969) Interaction of information in word recognition. *Psychological Review*, 165–178. doi.org/10.1037/h0027366

Nairne, J. S., Riegler, G. L., & Serra, M. (1991). Dissociative effects of generation on item and order retention. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *17*(4), 702.

Nelson, P. T., Alafuzoff, I., Bigio, E. H., Bouras, C., Braak, H., Cairns, N. J., ... & Duyckaerts, C. (2012). Correlation of Alzheimer disease neuropathologic changes with cognitive status: a review of the literature. *Journal of Neuropathology & Experimental Neurology*, *71*(5), 362-381.

Nittrouer, S., & Boothroyd, A. (1990). Context effects in phoneme and word recognition by young children and older. *The Journal of the Acoustical Society of America*, *87*(6), 2705–2715. doi.org/10.1121/1.399061

Norman, S., Kemper, S., Kynette, D., Cheung, H., & Anagnopoulos, C. (1991). Syntactic complexity and adults' running memory span. *Journal of Gerontology*, *46*(6), P346–P351. doi:10.1093/geronj/46.6.P346

Park, D.C., Lautenschlager, G., Smith, A.D., & Earles J.L. (1996). Mediators of long-term memory performance across the life span. *Psychology and Aging*, *11*, 621–37. doi.org/10.1037//0882-7974.11.4.621

Payer, D., Marshuetz, C., Sutton, B., Hebrank, A., Welsh, R. C., & Park, D. C. (2006). Decreased neural specialization in old adults on a working memory task. *Neuroreport, 17*(5), 487-491.

Perry, A. R., & Wingfield, A. (1994). Contextual encoding by young and elderly adults as revealed by cued and free recall. *Aging and Cogntion*, *1*(2), 120-139. doi.org/10.1080/09289919408251454

Pichora-Fuller, M. K. (2003). Cognitive aging and auditory information processing. *International Journal of Audiology*, *42*, 226–232. doi.org/10.3109/14992020309074641

Pichora-Fuller, M. K., & Singh, G. (2006). Effects of age on auditory and cognitive processing: implications for hearing aid fitting and audiologic rehabilitation. *Trends in amplification, 10*(1), 29-59.

Pichora-Fuller, M. K., Schneider, B. A., & Daneman, M. (1995). How young and old adults listen to and remember speech in noise. *Journal of the Acoustical Society of America*, *97*(1). doi.org/10.1121/1.412282

Pichora-Fuller, M.K. (2007). Audition and cognition: What audiologists need to know about listening. In C. Palmer & R. Seewald (eds.) Hearing Care for Adults. Stäfa, Switzerland: Phonak, pp. 71-85.

Rabbit, P.M.A. (1968). Channel capacity, intelligibility and immediate memory. *Quarterly Journal of Experimental Psychology*, 20, 241–248. doi.org/10.1080/14640746808400158

Rabbit, P.M.A. (1991). Mild hearing loss can cause apparent memory failures with increase with age and reduce with IQ. *Acta Otolaryngologica*, *476*(Suppl.), 167–176. doi.org/10.3109/00016489109127274

Radvansky, G. A., Copeland, D. E., & von Hippel, W. (2010). Stereotype activation, inhibition, and aging. *Journal of Experimental Social Psychology*, *46*, 51–60. doi.org/10.1016/j.jesp.2009.09.010

Rayner, K., Reichle, E. D., Stroud, M. J., Williams, C. C., & Pollatsek, A. (2006). The effect of word frequency, word predictability, and font difficulty on the eye movements of young and older readers. *Psychology and aging*, *21*(3), 448.

Rayner, K., Yang, J., Castelhano, M. S., & Liversedge, S. P. (2011). Eye movements of older and younger readers when reading disappearing text. *Psychology and Aging*, *26*(1), 214.

Reuter-Lorenz, P. A., & Cappell, K. A. (2008). Neurocognitive aging and the compensation hypothesis. *Current Directions in Psychological Science*, *17*(3), 177-182. doi.org/10.1111/j.1467-8721.2008.00570.x

Reuter-Lorenz, P. A., & Lustig, C. (2005). Brain aging: reorganizing discoveries about the aging mind. *Current Opinion in Neurobiology*, *15*(2), 245-251. doi.org/10.1016/j.conb.2005.03.016

Reuter-Lorenz, P. A., Jonides, J., Smith, E. E., Hartley, A., Miller, A., Marshuetz, C., & Koeppe, R. A. (2000). Age differences in the frontal lateralization of verbal and spatial working memory revealed by PET. *Journal of Cognitive Neuroscience*, *12*(1), 174-187.

Reuter-Lorenz, P. A., Marshuetz, C., Jonides, J., Smith, E. E., Hartley, A., & Koeppe, R. (2001). Neurocognitive ageing of storage and executive processes. *European Journal of Cognitive Psychology*, *13*(1-2), 257-278.

Reyna, V. F., & Brainerd, C. J. (1995). Fuzzy-trace theory: An interim synthesis. *Learning and Individual Differences*, *7*(1), 1-75.

Ries, P. W. (1994). Prevalence and characteristics of persons with hearing trouble: United States, 1990-91. *Vital and Health Statistics. Series 10, Data from the National Health Survey*, (188), 1-75.

Roediger, H.L., Balota, D.A., & Watson, J.M. (2001). Spreading activation and the arousal of false memories. In H. L. Roediger III, J. S. Nairne, I. Neath, & A. M. Surprenant (Eds.), *The nature of remembering: Essays in honor of Robert G. Crowder*, (pp. 95–115). Washington DC: American Psychological Association.

