Sensory and cognitive contributions to age-related changes in spoken word recognition

Alexis Johns[1,2,3]

Emily Myers[1,4]

Erika Skoe[4]

1 Psychological Sciences, University of Connecticut
2 Department of Psychology, Brandeis University
3 Volen National Center for Complex Systems, Brandeis University
4 Speech, Language, and Hearing Sciences, University of Connecticut

Final Preprint Manuscript

Johns, A. J., Skoe, E., & Myers, E.B. (2018). Sensory and cognitive contributions to age-related changes in spoken word recognition. Language and Linguistics Compass 12(2), 1-25.
https://doi.org/10.1111/lnc3.12272

ABSTRACT

Many older adults experience declines in auditory and cognitive abilities that negatively affect language comprehension, including spoken word recognition. In the case of auditory function, poor neural responses to sound at the earliest stages of auditory processing may adversely affect phoneme identification, and ultimately, lexical access. Declines in cognitive functions, such as inhibitory control or working memory, may also impede word recognition. Furthermore, complex interactions between auditory and cognitive declines make it difficult to distinguish these possible causes of age differences in speech perception. We review age-related changes in spoken word recognition, with respect to current models of this process. Then, we invoke frameworks of sensory-cognitive compensation, and argue that online, sensitive measures of sensory processing and of comprehension are important in distinguishing between effects of sensory and cognitive decline. We conclude that investigations of spoken word recognition in older listeners must carefully assess listener differences at early levels of auditory processing, in conjunction with cognitive abilities.

There is a complex relationship between aging, auditory sensory decline, and cognitive decline, as related to spoken word recognition in older listeners. This sensory and cognitive interaction is well-known within cognitive hearing science (e.g., CHABA, 1988; Baltes & Lindenberger, 1997; Lindenberger & Baltes, 1994), as evident in previous excellent reviews (e.g., Albers et al., 2015; Humes et al., 2012; Lin et al., 2013; Schneider & Pichora-Fuller, 2000; Schneider, Daneman, & Pichora-Fuller, 2002; Schneider, Pichora-Fuller, & Daneman, 2010; Sommers, 2005). The current review has two broad goals: to bring this knowledge to a wider audience, and to emphasize online measures of both auditory and cognitive processing. Specifically, in the context of current models of spoken word recognition, we discuss how a multitude of factors, including low-quality neural responses to sound, or reduced working memory or inhibition, could negatively affect lexical access (Alain, McDonald, Ostroff, & Schneider, 2004; Alain & Tremblay, 2007; Ison, Tremblay, & Allen, 2010). Motivated by the field of *cognitive hearing science (*e.g., Arlinger, Lunner, Lyxell, & Pichora-Fuller, 2009; Schneider et al., 2002; Stanley, Tun, Brownell, & Wingfield, 2012), and frameworks that posit that listeners cognitively compensate for auditory declines (Rönnberg et al., 2013; Wingfield, Tun, & McCoy, 2005), we argue that studies testing the of models of spoken word recognition, particularly amongst older listeners, must take an integrative approach, in which measures of both auditory processing and cognitive abilities are assessed (e.g., Schneider & Pichora-Fuller, 2000).

[INSERT BOX 1 HERE]

Age-related Changes in Auditory and Cognitive Processing

A substantial proportion of older adults will experience age-related declines in auditory processing (Cruickshanks, Zhan, & Zhong, 2010; Morrell, Gordon-Salant, Pearson, Brant, & Fozard, 1996). For example, Valentijn et al. (2005) found that the incidence of hearing impairment across a sample of 418 adults aged 55-83 rose from 7.7% to 32.7% over a period of six years. Although general age-related declines in language comprehension have classically been attributed to progressive losses in the ability to process higher frequencies of the acoustic input (Humes, 2007), there is also substantial evidence that changes in auditory thresholds are only one of many sources of auditory decline that contribute to speech comprehension (e.g., Bergman, 1980; Gordon-Salant & Fitzgibbons, 1999; Humes, 1996; Plomp, 1986). Specifically, in addition to declines in auditory threshold, the quality of the neural representation of the acoustic input is also negatively affected in older listeners (e.g., Clinard & Tremblay, 2013; Hellstrom & Schmiedt, 1990; Skoe, Krizman, Anderson, & Kraus, 2015). This review will emphasize how aging-related declines in neural responses to sound may negatively affect language comprehension.

Older listeners may also experience cognitive declines that can have adverse consequences for language comprehension. Current hypotheses posit that declines in working memory (Rönnberg et al., 2013; Wingfield et al., 2005) and/or inhibitory control (Sommers & Danielson, 1999) can impede language comprehension in older listeners. Although sentence-level processing is not the focus of this review, suggestive evidence shows that older adults, who as a population have somewhat lower working memory than younger adults, remember fewer details of syntactically complex sentences, and may struggle to suppress incorrect interpretations of a sentence (Wingfield, McCoy, Peelle, Tun, & Cox, 2006, Gernsbacher & Faust, 1991, see also January, Trueswell, & Thompson-Schill, 2009; Rodd, Davis, & Johnsrude, 2005). Declines in inhibitory control also can be observed in the way attention is allocated to the auditory scene: on average, older adults are less able than younger listeners to attend to a talker by ignoring a second talker in the background (Tun, O'Kane, & Wingfield, 2002), and this age difference persists whether there is real or simulated spatial separation between the talkers (Singh & Pichora-Fuller, 2008).

Furthermore, auditory and cognitive declines often co-occur as part of the aging process, such that older listeners with reduced cognitive function tend also to show reduced auditory processing abilities (e.g., CHABA, 1988). The exact cause and relationship between these declines is still unknown, and active research continues to be motivated by seminal findings from Lindenberger and Baltes that poor performance on cognitive tasks is mediated by declines in sensory function (Baltes & Lindenberger, 1997; Humes, Busey, Craig, & Kewley-Port, 2013; Lin, Ferrucci, Metter, An, Zonderman, & Resnick, 2011; Lindenberger & Baltes, 1994; for reviews see Craik & Salthouse, 1992; Salthouse, 1991; Schneider et al., 2010). For example, recent longitudinal work indicates that increases in auditory threshold (worse performance) precede large declines in cognitive abilities (Lin et al., 2013), and lead to an increased risk factor for dementia (Lin et al., 2011; for a review on the link between sensory declines and the development of dementia, see Albers et al., 2015). Additionally, it can be difficult to isolate the effects of only cognitive or sensory processing declines in older listeners because many tasks designed to measure sensory function may be confounded by declines in attention or working memory, such as dichotic listening tasks (as reviewed by Humes et al., 2012). Thus, older adults who participate in studies of language comprehension likely experience combined interactions between age-related auditory and cognitive declines.

These potential interactions between age-related auditory and cognitive declines are crucial to understanding the difficulties older listeners confront during spoken language comprehension (e.g., Arlinger et al., 2009; Pichora-Fuller, 2003; Schneider & Pichora-Fuller, 2000; Wingfield & Tun, 2001; Wingfield et al., 2005). For example, listeners can use different types of knowledge to help “fill in the blanks” for words they did not hear clearly (e.g., Dubno, Ahlstrom, & Horwitz, 2000; Pichora-Fuller, 2009). Rabbitt (1968), and Wingfield and colleagues (2005) posit that such compensatory strategies for perceptual deficits may lead to the appearance of preserved comprehension, but at the expense of additional cognitive effort and resources.

In the first section of this review, we describe the processes involved in spoken word recognition as outlined by current models, along with experimental findings showing that older listeners perform worse than younger listeners in word identification. In the second section, we review the *Effortfulness Hypothesis* (Rabbitt, 1968; Wingfield et al., 2005) and the *Ease of Language Understanding* (ELU) model (Rönnberg et al., 2013), two complimentary frameworks of speech perception that hypothesize that processing difficulties stemming from both the auditory and cognitive levels (such as working memory and inhibitory control) contribute to declines in language comprehension. The third and fourth sections describe how speech perception is affected by age-related differences in auditory processing (as measured by auditory threshold and auditory encoding fidelity), and cognitive declines, respectively. In the final section, we describe two methods for measuring changes in cognitive processing over time as participants perform a task. We conclude with a hypothesis of how poor neural encoding can adversely affect lexical access, along with recommendations for avoiding potential sensory confounds in future investigations of language comprehension[1].

Theories of Spoken Word Recognition, and Age Effects in Word Identification

Listeners seemingly understand spoken language with minimal effort, despite complexities inherent to the acoustic signal. This section reviews three factors that are generally agreed to affect the speed and accuracy of lexical access across psycholinguistic theories and models of spoken word recognition: neighborhood density, lexical frequency, and inhibition (e.g., the Distributed Cohort Model: Gaskell & Marslen-Wilson, 1997; Neighborhood Activation Model: Luce, Goldinger, Auer, & Vitevitch, 2000, Luce & Pisoni, 1998; TRACE: McClelland & Elman, 1986; for a review, see Magnuson, Mirman, & Myers, 2013). Finally, we suggest that all three dimensions are affected in older listeners.