Rogers, C. S., Jacoby, L. L., & Sommers, M. S. (2012). Frequent false hearing by older adults: the role of age differences in metacognition. *Psychology and Aging*, *27*(1), 33–45. doi:10.1037/a0026231

Rönnberg, J., Lunner, T., Zekveld, A., Sörqvist, P., Danielsson, H., Lyxell, B., & Rudner, M. (2013). The Ease of Language Understanding (ELU) model: theoretical, empirical, and clinical advances. *Frontiers in Systems Neuroscience*, *7*(31), 1-17. doi:10.3389/fnsys.2013.00031

Rönnberg, J., Rudner, M., Foo, C., & Lunner, T. (2008). Cognition counts: A working memory system for ease of language understanding (ELU). *International Journal of Audiology*, *47 Suppl 2*, S99–105. doi:10.1080/14992020802301167

Rönnberg, J., Rudner, M., Lunner, T., & Zekveld, A.A. (2010). When cognition kicks in: working memory and speech understanding in noise. *Noise & Health*, *12*(49), 263–9. doi:10.4103/1463-1741.70505

Rönnlund, M., Nyberg, L., Backman, L., & Nilsson, L.G. (2005). Stability, growth, and decline in adult life span development of declarative memory: cross-sectional and longitudinal data from a population-based study. *Psychology and Aging*, *20*, 3–18. doi.org/10.1037/0882-7974.20.1.3

Rose T. L., Yesavage J. A., Hill R. D., Bower G. H. (1986). Priming effects and recognition memory in young and elderly adults. *Experimental Aging Research* 12:31-37. doi.org/10.1080/03610738608259432

Rudner, M., and Rönnberg, J. (2008). The role of the episodic buffer in working memory for language processing. *Cognitive Processing, 9*, 19–28. doi 10.1007/s10339-007-0183-x

Rudner, M., Fransson, P., Ingvar, M., Nyberg, L., & Rönnberg, J. (2007). Neural representation of binding lexical signs and words in the episodic buffer of working memory. *Neuropsychologia*, *45*(10), 2258-2276.

Rudner, M., Lunner, T., Behrens, T., Thorén, E. S., & Rönnberg, J. (2012). Working memory capacity may influence perceived effort during aided speech recognition in noise. *Journal of the American Academy of Audiology*, *23*(8), 577-589. doi.org/10.3766/jaaa.23.7.7

Rypma, B., & D'Esposito, M. (2000). Isolating the neural mechanisms of age-related changes in human working memory. *Nature Neuroscience*, *3*(5), 509-515.

Salthouse TA. (1991). *Theoretical Perspectives on Cognitive Aging*. Hillsdale, NJ: Elrbaum

Salthouse, T. a. (2009). When does age-related cognitive decline begin? *Neurobiology of Aging*, *30*(4), 507–14. doi:10.1016/j.neurobiolaging.2008.09.023

Salthouse, T. a. (2010). Selective review of cognitive aging. *Journal of the International Neuropsychological Society : JINS*, *16*(5), 754–60. doi:10.1017/S1355617710000706

Sarampalis, A., Kalluri, S., Edwards, B., & Hafter, E. (2009). Objective measures of listening effort: Effects of background noise and noise reduction. *Journal of Speech, Language, and Hearing Research*, *52*(5), 1230-1240.

Schacter, D. L., Savage, C. R., Alpert, N. M., Rauch, S. L., & Albert, M. S. (1996). The role of hippocampus and frontal cortex in age-related memory changes: a PET study. *Neuroreport*, *7*(6), 1165-1169.

Schaie, K. W. (1996). *Intellectual development in adulthood: The Seattle longitudinal study*. Cambridge University Press.

Schneider, B. A., & Pichora-Fuller, M. K. (2001). Age-related changes in temporal processing: implications for speech perception. *Seminars in hearing,* 22(3), 227-240.

Schneider, B. A., Daneman, M., & Murphy, D. R. (2005). Speech comprehension difficulties in older adults: Cognitive slowing or age-related changes in hearing? *Psychology and Aging*, *20*(2), 261.

Schneider, B. A., Daneman, M., & Pichora-Fuller, M. K. (2002). Listening in aging adults: from discourse comprehension to psychoacoustics. *Canadian Journal of Experimental Psychology/Revue canadienne de psychologie expérimentale*, *56*(3), 139.

Schneider, B. A., Pichora-Fuller, K., & Daneman, M. (2010). Effects of senescent changes in audition and cognition on spoken language comprehension. In *The aging auditory system* (pp. 167-210). Springer New York.

Schweizer, T. A., Ware, J., Fischer, C. E., Craik, F. I., & Bialystok, E. (2012). Bilingualism as a contributor to cognitive reserve: Evidence from brain atrophy in Alzheimer's disease. *Cortex*, *48*(8), 991-996.

Silagi, M. L., Rabelo, C. M., Schochat, E., & Mansur, L. L. (2015). Healthy Aging and Compensation of Sentence Comprehension Auditory Deficits. *BioMed research international*, *2015*.

Sommers, M. S. (2002). Washington University Speech and Hearing Lab Neighborhood Database. *Retrieved from neighborhoodsearch.wustl.edu/Home.asp*.

Sommers, M.S. (1996). The structural organization of the mental lexicon and its contribution to age-related declines in spoken-word recognition. *Psychology and Aging*, *11*, 333–341. doi.org/10.1037//0882-7974.11.2.333

Sommers, M.S., & Danielson, S.M. (1999). Inhibitory processes and spoken word recognition in young and older adults: the interaction of lexical competition and semantic context. *Psychology and Aging*, *14*(3), 458–72. doi.org/10.1037//0882-7974.14.3.458

Sörqvist, P., & Rönnberg, J. (2012). Episodic long-term memory of spoken discourse masked by speech: What is the role for working memory capacity? *Journal of Speech, Language and Hearing Research*, *55*(February), 210–219. doi:10.1044/1092-4388(2011/10-0353)a

Souza, P.E., & Turner, C.W. (1994). Masking of speech in young and elderly listeners with hearing loss. *Journal of Speech Language and Hearing Research*, *37*, 655–661.

Spieler, D. H., & Balota, D. A. (2000). Factors influencing word naming in younger and older adults. *Psychology and Aging*, *15*(2), 225. doi.org/10.1037//0882-7974.15.2.225

Stenfelt, S., & Rönnberg, J. (2009). The signal-cognition interface: interactions between degraded auditory signals and cognitive processes. *Scandinavian Journal of Psychology*, *50*(5), 385–93. doi:10.1111/j.1467-9450.2009.00748.x

Stern, Y. (2002). What is cognitive reserve? Theory and research application of the reserve concept. *Journal of the International Neuropsychological Society*, *8*(03), 448-460.

Stern, Y. (2009). Cognitive reserve. *Neuropsychologia*, *47*(10), 2015-2028.

Stine-Morrow, E. A.L, Miller, L. M. S., & Nevin, J. A. (1999). The effects of context and feedback on age differences in spoken word recognition. *The Journals of Gerontology Series B: Psychological Sciences and Social Sciences*, *54*(2), 125-134. doi.org/10.1093/geronb/54b.2.p125

Stine-Morrow, E.A.L, & Wingfield, A. (1990). How much do working memory deficits contribute to age differences in discourse memory? *European Journal of Cognitive Psychology*, *2*(3), 289-304. doi.org/10.1080/09541449008406209

Tainturier, M. J., Tremblay, M., & Lecours, A. (1989). Aging and the word frequency effect: A lexical decision investigation. *Neuropsychologia*, *27*(9), 1197-1202. doi.org/10.1016/0028-3932(89)90103-6

Tainturier, M. J., Tremblay, M., & Lecours, A. (1992). Educational level and the word frequency effect: A lexical decision investigation. *Brain and Language*, *43*(3), 460-474. doi.org/10.1016/0093-934x(92)90112-r

Takayanagi, S., Dirks, D. D., & Moshfegh, A. (2002). Lexical and talker effects on word recognition among native and non-native listeners with normal and impaired hearing. *Journal of Speech, Language, and Hearing Research*, *45*(3), 585-597.

Taler, V., Aaron, G.P., Steinmetz, L.G., & Pisoni, D.B. (2010). Lexical neighborhood density effects on spoken word recognition and production in healthy aging. *The Journals of Gerontology. Series B, Psychological Sciences and Social Sciences*, *65*(5), 551–60. doi:10.1093/geronb/gbq039

Titone, D.A., Koh, C.K., Kjelgaard, M.M., Bruce, S., Speer, S.R., & Wingfield, A. (2006). Age-related impairments in the revision of syntactic misanalyses: Effects of prosody. *Language and Speech*, *49*, 75–99. doi.org/10.1177/00238309060490010501

Tucker, A. M., & Stern, Y. (2011). Cognitive reserve in aging. *Current Alzheimer Research*, *8*(4), 354.

Tun, P. A. (1998). Fast noisy speech: Age differences in processing rapid speech with background noise. *Psychology and Aging*, *13*, 424–434. doi.org/10.1037//0882-7974.13.3.424

Tun, P. A., & Wingfield, A. (1999). One voice too many: Adult age differences in language processing with different types of distracting sounds. *The Journals of Gerontology Series B: Psychological Sciences and Social Sciences*, *54*(5), 317-327. doi.org/10.1093/geronb/54b.5.p317

Tun, P. A., McCoy, S., & Wingfield, A. (2009). Aging, hearing acuity, and the attentional costs of effortful listening. *Psychology and aging*, *24*(3), 761.

Tun, P. A., O'Kane, G., & Wingfield, A. (2002). Distraction by competing speech in young and older adult listeners. *Psychology and Aging*, *17*(3), 453–467. doi:10.1037//0882-7974.17.3.453

Tun, P. A., Wingfield, A., & Stine, E.A. (1991). Speech-processing capacity in young and older adults: A dual-task study. *Psychology and Aging*, *6*, 3-9. doi.org/10.1037//0882-7974.6.1.3

Tun, P. A., Wingfield, A., Rosen, M. J., & Blanchard, L. (1998). Response latencies for false memories: gist-based processes in normal aging. *Psychology and Aging*, *13*(2), 230. doi.org/10.1037//0882-7974.13.2.230

Turner, M. L., & Engle, R. W. (1989). Is working memory capacity task dependent?. *Journal of Memory and Language*, *28*(2), 127-154. doi.org/10.1016/0749-596x(89)90040-5

Umanath, S., & Marsh, E. J. (2012). Aging and the memorial consequences of catching contradictions with prior knowledge. *Psychology and Aging, 27*, 1033–1038. doi.org/10.1037/a0027242

Van der Linden, M., Hupet, M., Feyereisen, P., Schelstraete, M. A., Bestgen, Y., Bruyer, R., ... & Seron, X. (1999). Cognitive mediators of age-related differences in language comprehension and verbal memory performance. *Aging, Neuropsychology, and Cognition*, *6*(1), 32-55. doi.org/10.1076/anec.6.1.32.791

van Rooij, J.C.G.M., & Plomp, R. (1990). Auditive and cognitive factors in speech perception by elderly listeners. II. Multivariate analyses. *The Journal of the Acoustical Society of America*, *88*, 2611–2624. doi.org/10.1121/1.399981

Verhaeghen, P. (2003). Aging and vocabulary score: A meta-analysis. *Psychology and Aging*, *18*(2), 332–339. doi:10.1037/0882-7974.18.2.332

Verhaeghen, P., & Salthouse, T. A. (1997). Meta-analyses of age–cognition relations in adulthood: Estimates of linear and non-linear age effects and structural models. *Psychological Bulletin*, *122,* 231–249. doi.org/10.1037//0033-2909.122.3.231

West, R.F., Stanovich, K.E. & Cunningham, A.E. (1995). Compensatory processes in reading. In R. Dixon & L. Bäckman (eds.) *Compensating for Psychological Deficits and Declines: Managing Losses and Promoting Gains,* (pp. 275-296). Mahwah, NJ: Lawrence Erlbaum Associates

Whiting, W. L., Madden, D. J., Langley, L. K., Denny, L. L., Turkington, T. G., Provenzale, J. M., Hawk, T. C., & Coleman, R. E. (2003). Lexical and sublexical components of age-related changes in neural activation during visual word identification. *Journal of Cognitive Neuroscience, 15*, 475–487. doi.org/10.1162/089892903321593171

Whiting, W. L., Madden, D. J., Langley, L. K., Denny, L. L., Turkington, T. G., Provenzale, J. M., Hawk, T. C., et al. (2006). Lexical and sublexical components of age-related changes in neural activation during visual word identification. *Journal of Cognitive Neuroscience*, 15(3), 475–487.