Most theories agree that when a spoken word is heard, words are activated in parallel as a function of the degree of match with the acoustic input. For example, Luce and colleagues (e.g., Luce & Pisoni, 1998) have posited that the core competitor set of activated words (the *neighbors* of the target word) are words that differ from the input by a single phoneme, whether by deletion, addition, or substitution (thus, some of the many neighbors of the word *cat* include *at, scat, bat, cot,* and *can*), weighted by their frequencies. The standard experimental finding is that younger listeners are faster to identify spoken words that are in sparse neighborhoods than words in dense neighborhoods (Luce & Pisoni, 1998). In addition to neighborhood size, the frequency with which a word is used in the language contributes to how strongly a word competes for

[1] This review focuses on speech processing up to word-level comprehension; for reviews of sentence integration and discourse processing in older listeners, see Wlotko, Lee, & Federmeier (2015).

recognition, with high frequency words being easier to identify than low frequency words (*cat* is used much more often in the language than the neighbor *vat*; e.g., Dahan, Magnuson, & Tanenhaus, 2001; Howes & Solomon, 1951; Marslen-Wilson, 1987), and with words that have more frequent neighbors being harder to recognize (e.g., Luce & Pisoni, 1998; Magnuson, Dixon, Tanenhaus, & Aslin, 2007). This suggests that higher frequency words are activated more quickly, and/or with a greater strength of activation than lower frequency words. Finally, most theories also propose that lexical activation also depends on competition between active words, which is often instantiated via lateral inhibition between words (e.g., Chen & Mirman, 2015; Luce & Pisoni, 1998; McClelland & Elman, 1986). Thus, when acoustic input matches many similar words, multiple words become activated and compete with each other. Therefore, the degree to which the auditory input matches the phonological form of a word stored in memory, as well as neighborhood density and word frequency, all affect the difficulty of identifying any particular word.

Age-related differences have been documented in all three aspects of spoken word recognition. For example, older adults exhibit greater activation of a rhyme neighbor (Ben-David, Chambers, Daneman, Pichora-Fuller, Reingold, & Schneider, 2011), and larger neighborhood density effects in word recall for sentences in noise (Taler, Aaron, Steinmetz, & Pisoni, 2010). Older adults are also more influenced by lexical frequency than are younger listeners (Pirog Revill & Spieler, 2012), and this increased frequency effect is associated with poorer auditory thresholds (Janse & Newman, 2013). Effects of neighborhood density and frequency have the consequence of temporarily increasing the uncertainty as to the identity of the target word and/or slowing access to the target itself. Additionally, the increased phonological competitor effect in older adults compared to younger adults is associated with inhibitory declines more generally (Sommers & Danielson, 1999), hinting that the process of inhibiting many activated competitor words may be adversely affected in some older adults. Finally, poorer accuracy for older compared to younger listeners also emerges on tasks that involve identifying words presented with and without context, and in quiet and noise (Benichov, Cox, Tun, & Wingfield, 2012; Lash, Rogers, Zoller, & Wingfield, 2013). In summary, these findings broadly suggest that older adults experience slowing and uncertainty in spoken word recognition. In the next sections, we review evidence that slowing in lexical access arises from auditory declines and cognitive declines.

Modeling the Effects of Sensory and Cognitive Declines on Language Comprehension

One recurring theme in cognitive hearing science is that listeners recruit working memory, inhibition, and other cognitive resources to aid in speech perception when auditory processes struggle or fail (e.g., Arlinger et al., 2009; Rönnberg, Rudner, & Lunner, 2011; Schneider et al., 2002; Stanley et al., 2012; Wingfield, Amichetti, & Lash, 2015). Two models have been proposed to explain this relationship: the Effortfulness Hypothesis (Rabbitt, 1968; Wingfield et al., 2005) and the Ease of Language Understanding model (Rönnberg et al., 2013). The two models are largely complimentary, as they both focus on explaining the impact of cognitive and sensory declines on language comprehension in older adults.

According to the *Effortfulness Hypothesis* (Rabbitt, 1968; Wingfield et al., 2005), listeners with impaired low-level auditory processing abilities route more cognitive resources, such as auditory attention, to the early stages of perceptual processing. However, in reallocating cognitive effort, the listener also draws from resources normally available for performing higher-order linguistic tasks such as the working memory and cognitive control demands required to integrate information across multiple sentences. Thus, while word-level comprehension may be intact, higher-level comprehension is compromised due to the additional effort required to successfully perceive the input. For example, listeners are better able to recall lists of words that are presented in quiet rather than noise (Rabbitt, 1968). One interpretation of this finding is that the degraded signal requires listeners to recruit additional higher cognitive processes for comprehension, thus depleting resources used to encode these words in memory. This hypothesis also predicts that older adults with sensory and/or cognitive declines will have exaggerated difficulties comprehending speech. For example, older adults with normal auditory thresholds recall word lists better than older adults with elevated auditory thresholds (McCoy et al., 2005). Additionally, older adults compared to younger adults exhibit reduced ability to remember details or make inferences after listening to a spoken passage in quiet (Schneider, Daneman, Murphy, & See, 2000), and are adversely affected on a listening memory task when speech is presented at varying levels of intensity (Baldwin & Ash, 2011; Rabbitt, 1968, 1991). These findings could emerge due to a demand on cognitive resources to encode the speech, a decline in the memory resources available to report the answers, or both.

A similar model to the Effortfulness Hypothesis is the previously cited Ease of Language Understanding (ELU) model of language comprehension in older adults (Rönnberg et al., 2013). The ELU posits that word identification proceeds automatically and effortlessly when the multimodal input matches a word stored in long-term memory, but when there is not a clear match, then word recognition becomes effortful and additional resources are recruited. According to the ELU, increased effort involves recruiting a working memory buffer to re-analyze the auditory input. Breakdowns in automatic processing can occur due to idiosyncrasies in the signal (e.g., if a speaker pronounces a word in an atypical manner; Van Engen & Peelle, 2014), or when high frequency hearing loss limits the acoustic information available for matching the signal to words in long term memory (Humes, 1996). Furthermore, Rönnberg et al. (2013) posit that working memory declines can also impair the reanalysis process. Evidence supporting the ELU comes in part from findings that for hearing-impaired listeners, better working memory capacity is related to better performance on rhyme judgments (e.g., Classon, Rudner, Johansson, & Rönnberg, 2013; see Wingfield et al. (2015) for a more detailed review and critique of the ELU).

While both models concern the allocation of cognitive resources during spoken language comprehension, the two models differ in their specificity. The Effortfulness Hypothesis broadly posits that a reallocation of limited resources can occur in response to difficult listening. Conversely, the ELU provides a conceptual framework for the specific perceptual circumstances that would require a listener to shift their resources. In this sense, the ELU can be seen as a more specific characterization of the more general Effortfulness Hypothesis. However, neither model is a computational model, and indeed, we know of no computational models on age-related changes to language comprehension. Therefore, there is still more work to be done in this area of allocating resources and language comprehension. For a review summarizing the gaps that remain to be filled on this topic, refer to Wingfield and colleagues (2015).

Nevertheless, the two frameworks converge on the same point: effects in spoken word recognition that seem to stem from a decline in cognitive processing (Abada, Baum, & Titone, 2008; Baum, 2003; Mattys & Scharenborg, 2014; Sommers & Danielson, 1999) may actually be the result of shifts in cognitive resources that are required in the face of auditory processing deficits (Schneider & Pichora-Fuller, 2000). Evidence for such compensation can be seen in neuroimaging studies. For example, older adults show increased activation to the frontal motor cortex, compared to younger listeners, when identifying syllables presented in varying levels of noise (Du, Buchsbaum, Grady, & Alain, 2016). This suggests that older adults compensate for poor auditory encoding by recruiting information related to the motor movements associated with speech sounds.

In the next two sections, we review age-related changes to auditory and cognitive processes as related to spoken word recognition.

Age-related Differences in Auditory Processing

As listeners age, there is a progressive loss of cochlear and central auditory nervous system function, resulting in a host of perceptual difficulties for the older adult, including high frequency hearing loss (e.g., CHABA, 1988, Kujawa & Liberman, 2015; Kamal, Holman, & de Villers-Sidani, 2013). Some of these processing declines are observed in animals as well, suggesting fundamental age-related changes to physiological processes (Kamal et al., 2013; Möhrle et al., 2016). Additionally, evidence from human imaging data indicates that reduced peripheral input corresponds to changes in cortical function. This pattern, first reported by Peelle and colleagues and subsequently replicated, links elevated pure tone thresholds among older adults with reductions in gray matter volume in the auditory cortex (Eckert, Cute, Vaden, Kuchinsky, & Dubno, 2012; Lin et al., 2014; Peelle, Troiani, Grossman, & Wingfield, 2011). Thus, changes to the overall quality of auditory processing is closely coupled with the aging process. For a more detailed examination of age-related changes to the peripheral and central auditory system than we can provide here, we refer the reader to recent reviews (Ouda, Profant, & Syka, 2015; Peelle & Wingfield, 2016; Roth, 2014). In this review, we consider age-related changes to two aspects of auditory encoding fidelity, which we call *temporal encoding fidelity* and *neural response consistency,* that are postulated to affect phoneme perception and word identification (e.g., Fitzgibbons & Gordon-Salant, 1996; Pichora-Fuller, Schneider, MacDonald, Pass, Brown, 2007).

There are multiple temporal cues in the speech input that can facilitate phoneme perception. For example, Rosen (1992) hypothesizes a strictly temporal model of speech perception, in which phoneme identification emerges from three temporal features of the speech input: envelope (related to low-frequency changes in acoustic intensity over time), periodicity (whether sounds within a short interval are regular and harmonic, or irregular and continuous), and temporal fine-structure (high-frequency variation in the input that relates to timbre or voice quality). Unreliable access to temporal fine structure can impair lexical access, as observed in behavioral studies that presented temporally jittered speech to younger adults, intended to simulate poor temporal processing in older adults (Pichora-Fuller, Schneider, & Daneman, 1995; Pichora-Fuller et al., 2007). That is, reducing the reliability of timing cues in the auditory speech signal made it more difficult for younger listeners to identify spoken words, in a manner that resembled comprehension by older listeners. For specifics regarding age-related changes to these and other types of auditory temporal processing see: Pichora-Fuller & MacDonald (2008), and Schneider & Pichora-Fuller (2000).

In addition to temporal jitter reducing overall word perception, poor temporal encoding fidelity can lead to increased confusability between acoustically similar words. For example, English voiced and voiceless phoneme pairs in syllable-initial positions (e.g., /d/ and /t/ in the words *dime* and *time*) contrast primarily in the lag between the burst at the beginning of the stop and the onset of the vowel (voice onset time; Lisker & Abramson, 1964), thus sensitivity to the duration of the temporal cue would be highly relevant for differentiating those two words. Gordon-Salant and colleagues tested whether age or hearing loss affected the ability to perceive differences between word pairs that only differed along one timing feature (*buy/pie*, *wheat/weed*, *dish/ditch*, and *beat/wheat*; Gordon-Salant, Yeni-Komshian, Fitzgibbons, & Barrett, 2006). Gordon-Salant et al. found that while high frequency hearing loss may make it difficult for listeners to perceive high frequency speech cues that are directly related to temporal cues, age differences in duration detection also relate to the ability to differentiate between similar sounding words that only differ by temporal information.

One common measure of temporal encoding fidelity is gap detection, a behavioral measure that assesses listener precision for detecting silent gaps of varying durations embedded in noise bursts (e.g., Musiek, Shinn, Jirsa, Bamiou, Baran, & Zaida, 2005; Strouse, Ashmead, Ohde, and Grantham, 1998; van Rooij & Plomp, 1990). Performance on gap detection is highly variable; some older adults are able to detect very short gaps, e.g., 3 ms, whereas others are only able to detect longer gaps (e.g., 6 ms) despite presenting with clinically normal auditory thresholds (e.g., Pichora-Fuller, 2003, Pichora-Fuller & MacDonald, 2008). Importantly, age-related changes to gap detection thresholds are observed independently of increases in auditory thresholds (Lister, Besing, & Koehnke, 2002; Snell & Frisina, 2000). For a recent review of age differences in gap detection, see Humes et al., (2012).

Gap detection materials can vary widely depending on the specific goals of each study, sometimes making it difficult to compare results across studies. For example, tasks can vary the duration of the noise bursts (Schneider & Hamstra, 1999), and the type of noise burst used (e.g., broad spectrum noise, tones; for a review see Fitzgibbons & Gordon-Salant, 2010). Additionally, there are between-channel gap detection tasks that place a silent interval between two spectrally-different acoustic markers, in contrast to within-channel gap tasks in which a silent gap is flanked by identical acoustic markers (Phillips, Taylor, Hall, Carr, & Mossop, 1997).

Performance for within vs. between channel gap tasks has shown to only weakly correlate (Phillips & Smith, 2004), and Phillips and colleagues argue that between-channel gap detection may tap into processes used for speech perception more so than within-channel gap detection does. For example, Pichora-Fuller and colleagues found that while younger adults were able to detect smaller gaps than older adults across both within and between-channel gaps, all listeners could detect smaller gaps when the between-channel input was speech (Pichora-Fuller, Schneider, Benson, Hamstra, & Storzer, 2006). Pichora-Fuller et al. interpret this improved perception for between-channel gaps as a potential linguistic advantage to detect gaps in natural speech. For behavioral gap detection tasks, it is important to use the two-interval, two-alternative forced-choice paradigm, in which participants hear two sequential trials and must respond by indicating which of the two trials had a gap present (e.g., as reviewed by Schneider & Parker, 2009). A reduced version of this task, which is frequently employed in other psycholinguistic literature, presents participants with only one stimulus, and listeners are required to decide explicitly if a gap was present in the stimulus. This reduced method may increase variation between younger and older listeners as age differences may arise, for example, because older listeners are known to set a higher confidence threshold for a decision in order to minimize error (Starns & Ratcliff, 2010). Therefore, behavioral gap detection tasks should employ the two-interval approach to reduce age differences in response criterion.

In contrast to behavioral measures of auditory processing, electrophysiological measures of early auditory processes, recorded from electrodes placed at the surface of the scalp, circumvent the need for the listener to make a decision-based response by providing an objective index of auditory encoding fidelity, from which indices of both temporal encoding fidelity and neural response consistency can be assessed. Three such event-related response (ERP) measures that reveal age differences in auditory encoding, and are automatic and do not require directed attention, are the Auditory Brainstem Response, which emerges roughly 1-2 ms after the onset of an acoustic stimulus (e.g., Jewett & Williston, 1971), the N1-P2 complex that appears roughly 60 ms after the onset of a stimulus (Martin, Sigal, Kurtzberg, & Stapells, 1997; McCandless & Best, 1966), and the mismatch negativity response (MMN), which begins roughly 170 ms after the onset of a stimulus that acoustically deviates from an established acoustic pattern (Näätänen, Gaillard, & Mäntysalo, 1978; for a review see Näätänen, Paavilainen, Rinne, & Alho, 2007). Methodologically, age-related differences in ERP waveform morphology may emerge due to: 1) increases in variability in the neural response from trial to trial; 2) overall fewer neurons responding to a stimulus, and/or 3) a reduced neural response to a repeating stimulus (Alain & Tremblay, 2007; Luck, 2014). Age-related changes to ERPs are well-documented with accounts dating back to the 1960s and 1970s. Here we focus on several recent studies.

The ABR indexes early acoustic processing within the subcortical auditory pathway, up to and including activation in the inferior colliculus in the brainstem. This early neural response to sound has high test-retest reliability and is relatively immune to changes in listener state, such as wakefulness (Campbell & Bartoli, 1986; Lauter & Loomis, 1986; Song, Nicol, & Kraus, 2011), but the waveform is very small (typically less than 1 microvolt) and requires an averaged response across thousands of presentations of a sound. Information about the integrity of the auditory system can be ascertained from the latency, amplitude, and consistency of waves in the ABR, and ABR measures can detect differences in hearing sensitivity that are difficult to measure using audiometric thresholds (Anderson, Parbery-Clark, Bramhall, Konrad-Martin, McMillan & Griest, 2017; White-Schwoch, & Kraus, 2012; Mehraei et al., 2016; Shinn-Cunningham & Best, 2008; Stamper & Johnson, 2015). Auditory encoding fidelity, as measured by the ABR, varies across listeners, and for an individual listener can change across the lifespan (Krizman et al., 2015; Skoe et al., 2015). Longer ABR latencies and less consistent responses have been observed in older compared to younger listeners, even when the stimulus is presented well above threshold (Anderson et al., 2012; Jerger & Johnson, 1988; Jerger & Hall, 1980; Skoe et al., 2015; Vander Werff & Burns, 2011). A recent series of studies has indexed auditory encoding fidelity in older listeners in response to CV syllables (e.g., Anderson et al., 2012; Anderson, White-Schwoch, Parbery-Clark, & Kraus, 2013a; Anderson, White-Schwoch, Parbery-Clark, & Kraus, 2013b; Clinard & Tremblay, 2013; Skoe et al., 2015), indicating that the ABR can also be used to measure auditory processing of spectrally complex speech patterns important for word recognition. ABRs require a high degree of neural synchrony in order to emerge at all (e.g., Wynne et al., 2013), thus, measurement of the ABR at scalp electrodes depends on the underlying neural response maintaining a high degree of stability, or consistency, from one stimulus presentation to the next. Neural response consistency of the ABR can be measured by comparing the waveform morphology of two ABR responses measured to the same stimulus at two different points in time (Anderson et al., 2012; Hornickel & Kraus, 2013; Skoe et al., 2015).

The waveform morphology of the N1-P2 complex varies in response to features of the acoustic input, which is useful for assessing neural encoding of speech in older listeners. Tremblay and colleagues presented young adults and older adults with good and poor hearing with speech stimuli increasing in VOT from *ba* to *pa*, and found changes to the waveforms relating to both age and hearing acuity (Tremblay, Piskosz, & Souza, 2003). Specifically, all older adults showed delayed P2 responses, as well as differentially longer N1 latencies for longer VOT, compared to younger adults. Additionally, elevated pure tone thresholds among older listeners were associated with even longer N1 latencies for longer VOTs, suggesting potentially a weaker neural response as a function of poor hearing thresholds. This finding is in contrast to research by Palmer and Musiek (2014), who recently found no differences between behavioral and electrophysiological measures of gap detection, both for younger and older adults. Regarding the perception of speech, another study reported that an unusually large N1-P2 cortical response among older compared to younger adults corresponded to slower and less consistent behavioral responses in the identification of speech vowels (Bidelman, Villafuerte, Moreno, & Alain, 2014). Bidelman and colleagues interpret the large cortical response (as well as a reduced brainstem response) as negatively impacting the acoustic-phonetic processing of older listeners, suggesting a link between neural encoding and lexical access.