Wingfield, A., & Stine-Morrow, E.A. (2000) Language and speech. In F.I.M. Craik & T.A. Salthouse (Eds.) *Handbook of Aging and Cognition*: *2nd edition* (pp 359-416). Mahwah, NJ: Erlbaum.

Wingfield, A., & Tun, P.A. (2007). Cognitive supports and cognitive constraints on comprehension of spoken language comprehension. *Journal of the American Academy of Audiology*, *18*, 548–558. doi.org/10.3766/jaaa.18.7.3

Wingfield, A., Aberdeen, J.S., & Stine, E.A.L. (1991). Word onset gating and linguistic context in spoken word recognition by young and elderly adults. *Journal of Gerontology*, *46*(3), 127–129. doi:10.1093/geronj/46.3.P127

Wingfield, A., Poon, L. W., Lombardi, L., & Lowe, D. (1985). Speed of processing in normal aging: Effects of speech rate, linguistic structure, and processing time. *Journal of Gerontology*, *40*(5), 579-585. doi.org/10.1093/geronj/40.5.579

Wingfield, A., Stine, E.A.L., Lahar, C.J., & Aberdeen, J.S. (1988). Does the capacity of working memory change with age? *Experimental Aging Research*, *14*, 103–107. doi.org/10.1080/03610738808259731

Zacks, R.T. & Hasher, L. (1994). Directed ignoring: Inhibitory regulation of working memory. In: Dagenbach D, Carr TH (Eds.) *Inhibitory Processes in Attention, Memory, and Language* (pp. 241–264). San Diego, CA: Academic Press

Zekveld, A.A., Kramer, S.E., & Festen, J.M. (2010). Pupil response as an indication of effortful listening: the influence of sentence intelligibility. *Ear & Hearing*, *31*(4), 480–490. doi.org/10.1097/aud.0b013e3181d4f251

Zekveld, A.A., Kramer, S.E., & Festen, J.M. (2011). Cognitive load during speech perception in noise: The influence of age, hearing loss, and cognition on the pupil response. *Ear & Hearing*, 32, 498–510. doi.org/10.1097/aud.0b013e31820512bb

Zekveld, A.A., Rudner, M., Johnsrude, I.S., Dirk, J., Heslenfeld, D.J., & Rönnberg, J. (2012). Behavioural and fMRI evidence that cognitive ability modulates the effect of con- text on speech intelligibility. *Brain and Language*, *122*, 103–113. doi: 10.1016/j. bandl.2012.05.006

Zurif, E., Swinney, D., Prather, P., Wingfield, A. & Brownell, H. (1995). The allocation of memory resources during sentence comprehension: Evidence from the elderly. *Journal of Psycholinguistic Research*, *24*, 165–82. doi.org/10.1007/bf02145354

APPENDIX A.

Demographics Questionnaire

1) How would you describe your socioeconomic status (SES) relative to society?
   a) Significantly above average
   b) Above average
   c) Average
   d) Below average
   e) Significantly below average

2) What is your approximate income bracket? If currently retired, select income during past employment. If dependent, select household income bracket.
   a) $0- $19,999
   b) $20,000- $49,999
   c) $50,000- $79,999
   d) $80,000- $109,999
   e) $110,000- $139,999
   f) $140,000- $169,999
   g) $170,000- $199,999
   h) $200,000+

3) How many complete years of education do you have? (12 = through high school)

APPENDIX B.

Reading Habits Questionnaire (from Stanovich & West, 1995)

1) How often do you read for pleasure?

   a) Almost never
   b) A couple times a year
   c) Every month
   d) Every week
   e) Everyday

2) Do you subscribe to or buy magazines on a regular basis?

   a) YES
   b) NO

If YES, how often?

   a) A couple times a year
   b) Every month
   c) Every week
   d) Everyday

3) How often do you read newspapers?

   a) More than one a day
   b) One each day
   c) Occasionally
   d) Rarely
   e) Never

4) How many books have you read over the past year?

   a) 0
   b) 1-2
   c) 3-10
   d) 10+

5) How much do you enjoy reading?

   a) Not very much
   b) A little
   c) Very much
   d) Extremely

APPENDIX C

List of Stimuli.

C1. High-Predictability (HP) and Low-Predictability (LP) Context – Single-Word Stimuli

Prime Word	Target Word	Forward Strength Association
LABEL	TAG	HP
ZEST	SOAP	HP
TAXI	CAB	HP
SICKLE	CELL	HP
PLASTER	WALL	HP
SOW	PIG	HP
SOCK	SHOE	HP
CHICKEN	SOUP	HP
BEANS	RICE	HP
DIM	LIGHT	HP
RAW	MEAT	HP
VILLAIN	BAD	HP
DEATH	LIFE	HP
POLISH	SHINE	HP
HURT	PAIN	HP
CRESCENT	MOON	HP
SUN	TAN	HP
HULL	BOAT	HP
HANDLE	CARE	HP
MORSE	CODE	HP
PICTURE	FRAME	HP
SHAME	GUILT	HP
HURRICANE	STORM	HP
HUT	STRAW	HP
POCKET	JEANS	HP