Finally, the latest ERP component we discuss is the MMN, which is valuable for assessing perceptual discrimination because the amplitude of the waveform increases as a function of how saliently an acoustic input deviates from an established pattern (Näätänen et al., 2007). This makes the MMN valuable in objectively investigating gap detection among older adults, given that no overt behavioral responses are required. Interestingly, even after broadly controlling for age differences in gap thresholds, increasing age correlated with smaller MMN responses to stimuli with gaps (Alain et al., 2004). Alain and colleagues interpret this muted gap detection among older adults (who were presented with larger gaps), as reflecting age differences that arise early within the automatic processing of acoustic input. As discussed at the beginning of this section, cortical volume is related to the quality of the input at the ear (Peelle et al., 2011). Therefore, it is highly likely that age-related differences in these ERP components reflect a combination of age-related differences at their respective cortical locations, as well as processing declines that are inherited from the earlier subcortical processes.

Age-related Differences in Working Memory and Inhibition

While the previous section highlighted that language comprehension relies on fine-grained details of sensory processing, declines in cognitive abilities may still have some explanatory power in accounting for differences in lexical access in the older population beyond those accounted for by auditory changes. For example, listener differences in working memory and inhibitory control predict performance on a variety of receptive language tasks in older adults (e.g., Benichov et al., 2012; Huettig & Janse, 2016; Lash et al., 2013; Mattys & Scharenborg, 2014; Sommers & Danielson, 1999; for discussions on the inter-relationship between working memory, executive function, and inhibition, see McCabe, Roediger, McDaniel, Balota, & Hambrick, 2010; Wingfield, 2016). Furthermore, although measures of auditory processing are the strongest predictor of comprehension of speech presented in background noise, a review of the literature suggests that working memory consistently explains additional variance (Akeroyd, 2008). In this section, we discuss how declines in working memory and inhibitory control relate to age differences in word recognition.

Cognitive function, including performance on working memory tasks, predicts accuracy on word recognition (Benichov et al., 2012; Lash et al., 2013), and declines in working memory might lead older listeners to compensate for processing difficulties by relying on top-down expectations for what they might hear. For example, older adults tend to both over-rely on cognitive expectations to help understand spoken language, and to be overconfident compared to younger listeners about what they heard (Rogers, Jacoby, & Sommers, 2012; Rogers & Wingfield, 2015). Rogers et al. (2012) reported that older listeners were more likely to misidentify a spoken word and respond with a word that was semantically consistent with previous semantic context. For instance, older listeners who hear the word *barn* in quiet, and then the word *pay* in background noise, were more likely than younger listeners to report with high confidence that the second word they heard was *hay*. Additionally, older adults make use of contextual cues more than younger listeners when asked to identify a word-initial ambiguous phoneme located in the final word of a sentence (Abada et al., 2008). For example, in the sentence *Sally was very upset after she noticed her son's ?ash* (where "?" indicates a phoneme that has been replaced by an ambiguous phoneme between *g* and *k*), older listeners are more likely than younger listeners to be influenced by the context, and identify the ambiguous sound such that the final word is *gash*, even though the token is identified as *cash* when presented without sentence cues. While listeners of all ages benefit from semantic context, older adults show greater improvements in reaction times, compared to younger adults (Goy, Pelletier, Coletta, & Pichora-Fuller, 2013). At the level of word identification, older adults can make use of context to compensate for low perceptual acuity (e.g., Lash et al., 2013; Wingfield, Aberdeen, & Stine, 1991), but perhaps as a function of declines in working memory, older adults are less able to make use of disambiguating context that occurs after a target word (Wingfield, Alexander, & Cavigelli, 1994). Thus, listeners can make use of what they know (context, and common words) to adapt for what they cannot hear or remember.

Across domains, older adults also exhibit a reduced ability to inhibit irrelevant information, such as ignoring printed words that are superimposed onto pictures (e.g., Campbell, Grady, Ng, & Hasher, 2012; for a review see Zacks & Hasher, 1997). Older listeners rely more on top-down cues during a phoneme identification task than do younger listeners (Baum, 2003), and are more influenced by lexical information when identifying a word-initial ambiguous phoneme, even if explicitly asked to ignore lexical status (Mattys & Scharenborg, 2014), possibly reflecting difficulty inhibiting task-irrelevant information. Regarding word recognition, after accounting for auditory thresholds, performance on language-related inhibition tasks correlated with difficulty in identifying low-frequency words that had many phonological competitors (Sommers & Danielson, 1999). Sommers and Danielson explained the correlation in terms of the Neighborhood Activation Model (Luce & Pisoni, 1998), and proposed that age-related inhibitory declines affect the ability to suppress phonologically related words. According to Sommers (1996), older adults struggle to identify a target when many phonological neighbors are activated and compete for selection, due to a reduced ability to inhibit competitors. Eye tracking measures have proven to be valuable for testing both the inhibition and working memory hypotheses among both younger and older listeners, as we discuss these online measures in the next section.

Online Measures of Cognitive Processing

Similar to the strategies discussed for auditory processing, online measures of comprehension and effort that measure incremental processing of the speech signal can help elucidate the hidden cognitive effort that older adults may experience during some language tasks. For example, online measures that track eye movements and pupil dilation as listeners attend to speech input may provide a window into the allocation of cognitive resources. Briefly, it has been shown that listeners reliably look at items based on what they hear, and so tracking eye movements to an array of visual objects (which includes a target item among a set of competitors) as listeners hear speech input is a well-established method for measuring how quickly listeners comprehend a spoken word (Tanenhaus, Magnuson, Dahan, & Chambers, 2000; Tanenhaus, Spivey-Knowlton, Eberhard, & Sedivy, 1995). Furthermore, since eye tracking measures can be computationally linked to models of spoken word recognition (e.g., Allopenna, Magnuson, & Tanenhaus, 1998), it is hypothesized that eye fixations can give insight into the words that listeners activate as they hear a spoken word unfold over time. This makes it possible to query the online activation and inhibition of a lexical neighborhood by measuring differences in fixation proportions to objects in an array, for instance, the relative proportion of fixations to an image of a *speaker* when participants are presented with the auditory word *beaker*. The finding that the speed of eye movements is similar in younger and older adults (Ben-David et al., 2011; Pirog Revill & Spieler, 2012; Pratt, Dodd, & Welsh, 2006), makes eye tracking an especially attractive methodology for studying processing in older populations, particularly in light of findings that reaction time tends to increase in older adults (Ayasse, Lash & Wingfield, 2016).

Measuring pupil dilation during processing is another non-invasive method to monitor the cognitive effort required to perform language tasks. This paradigm uses the same equipment as eye tracking, but participants are instructed to instead direct their gaze to a single location on the computer monitor (e.g., a fixation cross) while presented with an auditory input. Increase in pupil size has been linked to increased perceptual or cognitive effort, such as listening to degraded speech input (Kahneman & Beatty, 1966; Zekveld, Kramer, & Festen, 2011). To compare age differences in cognitive effort, pupil dilation measures are often standardized within an individual's own dynamic range, in order to account for age group differences in physiological processes. Thus, pupillometry can elucidate increases in hidden effort that older adults experience despite preserved behavioral performance (Piquado, Isaacowitz, & Wingfield, 2010). Functional magnetic resonance imaging (fMRI) can provide information about which and to what extent neural substrates are activated during a task. As such, neuroimaging studies can provide valuable insight regarding the allocation of resources during speech comprehension across neural systems. This is the most common use of fMRI in the study ofspeech processing in older adults. Studies using fMRI have revealed that older adults recruit compensatory brain networks in order to preserve cognitive function (e.g., Cabeza, Anderson, Lcantore, & McIntosh, 2002). For example, older adults recruit different cortical networks compared to younger adults, in order to successfully comprehend syntactically complex speech (Peelle et al., 2011). When processing speech in noise, despite similar behavioral performance between younger and older adults, older listeners recruit more regions involved in domain‐general cognitive processes (Wong et al., 2009) in addition to language‐sensitive cortex. This suggests that the older adults compensate for declining performance in language processing by increasing their reliance on cognitive abilities. Under difficult listening conditions, listeners who exhibit a larger pupil response also show increased activation in auditory cortex, suggesting a relationship between listening effort and increased attention on processing the acoustic input (Kuchinsky et al., 2016; Zekveld, Heslenfeld, Johnsrude, Versfeld, & Kramer, 2014a). Thus, eye tracking, pupillometry, and fMRI can detect subtle differences in effort that emerge independent of listeners making an overt behavioral judgment.

Conclusions

We have reviewed evidence that auditory encoding fidelity (via measures of temporal encoding fidelity and neural response consistency) provides information about auditory processing not captured by conventional auditory threshold measures, that cognitive declines may contribute to word recognition, and that the two domains can interact. Since the reliability of early auditory processing (encoding fidelity) can vary across listeners (Skoe et al., 2015), or even for one listener across the lifespan (Krizman et al., 2015;), it is important to understand how variation in this earliest aspect of auditory encoding has cascading effects in word recognition and language comprehension. Specifically, we argue that poor auditory encoding might affect the strength of activation of phonemes and constituent words, and redirect cognitive resources to make it appear that a listener has cognitive deficits (Rabbitt, 1968; Rönnberg et al., 2013; Wingfield et al., 2005; Schneider & Pichora-Fuller, 2000). Further, cognitive deficits might lead to outcomes that appear to be auditory in nature. For example, reduced inhibitory control might masquerade as imperfect auditory word recognition, stemming from increased competition (Sommers & Danielson, 1999). Thus, auditory and cognitive declines in older listeners lead to complex interactions that may affect more than one aspect of spoken word recognition. For a window into real-time processing, we recommend online measures of sensory processing (e.g., ABR, ERP), and cognitive effort in word recognition (eye tracking, pupillometry, fMRI) because they do not rely on listeners having to execute explicit, post-hoc decision-based responses.

Additional recommendations for ways to better control for differences in audibility when comparing language performance for younger and older adults (Humes et al., 2012; see also Schneider et al., 2010) include: screening participants for adequate pure tone thresholds up to 4,000 Hz, using a four-group experiment design such as young/old listeners with good/poor hearing, simulating hearing loss in younger adults by masking or filtering the speech input in order to separate effects of degraded input from cognitive aging, or using large samples and statistically partial out effects of sensory abilities. Another strategy that can equate baseline difficulty is to use speech recognition thresholds to tailor the stimulus level for each participant (e.g., as reviewed by Sommers, 2005). Equating baseline difficulty in particular when measuring performance on a complex linguistic task ensures that older adults are not placed at an overall disadvantage simply because of age differences in ability to perceive the input.

Regarding the downstream effects of poor auditory processing, we hypothesize that increased variability in the neural response to a singular speech sound may lead to a fuzzy and poorly defined representation of the acoustic stimulus by the central nervous system (Hornickel & Kraus, 2013; Skoe et al., 2015), which may ultimately adversely affect processes crucial to word recognition. Listeners with low auditory encoding fidelity (as measured by temporal encoding fidelity and/or neural response consistency) might, as a consequence, not accurately encode subtle but meaningful phonetic distinctions, which, we propose, could lead to increased difficulty during lexical access. Indeed, results from a recent study suggest that high ABR consistency leads to faster word recognition (Johns, Myers, Skoe, & Magnuson, 2017). Consider that reduced auditory encoding fidelity could contribute to increased competition as follows: unreliable or inconsistent neural responses to sound might lead to a less precise, "fuzzy" neural encoding of the speech input. The fuzzy encoding might lead to more words becoming partially activated as potential target words, effectively increasing the size of the competitor set and impeding robust word recognition. For example, poor auditory encoding of *bear* might lead to *bear* and *pear* becoming similarly activated (along with many words that would not be strongly activated by a precise encoding of *bear*, such as *pain*). Activation of many words without a clear bottom-up advantage for the target word would lead to a prolonged and sluggish competition process in a model like TRACE (McClelland & Elman, 1986), without any change in the inhibition process itself. Thus, increased competition effects (Ben-David et al., 2011; Sommers & Danielson, 1999; Taler et al., 2010) might emerge from unreliable neural responses to auditory input. While Sommers and Danielson (1999) attribute slowing in lexical access under conditions of increased competition to poor inhibition in the older population, we argue that the data cannot actually distinguish between this account and one which points to declines in auditory encoding fidelity because the authors did not include a measure of encoding fidelity. Recently, Johns and colleagues (2017) conducted a more complete assessment of the relation between cognitive abilities, sensory abilities, and online measures of spoken word recognition and found that neural response consistency predicted the speed of spoken word recognition for both younger and older adults. This is preliminary evidence that supports the notion that a fuzzy auditory encoding will impede lexical access, and future work is needed to further investigate this hypothesis.

In sum, we suggest that future work will be needed to determine whether auditory and cognitive deficits combine to give rise to these competition effects. What are the implications of these complex interactions of auditory and cognitive factors on speech perception? In the coming years, research directed at the following questions will help us to continue to disentangle auditory and cognitive effects on word recognition:

1) If older listeners struggle with spoken word recognition as a function of auditory difficulties, then are similar patterns observed in younger listeners who never fully developed quality auditory encoding (e.g., reading impairment, Hornickel & Kraus, 2013; Neef, Schaadt, & Friederici, 2017)?
2) Are there lifetime (or late-in-life) experiences that can preserve word recognition for a listener with auditory and/or cognitive declines (e.g., Gordon-Salant et al., 2006; Pichora-Fuller et al., 2006)? For example, training older listeners on perceptual discrimination can improve phoneme categorization (Anderson et al., 2013b). This then leads us to ask how perceptual training affects the understanding of real words, and whether the effects generalize to improved communication outside the laboratory.

3) In real-world situations where communication hinges on understanding more than just single words, to what degree do auditory and cognitive processes interact? For example, Schneider and colleagues reported age differences in passage recall (Schneider et al., 2000; see Schneider et al., 2010 for a review of processing speech in a noisy setting).
4) Can older adults capitalize on their decades of experience with auditory and language input to mitigate auditory processing declines? Much research is taken from the perspective that the older listener experience deficits in language comprehension, however, other evidence suggests that older listeners are better than younger listeners at filling in linguistic information based on expectation (Pichora-Fuller, 2009). Likewise, might older adults be better than younger listeners at attending to specific, relevant aspects of the acoustic signal because they have had more time to learn what can help differentiate a potentially ambiguous word?

Some of these questions are currently being investigated in our labs and others, while others are fertile ground for further exploration. Given that phoneme and word identification rely on successful neural transduction of the auditory input, that the neural encoding of auditory input is variable across listeners and across the lifespan, and that there may be limits to how much compensation can be achieved from cognitive resources, these research questions and others relevant to spoken language processing in older (and younger) listeners call for an interdisciplinary approach that includes rigorous assessment of auditory encoding and cognitive abilities.

Box 1. Key Terms Defined

- ***Older adult:*** varies by study, but is usually around 60 years or older.
- ***Younger adult:*** roughly 18-24 years old, which is the typical age range of college undergraduates.
- ***Auditory processing:*** The peripheral (cochlear) and central (subcortical and cortical) auditory system processes that culminate in the perception of a sound. Auditory processing is often assessed by determining auditory thresholds. Threshold measures the lowest intensity at which a listener can detect an auditory stimulus. (In this review, we refer specifically to auditory pure tone thresholds, the lowest intensity at which a listener can detect a tone of a particular frequency, because those are most commonly used outside of communication sciences; however, speech reception thresholds are an additional, and perhaps more relevant, measure of auditory thresholds.)
- ***Auditory encoding fidelity:*** An important aspect of auditory processing that refers to the precision with which specific acoustic features of the stimulus are preserved in the neural response to auditory input, as measured by behavioral tasks and electrophysiological recordings. We consider two facets of auditory encoding fidelity:
    - ***Temporal encoding fidelity*** the precision of encoding the temporal features of a stimulus, such as a voice onset time or formant transitions within a speech syllable.
    - ***Neural response consistency*** how consistently the neural response is produced when the same sound is played in a repeated fashion (Anderson, Parbery-Clark, White-Schwoch, & Kraus, 2012).
- ***Working memory:*** Postle defines working memory: "Working memory refers to the retention of information in conscious awareness when this information is not present in the environment, to its manipulation, and to its use in guiding behavior" (Postle, 2006, p. 23; Wingfield, 2016). Working memory is often assessed in older listeners with a reading span (Daneman & Carpenter, 1980) or a digit span task.
- ***Inhibitory control:*** A cognitive process that is involved in actively suppressing irrelevant information (cf., Bialystok, Craik, & Luk, 2008; Novick, Trueswell, & Thompson-Schill, 2005), often assessed with tasks such as the Stroop test (Stroop, 1935) or the Trail Making Test (Reitan, 1992).

Acknowledgements

We are grateful for constructive input from two anonymous reviewers, and from Arthur Wingfield. We also thank James Magnuson, who provided helpful input on earlier versions of this manuscript. This review was written with support from NIH: R01 AG 019714, T32 NS 007292-30,

Works Cited

Abada, S. H., Baum, S. R., & Titone, D. (2008). The effects of contextual strength on phonetic identification in younger and older listeners. *Experimental Aging Research*, *34*(3), 232-250.

Akeroyd, M. A. (2008). Are individual differences in speech reception related to individual differences in cognitive ability? A survey of twenty experimental studies with normal and hearing-impaired adults. *International Journal of Audiology*, *47*(sup2), S53-S71.

Alain, C., McDonald, K. L., Ostroff, J. M., & Schneider, B. (2004). Aging: a switch from automatic to controlled processing of sounds? *Psychology and aging*, *19*(1), 125-133.

Alain, C., & Tremblay, K. (2007). The role of event-related brain potentials in assessing central auditory processing. *Journal of the American Academy of Audiology*, *18*(7), 573-589.