ACCELERATE	SPEED	HP
FROWN	SMILE	HP
OFFICE	DESK	HP
HIKING	BOOTS	HP
SNOTTY	SNOB	HP
BANANA	FRUIT	HP
FACULTY	STAFF	HP
LEDGE	CLIFF	HP
PINT	QUART	HP
COMPLAIN	WHINE	HP
NORTH	SOUTH	HP
HOLE	GROUND	HP
EMBARRASS	BLUSH	HP
WRITE	PRINT	HP
MENTAL	HEALTH	HP
CONTINENT	BONE	LP
FEET	FAKE	LP
LEND	DATE	LP
FIGHT	LACE	LP
DUCKS	FAIR	LP
NERD	WEST	LP
BEST	CAKE	LP
SAINT	STATE	LP
FORM	LAW	LP
TANK	BUMP	LP
CON	FUN	LP
HARBOR	LUCK	LP
CASE	BLOW	LP
WINDOW	OWL	LP
GRAVEL	CHAIR	LP
SERVICE	STACK	LP

NOTHING	HAT	LP
FLOWERS	ROPE	LP
SPOT	STICK	LP
OPEN	SMUDGE	LP
HOUR	FUDGE	LP
HEAVEN	DUST	LP
EASTER	NOISE	LP
LOTS	DRUG	LP
HINT	FAINT	LP
WINGS	STRESS	LP
NOON	PLACE	LP
PAN	STRAP	LP
LEGAL	GRAPH	LP
ASTRONAUT	CLIMB	LP
REALIZE	PROOF	LP
DRUNK	STAMP	LP
DEVIL	CLUB	LP
REPENTANCE	POINT	LP
DAMP	THIRST	LP
BUBBLE	BLAME	LP
SKIP	MIX	LP
LIGHTNING	PLANT	LP
FISSURE	THREAD	LP
TWICE	HORSE	LP
MONASTERY	EYES	HP
PICK	CHOOSE	HP
SATIN	SILK	HP
PITCHFORK	HAY	HP
FROSTED	FLAKES	HP
GULLY	BRIDE	HP
ACRE	LAND	HP

ARCHITECT	EYE	HP
SOIL	DIRT	HP
LUNCH	GAS	HP
BLOUSE	HAIR	HP
PORCELAIN	DOLL	HP
CARDS	BASS	HP
DAWN	DUSK	HP
LEADER	FEAR	HP
CLEAN	BLOOD	HP
MUTTON	LAMB	HP
CHARCOAL	GRILL	HP
LEAST	BATH	HP
NIGHT	DAY	HP
CROOK	FAITH	HP
CALCULATOR	MATH	HP
KNAPSACK	BOY	HP
ADMISSION	AX	HP
SELECTION	CHOICE	HP
TRUTHFUL	LEAF	HP
MALL	LAKE	HP
ARIGHT	FOLD	HP
CORRIDOR	HALL	HP
FINGER	HAND	HP
EXHALE	LEG	HP
EFFECT	GROUP	HP
HIVE	BEE	HP
PIG	HOG	HP
PRO	CON	HP
SUBJECT	CLASS	HP
WIDE	BOOK	HP
BALLET	DANCE	HP

LEAN	CHIP	HP
CUP	HORN	HP
THING	RIBS	LP
KEEPER	DRESS	LP
JAWS	STRIPE	LP
ROUGH	SMOOTH	LP
CLEANER	MAID	LP
SABER	ROCK	LP
CRY	TEARS	LP
SNEAK	SICK	LP
MEMORIAL	STAIN	LP
GUITAR	STRING	LP
CLOUD	SKY	LP
DAIRY	BELT	LP
ANTEATER	RING	LP
SEASHORE	SHELL	LP
CRUSH	SPEECH	LP
COBRA	SNAKE	LP
THRESHOLD	MAIL	LP
SORRY	TOWN	LP
SLANDER	LIE	LP
HESITATE	WAIT	LP
SPEAKER	NAIL	LP
HUSBAND	WIFE	LP
BEAUTIFUL	STILL	LP
FLOOR	TILE	LP
HONEST	TRUTH	LP
BROOK	QUEEN	LP
TALK	SPEAK	LP
IGLOO	MEAN	LP
TOE	RIDE	LP

BISON	YEAR	LP
LEASE	RENT	LP
PAIL	SLIP	LP
STATION	TRAIN	LP
GLOBE	MILK	LP
POLE	VAULT	LP
CHAMBER	ROOM	LP
MASK	NECK	LP
BREEZE	WIND	LP
GUESS	NOSE	LP
SWAP	TRADE	LP

C2. High-Predictability (HP) and Low-Predictability (LP) – Sentence Stimuli

Sentence	Target Word	Semantic Predictability
The watchdog gave a warning	GROWL	HP
The old train was powered by	STEAM	HP
He caught the fish in his	NET	HP
Close the window to stop the	DRAFT	HP
My T.V. has a twelve-inch	SCREEN	HP
The boat sailed along the	COAST	HP
After his bath he wore a	ROBE	HP
She made the bed with clean	SHEETS	HP
I can't guess so give me a	HINT	HP
The farmer harvested his	CROP	HP
All the flowers were in	BLOOM	HP
She wore a feather in her	CAP	HP
The Admiral commands the	FLEET	HP
The beer drinkers raised their	MUGS	HP
He was hit by a poisoned	DART	HP
A rosebush has prickly	THORNS	HP
The shipwrecked sailors built a	RAFT	HP
Ruth poured the water down the	DRAIN	HP
The boy gave the football a	KICK	HP
The cop wore a bullet-proof	VEST	HP
The bread was made from whole	WHEAT	HP
I made the phone call from a	BOOTH	HP
The cut on his knee formed a	SCAB	HP
His boss made him work like a	SLAVE	HP
The fruit was shipped in wooden	CRATES	HP
The furniture was made of	PINE	HP
Tear off some paper from the	PAD	HP
A termite looks like an	ANT	HP