Albers, M. W., Gilmore, G. C., Kaye, J., Murphy, C., Wingfield, A., Bennett, D. A., ... & Duffy, C. J. (2015). At the interface of sensory and motor dysfunctions and Alzheimer's disease. *Alzheimer's & Dementia*, *11*(1), 70-98.

Allopenna, P. D., Magnuson, J. S., & Tanenhaus, M. K. (1998). Tracking the time course of spoken word recognition using eye movements: Evidence for continuous mapping models. *Journal of Memory and Language, 38*, 419-439.

Anderson, S., Parbery-Clark, A., White-Schwoch, T., & Kraus, N. (2012). Aging affects neural precision of speech encoding. *The Journal of Neuroscience*, *32*(41), 14156-14164.

Anderson, S., White-Schwoch, T., Parbery-Clark, A., & Kraus, N. (2013a). A dynamic auditory-cognitive system supports speech-in-noise perception in older adults. *Hearing Research*, *300*, 18-32.

Anderson, S., White-Schwoch, T., Parbery-Clark, A., & Kraus, N. (2013b). Reversal of age-related neural timing delays with training. *Proceedings of the National Academy of Sciences*, *110*(11), 4357-4362.

Arlinger, S., Lunner, T., Lyxell, B., & Kathleen Pichora-Fuller, M. (2009). The emergence of cognitive hearing science. *Scandinavian Journal of Psychology*, *50*(5), 371-384.

Ayasse, N. D., Lash, A., & Wingfield, A. (2016). Effort not speed characterizes comprehension of spoken sentences by older adults with mild hearing impairment. *Frontiers in aging neuroscience*, *8*, 1-12.

Baldwin, C. L., & Ash, I. K. (2011). Impact of sensory acuity on auditory working memory span in young and older adults. *Psychology and Aging*, *26*(1), 85-91.

Baltes, P. B., & Lindenberger, U. (1997). Emergence of a powerful connection between sensory and cognitive functions across the adult life span: A new window to the study of cognitive aging? *Psychology and Aging, 12*(1), 12-21.

Baum, S. R. (2003). Age differences in the influence of metrical structure on phonetic identification. *Speech Communication*, *39*(3), 231-242.

Ben-David, B. M., Chambers, C. G., Pichora-Fuller, M. K., Reingold, E. M., & Schneider, B. A. (2011). Effects of aging and noise on real-time spoken word recognition: Evidence from eye movements. *Journal of Speech, Language, and Hearing Research*, *54*(1), 243-262.

Benichov, J., Cox, L. C., Tun, P. A., & Winfield, A. (2012). Word recognition within a linguistic context: Effects of age, hearing acuity, verbal ability, and cognitive function. *Ear and Hearing, 32*(2), 250-256.

Bergman, M. (1980). *Aging and the perception of speech*. University Park Press.

Bialystok, E., Craik, F., & Luk, G. (2008). Cognitive control and lexical access in younger and older bilinguals. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *34*(4), 859-873.

Bidelman, G. M., Villafuerte, J. W., Moreno, S., & Alain, C. (2014). Age-related changes in the subcortical–cortical encoding and categorical perception of speech. *Neurobiology of aging*, *35*(11), 2526-2540.

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.

Campbell, K. B., & Bartoli, E. A. (1986). Human auditory evoked potentials during natural sleep: the early components. *Electroencephalography and Clinical Neurophysiology/Evoked Potentials Section*, *65*(2), 142-149.

Campbell, K. L., Grady, C. L., Ng, C., & Hasher, L. (2012). Age differences in the frontoparietal cognitive control network: implications for distractibility. *Neuropsychologia*, *50*(9), 2212-2223.

Chen, Q., & Mirman, D. (2015). Interaction between phonological and semantic representations: Time matters. *Cognitive Science*, *39*(3), 538-558.

Classon, E., Rudner, M., Johansson, M., & Rönnberg, J. (2013). Early ERP signature of hearing impairment in visual rhyme judgment. *Frontiers in Psychology*, *4*, 1-18.

Clinard, C. G., & Tremblay, K. L. (2013). Aging degrades the neural encoding of simple and complex sounds in the human brainstem. *Journal of the American Academy of Audiology*, *24*(7), 590-599.

Committee on Hearing and Bioacoustics and Biomechanics (CHABA). (1988) Speech understanding and aging. *Journal of the Acoustical Society of America, 83,* 859–895.

Craik, F. I. M, & Salthouse, T. A. (Eds.). (1992). The handbook of aging and cognition. Hillsdale, NJ: Erlbaum.

Cruickshanks, K. J., Zhan, W., & Zhong, W. (2010). Epidemiology of age-related hearing impairment. In S. Gordon-Salant, R. D. Frisina, A. N. Popper, & R. R. Fay (Eds.), *The aging auditory system* (pp. 259-274). New York: Springer.

Dahan, D., Magnuson, J. S., & Tanenhaus, M. K. (2001). Time course of frequency effects in spoken-word recognition: Evidence from eye movements. *Cognitive Psychology*, *42*(4), 317-367.

Daneman, M., & Carpenter, P. A. (1980). Individual differences in working memory and reading. *Journal of Verbal Learning and Verbal Behavior*, *19*(4), 450-466.

Du, Y., Buchsbaum, B. R., Grady, C. L., & Alain, C. (2016). Increased activity in frontal motor cortex compensates impaired speech perception in older adults. *Nature Communications, 7*, 1-12.

Dubno, J. R., Ahlstrom, J. B., & Horwitz, A. R. (2000). Use of context by young and aged adults with normal hearing. *The Journal of the Acoustical Society of America*, *107*(1), 538-546.

Eckert, M. A., Cute, S. L., Vaden, K. I., Kuchinsky, S. E., & Dubno, J. R. (2012). Auditory cortex signs of age-related hearing loss. *Journal of the Association for Research in Otolaryngology*, *13*(5), 703-713.

Fitzgibbons, P. J., & Gordon-Salant, S. (1996). Auditory temporal processing in elderly listeners. *American Academy of Audiology, 7*, 183-189.

Fitzgibbons, P. J., & Gordon-Salant, S. (2010). Behavioral studies with aging humans: Hearing sensitivity and psychoacoustics. In S. Gordon-Salant, R. D. Frisina, A. N. Popper, & R. R. Fay (Eds.), *The aging auditory system* (pp. 111-134). New York: Springer.

Gaskell, M. G., & Marslen-Wilson, W. D. (1997). Integrating form and meaning: A distributed model of speech perception. *Language and Cognitive Processes*, *12*(5-6), 613-656.

Gernsbacher, M. A., & Faust, M. (1991). The role of suppression in sentence comprehension. *Advances in psychology*, *77*, 97-128.

Gordon-Salant, S., & Fitzgibbons, P. J. (1999). Profile of auditory temporal processing in older listeners. *Journal of Speech, Language, and Hearing Research*, *42*(2), 300-311.

Gordon-Salant, S., Yeni-Komshian, G. H., Fitzgibbons, P. J., & Barrett, J. (2006). Age-related differences in identification and discrimination of temporal cues in speech segments. *The Journal of the Acoustical Society of America*, *119*(4), 2455-2466.

Goy, H., Pelletier, M., Coletta, M., & Pichora-Fuller, M. K. (2013). The effects of semantic context and the type and amount of acoustic distortion on lexical decision by younger and older adults. *Journal of Speech, Language, and Hearing Research*, *56*(6), 1715-1732.

Hornickel, J., & Kraus, N. (2013). Unstable representation of sound: a biological marker of dyslexia. *The Journal of Neuroscience*, *33*(8), 3500-3504.

Howes, D. H., & Solomon, R. L. (1951). Visual duration threshold as a function of word-probability. *Journal of Experimental Psychology*, *41*(6), 401-410.

Hellstrom, L. I., & Schmiedt, R. A. (1990). Compound action potential input/output functions in young and quiet-aged gerbils. *Hearing Research*, *50*(1), 163-174.

Huettig, F., & Janse, E. (2016). Individual differences in working memory and processing speed predict anticipatory spoken language processing in the visual world. *Language, Cognition and Neuroscience*, *31*(1), 80-93.

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

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*(7), 590-603.

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., Dubno, J. R., Gordon-Salant, S., Lister, J. J., Cacace, A. T., Cruickshanks, K. J., … & Wingfield, A. (2012). Central Presbycusis: A review and evaluation of the evidence. *Journal of the American Academy of Audiology*, *23*(8), 635-666.

Ison, J. R., Tremblay, K. L., & Allen, P. D. (2010). Closing the gap between neurobiology and human presbycusis: behavioral and evoked potential studies of age-related hearing loss in animal models and in humans. In S. Gordon-Salant, R. D. Frisina, A. N. Popper, & R. R. Fay (Eds.), *The aging auditory system* (pp. 75-110). New York: Springer.

Janse, E., & Newman, R. S. (2013). Identifying nonwords: Effects of lexical neighborhoods, phonotactic probability, and listener characteristics. *Language and Speech*, *56*(4), 421-441.

January, D., Trueswell, J. C., & Thompson-Schill, S. L. (2009). Co-localization of Stroop and syntactic ambiguity resolution in Broca's area: Implications for the neural basis of sentence processing. *Journal of Cognitive Neuroscience*, *21*(12), 2434-2444.