We saw a flock of wild	GEESE	HP
Drop the coin through the	SLOT	HP
The old man discussed the	DIVE	LP
Bob heard Paul called about the	STRIPS	LP
I should have considered the	MAP	LP
Miss Brown shouldn't discuss the	SAND	LP
They might have considered the	HIVE	LP
David has discussed the	DENT	LP
The old man discussed the	YELL	LP
She's spoken about	BOMB	LP
They're glad we heard about the	TRACK	LP
Sue was interested in	BRUISE	LP
Ruth will consider the	HERD	LP
You heard Jane called about the	VAN	LP
Nancy had considered the	SLEEVES	LP
Ben wants to know about the	TRUNK	LP
We should have considered the	JUICE	LP
Bob could have known about the	SPOON	LP
Bill might discuss the	FOAM	LP
Tom could not discuss the	BARN	LP
You were considering the	HANG	LP
Nancy should consider the	FIST	LP
Paul should have discussed the	FLOCK	LP
Jane has a problem with the	COIN	LP
Bill heard Tom called about the	COACH	LP
Tom will discuss the	SWAN	LP
Miss Black thought about the	LAP	LP
The girl talked about	GIN	LP
Paul can't discuss the	WAX	LP
He can't consider the	CRIB	LP
I am thinking about the	KNIFE	LP

Bill had a problem with the	CHAT	LP
Bob has discussed the	SPLASH	LP
The man spoke about the	CLUE	LP
We’ve spoken about the	STEM	LP
We looked around and saw the	CARDS	LP
They knew about the	FUR	LP
The man could not discuss the	MOUSE	LP
Miss White doesn't discuss the	CRAMP	LP
She has a problem with the	GOAL	LP
You were interested in the	SCREAM	LP
Ruth hopes he heard about the	HIPS	LP
The class should consider the	FLOOD	LP
They've considered the	SHEEP	LP
We’ve spoken about the	KNOB	LP
Ruth's grandmother discussed the	BROOM	LP
I'm talking about the	BENCH	LP
We are considering the	CHEERS	LP
Peter could consider the	DOVE	LP
She might have discussed the	APE	LP
We hear they asked about the	SHED	LP
Peter should consider the	COW	LP
Bill didn't discuss the	HEN	LP
He hopes Tom asked about the	BAR	LP
Paul hopes we heard about the	LOOT	LP
Paul could not consider the	RIM	LP
She's glad Bill called about the	BEAK	LP
We will consider the	DEBT	LP
Peter bought a new	MAT	LP
Bill cannot consider the	DEN	LP
He has a problem with the	NET	LP
Mr. Smith spoke about the	AID	LP

He wiped the sink with a	SPONGE	HP
Break the dry bread into	CRUMBS	HP
The ship's Captain summoned his	CREW	HP
Get the pie and cut me a	SLICE	HP
The candle burned with a bright	FLAME	HP
Throw out all this useless	JUNK	HP
The plow was pulled by an	OX	HP
the soup was served in a	BOWL	HP
The bomb exploded with a	BLAST	HP
Lubricate the car with	GREASE	HP
The works are digging a	DITCH	HP
They marched to the beat of the	DRUM	HP
No one was injured in the	CRASH	HP
The sailor swabbed the	DECK	HP
The kitten climbed out on a	LIMB	HP
The storm broke the sailboat's	MAST	HP
This key won't fit in the	LOCK	HP
I gave her a kiss and a	HUG	HP
This nozzle sprays a fine	MIST	HP
The bloodhound followed the	TRAIL	HP
The cookies were kept in a	JAR	HP
We heard the ticking of the	CLOCK	HP
The sick child swallowed the	PILL	HP
She cooked him a hearty	MEAL	HP
Wash the floor with a	MOP	HP
For dessert he had apple	PIE	HP
Paul took a bath in the	TUB	HP
We camped in our	TENT	HP
He was scared out of his	WITS	HP
Paul was arrested by a	COP	HP

C3. High-Frequency (HF) and Low-Frequency (LF) – Single-Word Stimuli

Target Word	Frequency
TON	HF
WAVE	HF
FATE	HF
BIKE	HF
FLAMES	HF
PLAN	HF
SWORD	HF
KEEPS	HF
MINDS	HF
FIGHT	HF
STRIP	HF
MOVES	HF
BASE	HF
CHEESE	HF
BIDS	HF
JAIL	HF
NEEDS	HF
WALLS	HF
PRIZE	HF
SEA	HF
HEAT	HF
CURE	HF
CODES	HF
TEA	HF
SAKE	HF
CLONE	HF
SMELL	HF
SHIRT	HF

DUKE	HF
WINE	HF
FORT	HF
TURNS	HF
HELP	HF
FEED	HF
HOOK	HF
PUB	HF
ENDS	HF
SEAT	HF
SOUND	HF
MOUTH	HF
SQUAB	LF
KNAVES	LF
RINDS	LF
BLOTCH	LF
STEWS	LF
SPLINT	LF
SHEAF	LF
NEIGH	LF
FRILL	LF
FROCK	LF
SLAW	LF
MEWS	LF
SCION	LF
TERN	LF
GROAT	LF
GRUEL	LF
LUTES	LF
THANE	LF
SHOAL	LF

SPATS	LF
DALES	LF
TUFT	LF
MYRRH	LF
CHIVES	LF
TRYST	LF
DIRGE	LF
BROIL	LF
PLEATS	LF
PEWS	LF
RASP	LF
AEONS	LF
SWARMS	LF
THRONG	LF
YULE	LF
CLINK	LF
ALMS	LF
POMP	LF
SCRUFF	LF
FLAN	LF
PYRE	LF
BOX	HF
CULT	HF
CROSS	HF
CURE	HF
FARM	HF
DRAW	HF
FLESH	HF
FLOOR	HF
GROWTH	HF
BULB	HF