Jerger, J., & Hall, J. (1980). Effects of age and sex on auditory brainstem response. *Archives of Otolaryngology*, *106*(7), 387-391.

Jerger, J., & Johnson, K. (1988). Interactions of age, gender, and sensorineural hearing loss on ABR latency. *Ear and Hearing*, *9*(4), 168-176.

Jewett, D., & Williston, J. S. (1971). Auditory-evoked far fields averaged from the scalp of humans. *Brain*, *94*(4), 681-696.

Johns, A. R., Myers, E. B., Skoe, E., & Magnuson, J. M. (in preparation). Spoken word recognition in younger and older adults relates to quality of neural response.

Kamal, B., Holman, C., & de Villers-Sidani, E. (2013). Shaping the aging brain: role of auditory input patterns in the emergence of auditory cortical impairments. The effect of hearing loss on neural processing. *Frontiers in Systems Neuroscience, 7*, 1-11.

Kahneman, D., & Beatty, J. (1966). Pupil diameter and load on memory. *Science*, *154*(3756), 1583-1585.

Krizman, J., Tierney, A., Fitzroy, A. B., Skoe, E., Amar, J., & Kraus, N. (2015). Continued maturation of auditory brainstem function during adolescence: A longitudinal approach. *Clinical Neurophysiology*, *126*(12), 2348-2355.

Kujawa, S. G., & Liberman, M. C. (2015). Synaptopathy in the noise-exposed and aging cochlea: primary neural degeneration in acquired sensorineural hearing loss. *Hearing Research, 330*, 191-199.

Lash, A., Rogers, C. S., Zoller, A., & Wingfield, A. (2013). Expectation and entropy in spoken word recognition: Effects of age and hearing acuity. *Experimental Aging Research, 39*(3), 235-253.

Lauter, J. L., & Loomis, R. L. (1986). Individual Differences in Auditory Electric Responses: Comparisons of Between-subject and Within-Subject Variability I. Absolute latencies of brainstem vertex-positive peaks. *Scandinavian Audiology*, *15*(3), 167-172.

Lin, F. R., Ferrucci, L., An, Y., Goh, J. O., Doshi, J., Metter, E. J., ... & Resnick, S. M. (2014). Association of hearing impairment with brain volume changes in older adults. *NeuroImage*, *90*, 84-92.

Lin, F. R., Ferrucci, L., Metter, E. J., An, Y., Zonderman, A. B., & Resnick, S. M. (2011). Hearing loss and cognition in the Baltimore Longitudinal Study of Aging. *Neuropsychology*, *25*(6), 763-770.

Lin, F. R., Metter, E. J., O'Brien, R. J., Resnick, S. M., Zonderman, A. B., & Ferrucci, L. (2011). Hearing loss and incident dementia. *Archives of Neurology*, *68*(2), 214-220.

Lin, F. R., Yaffe, K., Xia, J., Xue, Q. L., Harris, T. B., Purchase-Helzner, E., ... & Health ABC Study Group, F. (2013). Hearing loss and cognitive decline in older adults. *JAMA Internal Medicine*, *173*(4), 293-299.

Lindenberger, U., & Baltes, P. B. (1994). Sensory functioning and intelligence in old age: A strong connection. *Psychology and Aging, 9*(3), 339-355.

Lisker, L., & Abramson, A. S. (1964). A cross-language study of voicing in initial stops: Acoustical measurements. *Word*, *20*(3), 384-422.

Lister, J., Besing, J., & Koehnke, J. (2002). Effects of age and frequency disparity on gap discrimination. *The Journal of the Acoustical Society of America*, *111*(6), 2793-2800.

Luck, S. J. (2014). *An introduction to the event-related potential technique*. Cambridge, MA: MIT press.

Luce, P. A., Goldinger, S. D., Auer, E. T., & Vitevitch, M. S. (2000). Phonetic priming, neighborhood activation, and PARSYN. *Perception & psychophysics*, *62*(3), 615-625.

Luce, P. A., & Pisoni, D. B. (1998). Recognizing spoken words: The neighborhood activation model. *Ear and Hearing*, *19*(1), 1-36.

Magnuson, J. S., Dixon, J. A., Tanenhaus, M. K., & Aslin, R. N. (2007). The dynamics of lexical competition during spoken word recognition. *Cognitive Science*, *31*(1), 133-156.

Magnuson, J.S., Mirman, D. and Myers, E. (2013). Spoken Word Recognition. In D. Reisberg (Ed.), *The Oxford Handbook of Cognitive Psychology* (pp 412-441). New York, USA: Oxford University Press.

Marslen-Wilson, W. D. (1987). Functional parallelism in spoken word-recognition. *Cognition*, *25*(1), 71-102.

Martin, B. A., Sigal, A., Kurtzberg, D., & Stapells, D. R. (1997). The effects of decreased audibility produced by high-pass noise masking on cortical event-related potentials to speech sounds/ba/and/da. *The Journal of the Acoustical Society of America*, *101*(3), 1585-1599.

Mattys, S. L., & Scharenborg, O. (2014). Phoneme categorization and discrimination in younger and older adults: A comparative analysis of perceptual, lexical, and attentional factors. *Psychology and Aging*, *29*(1), 150.

McCabe, D. P., Roediger III, H. L., McDaniel, M. A., Balota, D. A., & Hambrick, D. Z. (2010). The relationship between working memory capacity and executive functioning: evidence for a common executive attention construct. *Neuropsychology, 24*(2), 222.

McCandless, G. A., & Best, L. (1966). Summed evoked responses using pure-tone stimuli. *Journal of Speech, Language, and Hearing Research*, *9*(2), 266-272.

McClelland, J. L., & Elman, J. L. (1986). The TRACE model of speech perception. *Cognitive Psychology*, *18*(1), 1-86.

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 Section A*, *58*(1), 22-33.

Mehraei, G., Hickox, A. E., Bharadwaj, H. M., Goldberg, H., Verhulst, S., Liberman, M. C., & Shinn-Cunningham, B. G. (2016). Auditory Brainstem Response Latency in Noise as a Marker of Cochlear Synaptopathy. *The Journal of Neuroscience*, *36*(13), 3755-3764.

Möhrle, D., Ni, K., Varakina, K., Bing, D., Lee, S. C., Zimmermann, U., ... & Rüttiger, L. (2016). Loss of auditory sensitivity from inner hair cell synaptopathy can be centrally compensated in the young but not old brain. *Neurobiology of Aging, 44,* 173-184.

Morrell, C. H., Gordon-Salant, S., Pearson, J. D., Brant, L. J., & Fozard, J. L. (1996). Age-and gender-specific reference ranges for hearing level and longitudinal changes in hearing level. *The Journal of the Acoustical Society of America, 100*(4), 1949-1967.

Musiek, F. E., Shinn, J. B., Jirsa, R., Bamiou, D. E., Baran, J. A., & Zaida, E. (2005). GIN (Gaps-In-Noise) test performance in subjects with confirmed central auditory nervous system involvement. *Ear and Hearing*, *26*(6), 608-618.

Näätänen, R., Gaillard, A. W., & Mäntysalo, S. (1978). Early selective-attention effect on evoked potential reinterpreted. *Acta psychologica*, *42*(4), 313-329.

Näätänen, R., Paavilainen, P., Rinne, T., & Alho, K. (2007). The mismatch negativity (MMN) in basic research of central auditory processing: a review. *Clinical Neurophysiology*, *118*(12), 2544-2590.

Neef, N. E., Schaadt, G., & Friederici, A. D. (2017). Auditory brainstem responses to stop consonants predict literacy. *Clinical Neurophysiology*, *128*(3), 484-494.

Novick, J. M., Trueswell, J. C., & Thompson-Schill, S. L. (2005). Cognitive control and parsing: Reexamining the role of Broca's area in sentence comprehension. *Cognitive, Affective, & Behavioral Neuroscience*, *5*(3), 263-281.

Ouda, L., Profant, O., & Syka, J. (2015). Age-related changes in the central auditory system. *Cell and Tissue Research, 361*(1), 337-358.

Palmer, S. B., & Musiek, F. E. (2014). Electrophysiological gap detection thresholds: effects of age and comparison with a behavioral measure. *Journal of the American Academy of Audiology*, *25*(10), 999-1007.

Peelle, J. E., Troiani, V., Grossman, M., & Wingfield, A. (2011). Hearing loss in older adults affects neural systems supporting speech comprehension. *Journal of Neuroscience*, *31*(35), 12638-12643.

Peelle, J. E., & Wingfield, A. (2016). The neural consequences of age-related hearing loss. *Trends in Neurosciences*, *39*(7), 486-497.

Phillips, D. P., & Smith, J. C. (2004). Correlations among within-channel and between-channel auditory gap-detection thresholds in normal listeners. *Perception*, *33*(3), 371-378.

Phillips, D. P., Taylor, T. L., Hall, S. E., Carr, M. M., & Mossop, J. E. (1997). Detection of silent intervals between noises activating different perceptual channels: Some properties of "central" auditory gap detection. *The Journal of the Acoustical Society of America*, *101*(6), 3694-3705.

Pichora-Fuller, M. K. (2003). Processing speed and timing in aging adults: Psychoacoustics, speech perception, and comprehension. *International Journal of Audiology*, *42*, S59-S67.