LIGHTS	HF
MONTH	HF
PRAYER	HF
SCHOOL	HF
SELF	HF
SPACE	HF
FRONT	HF
TWIST	HF
WEALTH	HF
WOLF	HF
BURN	HF
CAR	HF
HOWL	HF
CRACK	HF
BOARD	HF
FIRE	HF
FORCE	HF
GUEST	HF
KID	HF
LOAD	HF
LOAN	HF
LOSS	HF
MIME	HF
MODE	HF
PAN	HF
PARK	HF
PLAY	HF
RAIN	HF
TEAM	HF
TIN	HF
BUTTE	LF

CLEF	LF
CLEFT	LF
FLAX	LF
GROG	LF
HOOVES	LF
KILN	LF
MINX	LF
NONCE	LF
POISE	LF
PRAWN	LF
SCRAWL	LF
SLEDGE	LF
SNITCH	LF
SQUALL	LF
SULK	LF
TALC	LF
THATCH	LF
TWINE	LF
WHIRR	LF
CULL	LF
CHIT	LF
COWL	LF
CREAK	LF
CRONE	LF
GAFF	LF
PITH	LF
JEER	LF
LOAM	LF
LILT	LF
NAPE	LF
NOOSE	LF

NUB	LF
PARD	LF
PUS	LF
SILT	LF
SLEET	LF
SWILL	LF
WILE	LF
WOAD	LF

C4. High-Frequency (HF) and Low-Frequency (LF) – Sentence Stimuli

Sentence	Target Word	Frequency
Paul could not consider the	CUSP	LF
We looked around and saw the	ELK	LF
Mr. White discussed the	SPUD	LF
Miss Smith heard the	WOOF	LF
We've spoken about the	FEUD	LF
He hopes Tom asked about the	MOTH	LF
Bill cannot consider the	JOWL	LF
Miss White thinks she saw	SPOOK	LF
The woman talked about the	WHIRL	LF
He is considering the	MULCH	LF
He heard they called about the	SNARL	LF
He could discuss the	SCREECH	LF
The woman looked around for her	GARB	LF
Ruth has a problem with the	BRUNCH	LF
Peter bought a new	HAUNCH	LF
The class learned about the	FIEF	LF
Bill can't have considered the	LICE	LF
Miss Smith couldn't discuss the	ROW	LF
He's thinking about the	ROAR	LF
You've considered the	POUT	LF
Paul hopes we heard about the	BRIM	LF
We are considering the	PELT	LF
We will consider the	BOUGH	LF
Bob has discussed the	WREATH	LF
We looked around and saw the	GULL	LF
Jim could not understand the	JEER	LF
Betty found a	WART	LF
From a distance they saw the	SPIRE	LF

We looked around and saw the	HEARSE	LF
Harry thought about the	RUNT	LF
Tom has been discussing the	BULB	HF
They knew about the	CUBE	HF
Bill didn't discuss the	ORB	HF
She might have discussed the	FONT	HF
Peter could consider the	HOAX	HF
The old man talked about the	LUNGS	HF
Mary heard the	LISP	HF
He was interested in the	PLOY	HF
Miss Brown will speak about the	GRIN	HF
Peter should consider the	MALT	HF
We looked around and saw the	ASP	HF
The woman talked about the	GOLF	HF
The girl should not discuss the	GOWN	HF
Bob was considering the	CLERK	HF
The woman spoke about the	TIME	HF
I've been considering the	CROWN	HF
Bill won't consider the	BRAT	HF
Ruth wants to speak about the	SLING	HF
You're discussing the	PLOT	HF
Betty has considered the	BARK	HF
I should have known about the	GUM	HF
James told me about the	RICE	HF
Yesterday we visited the	POOL	HF
We could not find the	BEND	HF
She hopes Jane called about the	CALF	HF
Mary can't consider the	TIDE	HF
Paul was interested in the	SAP	HF
Tom is talking about the	FEE	HF
Dora was angry about the	TOLL	HF

Mr. Smith knew about the	BAY	HF
The man could consider the	SPOOL	LF
Tom will discuss the	COT	LF
The old woman discussed the	THIEF	LF
Mary had considered the	SPRAY	LF
The boy might consider the	TRAP	LF
Toby heard the	TOOT	LF
He's glad you called about the	OAR	LF
Mr. Black lost the	STILTS	LF
Mr. Smith was looking for the	SLANTS	LF
I haven't discussed the	LOUSE	LF
You were interested in the	CLASP	LF
Bill had a problem with the	NIB	LF
She wants to talk about the	TROUPE	LF
Terri hopes his mother heard about the	BROOCH	LF
We're speaking about the	SCRAWL	LF
Jane did not speak about the	THRONES	LF
He has a problem with the	RAFTS	LF
Ruth hopes she remembered the	DRAPES	LF
The class learned about the	GOURD	LF
They've considered the	TONGS	LF
Harry will consider the	SHUNTS	LF
Paul should have discussed the	WHORL	LF
Hannah called about the	CHAISE	LF
He doesn't discuss the	FRIEZE	LF
Ruth could have discussed the	TROWEL	LF
Miss Smith knows about the	FAWNS	LF
The man could not discuss the	FIB	LF
Miss White doesn't discuss the	LUGE	LF
She has a problem with the	BLARE	LF
Bob has considered the	PEALS	LF

Miss Brown forgot her	TEETH	HF
The girl walked beside the	BUSH	HF
Ruth must have known about the	JAM	HF
Ruth hopes she called about	GATES	HF
The man should discuss the	PRINCE	HF
I'm talking about the	WILL	HF
David might consider the	SHOCK	HF
She's glad Bill called about the	ROOTS	HF
We've spoken about the	LUNCH	HF
Ruth's grandmother discussed the	FRONT	HF
Ruth has lost the	SENSE	HF
I'm talking about the	PRESS	HF
Mrs. Smith asked about the	CHILD	HF
They heard I asked about the	RULES	HF
Mr. White spoke about the	FIELD	HF
We could not find the	CAUSE	HF
They heard I called about her	VOICE	HF
Tom has not considered the	GLUE	HF
He has a problem with	OATH	HF
She has known about the	LIST	HF
Miss White would consider the	MOVE	HF
The woman talked about the	SKILLS	HF
Rita found the missing	FRIEND	HF
Ruth must have known about the	AIR	HF
The woman knew about the	LID	HF
I could not find the	CHUNKS	HF
He wants to know about the	RIB	HF
Jane had not considered the	FILM	HF
We were looking for the	END	HF
Ann was interested in the	BREATH	HF

APPENDIX D.

Pairwise Comparisons: Age x Stimulus Type x WM Load x Semantic Context

Both younger and older adults were negatively affected by the high WM load condition in comparison to the low WM load condition in accuracy for LP word stimuli, *F*'s > 4.81, *p*'s < .034, although older adults were disproportionately affected compared to younger adults, $F(1, 98) = 6.26$, $p = .017$, partial $\eta^2 = .13$. In contrast, high WM load conditions did not affect accuracy for HP targets for either age group, *F*'s > .58, *p*'s < .451.

Next, I more closely investigated performance as a function of stimulus type within the HP and LP context conditions, respectively.

Single-words. There were no age differences in identification accuracy of SW targets as a function of semantic context in the low WM load condition, *F*'s < .84, *p*'s > .363. However, older adults did performed significantly worse than younger adults in the LP context, high WM load condition, $F(1, 98) = 6.27$, $p = .017$, partial $\eta^2 = .14$. This age difference subsequently disappeared with the addition of HP context in the high load condition, $F(1, 98) = .24$, $p = .626$, partial $\eta^2 = .006$.

Sentences. For HP sentence stimuli, older adults' accuracy significantly exceeded that of younger adults, *F*'s > 14.46, *p*'s < .001, but this advantage did not change as a function of WM load condition, $F(1, 98) = .03$, $p = .870$, partial $\eta^2 = .001$. Younger adults also maintained high levels of accuracy in the HP condition across low and high WM load conditions for sentence stimuli, $F(1, 98) = .10$, $p = .752$, partial $\eta^2 = .003$. LP accuracy for sentence targets was equivalent for age groups in the low WM load condition, but was negatively affected in the high

WM load condition, *F*'s > 6.08, *p*'s < .018. Moreover, younger adults outperformed older adults for LP sentence stimuli in the high load condition, $F(1, 98) = 4.16$, $p = .048$, partial $\eta^2 = .09$.

APPENDIX E.

Pairwise Comparisons: Age x Stimulus Type x WM Load x Word Frequency

Single-words. In comparison to low WM load, high WM load had a significant negative effect on accuracy for both younger and older adults' accuracy of LF and HF SW targets, F's > 3.76, p's < .004. However, older adults showed a significant advantage for LF words in the high WM load condition over younger adults, F (1, 98) = 6.25, p = .011, partial η^2 = .46. In terms of the word frequency effect, younger adults showed a significantly larger word frequency effect than did older adults for both the low- (young: F (1, 98) = 11.23, p = .002; old: F (1, 98) = 3.12, p = .085) and the high-WM load condition (young: F (1, 98) = 8.43, p = .006; old: F (1, 98) = 2.45, p = .125).

Sentences. Older adults' advantage for LF targets also persisted for sentence stimuli in the high WM load condition, F (1, 98) = 3.21, p = .018, partial η^2 = .07, although both younger and older adults were negatively affected by high WM demands for LF targets, F's > 13.31, p's < .001. In contrast, both groups showed comparable accuracy for HF targets in both the low WM load condition F(1, 98) = .008, p = .930, partial η^2 < .001, and the high WM load condition F(1, 98) = .10, p = .750, partial η^2 = .003. Similar to the results for SW targets, younger adults showed a significantly larger word frequency effect than did older adults for the low-WM condition (young: F (1, 98) = 4.20, p = .047; old: F (1, 98) = 3.88, p = .056). Both groups however, showed equally large effects in the high-WM load condition (young: F (1, 98) = 28.39, p < .001; old: F (1, 98) = 25.29, p = < .001).

APPENDIX F.

Pairwise Comparisons: Age x Stimulus Type x Density x Semantic Context

Single-words. While accuracy for LP or HP word targets for younger adults did not differ as a function of density, *F*'s < 3.47, *p*'s < .076, older adults performed significantly worse in identifying HD targets, both in LP, $F(1,67) = 35.92$, $p < .001$, partial $\eta^2 = .47$, and HP contexts $F(1,67) = 12.05$, $p = .001$, partial $\eta^2 = .232$. Moreover, younger adults' accuracy exceeded older adults' for LP and HP targets in the HD condition (*F*'s > 5.24, *p*'s < .021) but not for LP or HP targets in the LD condition (*F*'s < 1.70, *p*'s > .200).

Sentences. The above pattern of results for LP accuracy as a function of density was also true for sentence stimuli, such that accuracy was significantly lower in the HD condition than in the LD condition for both younger $F(1,67) = 4.71$, $p = .036$, partial $\eta^2 = .10$ and older adults $F(1,67) = 51.96$, $p < .001$, partial $\eta^2 = .56$. Moreover, younger adults demonstrated higher accuracy for LP, HD targets than did older adults $F(1,67) = 5.91$, $p = .020$, partial $\eta^2 = .13$, although both groups showed comparable accuracy for LP, LD targets $F(1,67) = .78$ $p = .383$, partial $\eta^2 = .02$. It was also the case that younger adults' accuracy was poorer for HD targets compared to LD targets in the context of LP sentences, $F(1,67) = 8.25$, $p = .006$, partial $\eta^2 = .17$. A similar pattern was observed for older adults, although this difference just reached statistical significance, $F(1,67) = 4.12$, $p = .049$, partial $\eta^2 = .09$. However, older adults' accuracy exceeded that of younger adults for HP targets in both the LD and HD condition, *F*'s > 3.40, *p*'s < .037.