Pichora-Fuller, M. K., & MacDonald, E. W. E. N. (2008). Auditory temporal processing deficits in older listeners: from a review to a future view of presbycusis. In *Auditory Signal Processing in Hearing-Impaired Listeners. 1st International Symposium on Auditory and Audiological Research (ISAAR 2007)* (pp. 291-300). Elsinore: Centertryk A/S.

Pichora-Fuller, M. K. (2009). Using the brain when the ears are challenged helps healthy older listeners compensate and preserve communication function. In L. Hickson (Ed.), *Hearing Care for Adults* (pp. 53–65). Stäfa, Switzerland: Phonak.

Pichora-Fuller, M. K., Schneider, B. A., Benson, N. J., Hamstra, S. J., & Storzer, E. (2006). Effect of age on detection of gaps in speech and nonspeech markers varying in duration and spectral symmetry. *The Journal of the Acoustical Society of America*, *119*(2), 1143-1155.

Pichora-Fuller, M. K., Schneider, B. A., & Daneman, M. (1995). How young and old adults listen to and remember speech in noise. *The Journal of the Acoustical Society of America*, *97*(1), 593-608.

Pichora-Fuller, M. K., Schneider, B. A., MacDonald, E., Pass, H. E., & Brown, S. (2007). Temporal jitter disrupts speech intelligibility: A simulation of auditory aging. *Hearing Research*, *223*(1), 114-121.

Piquado, T., Isaacowitz, D., & Wingfield, A. (2010). Pupillometry as a measure of cognitive effort in younger and older adults. *Psychophysiology*, *47*(3), 560-569.

Pirog Revill, K., & Spieler, D. H. (2012). The effect of lexical frequency on spoken word recognition in young and older listeners. *Psychology of Aging, 27*, 80-87.

Plomp, R. (1986). A signal-to-noise ratio model for the speech-reception threshold of the hearing impaired. *Journal of Speech, Language, and Hearing Research*, *29*(2), 146-154.

Postle, B. R. (2006). Working memory as an emergent property of the mind and brain. *Neuroscience*, *139*, 23–38.

Pratt, J., Dodd, M., & Welsh, T. (2006). Growing older does not always mean moving slower: examining aging and the saccadic motor system. *Journal of Motor Behavior*, *38*, 373-382.

Rabbitt, P. M. (1968). Channel-capacity, intelligibility and immediate memory. *The Quarterly Journal of Experimental Psychology, 20*(3), 241-248.

Rabbitt, P. (1991). Mild hearing loss can cause apparent memory failures which increase with age and reduce with IQ. *Acta Oto-laryngologica*, *111*(sup476), 167-176.

Reitan, R. M. (1992). *Trail Making Test: Manual for administration and scoring*. Reitan Neuropsychology Laboratory.

Rodd, J. M., Davis, M. H., & Johnsrude, I. S. (2005). The neural mechanisms of speech comprehension: fMRI studies of semantic ambiguity. *Cerebral Cortex*, *15*(8), 1261-1269.

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.

Rogers, C. S., & Wingfield, A. (2015). Stimulus-independent semantic bias misdirects word recognition in older adults. *The Journal of the Acoustical Society of America*, *138*(1), EL26-EL30.

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*, 1-17.

Rönnberg, J., Rudner, M., & Lunner, T. (2011). Cognitive hearing science: The legacy of Stuart Gatehouse. *Trends in Amplification*, *15*(3), 140-148.

Rosen, S. (1992). Temporal information in speech: acoustic, auditory and linguistic aspects. *Philosophical Transactions of the Royal Society of London B: Biological Sciences*, *336*(1278), 367-373.

Roth, T. N. (2014). Aging of the auditory system. *Handbook of clinical neurology, 129*, 357-373.

Salthouse, T. A. (1991). *Theoretical perspectives on cognitive aging*. Hillsdale, NJ: Erlbaum.

Schneider, B. A., Daneman, M., Murphy, D. R., & See, S. K. (2000). Listening to discourse in distracting settings: the effects of aging. *Psychology and Aging*, *15*(1), 110-125.

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), 139-152.

Schneider, B. A., & Hamstra, S. J (1999). Gap detection thresholds as a function of tonal duration for younger and older listeners. *The Journal of the Acoustical Society of America*, *106*(1), 371-380.

Schneider, B. A., & Parker, S. (2009). Human Methods: Psychophysics. In Squire, L. R. (Ed.), Encyclopedia of Neuroscience Volume 5, (pp. 19-27). Oxford: Academic Press.

Schneider, B. A., & Pichora-Fuller, M. K. (2000). Implications of perceptual deterioration for cognitive aging research. In F. I. M. Craik & T. A. Salthouse (Eds.), *The handbook of aging and cognition*, (2nd ed.), (pp. 155-219). Mahwah, NJ: Erlbaum.

Schneider, B. A., Pichora-Fuller, K., & Daneman, M. (2010). Effects of senescent changes in audition and cognition on spoken language comprehension. In S. Gordon-Salant, R. D. Frisina, A. N. Popper, & R. R. Fay (Eds.), *The aging auditory system* (pp. 167-210). New York: Springer.

Shinn-Cunningham, B. G., & Best, V. (2008). Selective attention in normal and impaired hearing. *Trends in Amplification*, *12*(4), 283-299.

Singh, G., Pichora-Fuller, M. K., & Schneider, B. A. (2008). The effect of age on auditory spatial attention in conditions of real and simulated spatial separation. *The Journal of the Acoustical Society of America*, *124*(2), 1294-1305.

Skoe, E., Krizman, J., Anderson, S., & Kraus, N. (2015). Stability and plasticity of auditory brainstem function across the lifespan. *Cerebral Cortex*, *25*(6), 1415-1426.

Snell, K. B., & Frisina, D. R. (2000). Relationships among age-related differences in gap detection and word recognition. *The Journal of the Acoustical Society of America*, *107*(3), 1615-1626.

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.

Sommers, M. S. (2005). Age-related changes in spoken word recognition. In D. B. Pisoni & R. E. Remez (Eds). *The Handbook of Speech Perception* (pp. 469-493). MA: Blackwell Publishing.

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, 458-472.

Song, J. H., Nicol, T., & Kraus, N. (2011). Test–retest reliability of the speech-evoked auditory brainstem response. *Clinical Neurophysiology*, *122*(2), 346-355.

Stamper, G. C., & Johnson, T. A. (2015). Auditory function in normal-hearing, noise-exposed human ears. *Ear and Hearing*, *36*(2), 172-184.

Stanley, R., Tun, P.A., Brownell, H., & Wingfield, A. (2012). Hidden costs of effortful listening on speech comprehension. *Journal of Communications Research, 4*, 157-180.

Starns, J. J., & Ratcliff, R. (2010). The effects of aging on the speed–accuracy compromise: Boundary optimality in the diffusion model. *Psychology and Aging*, *25*(2), 377-390.

Stroop, J. R. (1935). Studies of interference in serial verbal reactions. *Journal of Experimental Psychology*, *18*(6), 643-662.

Strouse, A., Ashmead, D. H., Ohde, R. N., & Grantham, D. W. (1998). Temporal processing in the aging auditory system. *The Journal of the Acoustical Society of America*, *104*(4), 2385-2399.

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. *Journal of Gerontology: Psychological Sciences, 65*, 551-560.

Tanenhaus, M. K., Magnuson, J. S., Dahan, D., & Chambers, C. (2000). Eye movements and lexical access in spoken-language comprehension: Evaluating a linking hypothesis between fixations and linguistic processing. *Journal of psycholinguistic research*, *29*(6), 557-580.

Tanenhaus, M. K., Spivey-Knowlton, M. J., Eberhard, K. M., & Sedivy, J. C. (1995). Integration of visual and linguistic information in spoken language comprehension. *Science*, *268*(5217), 1632-1634.

Tremblay, K. L., Piskosz, M., & Souza, P. (2003). Effects of age and age-related hearing loss on the neural representation of speech cues. *Clinical Neurophysiology*, *114*(7), 1332-1343.

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.

Valentijn, S. A., Van Boxtel, M. P., Van Hooren, S. A., Bosma, H., Beckers, H. J., Ponds, R. W., & Jolles, J. (2005). Change in sensory functioning predicts change in cognitive functioning: Results from a 6-year follow-up in the Maastricht Aging Study. *Journal of the American Geriatrics Society, 53*(3), 374-380.

Van Engen, K. J., & Peelle, J. E. (2014). Listening effort and accented speech. *Frontiers in human neuroscience*, *8*, 1-4.

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*(6), 2611-2624.

Vander Werff, K. R., & Burns, K. S. (2011). Brain stem responses to speech in younger and older adults. *Ear and Hearing*, *32*(2), 168-180.

Wingfield, A. (2016). Evolution of Models of Working Memory and Cognitive Resources. *Ear and Hearing, 37*, 35S-43S.

Wingfield, A., Aberdeen, J. S., & Stine, E. A. (1991). Word onset gating and linguistic context in spoken word recognition by young and elderly adults. *Journal of Gerontology*, *46*(3), P127-P129.

Wingfield, A., Amichetti, N. M., & Lash, A. (2015). Cognitive aging and hearing acuity: modeling spoken language comprehension. *Frontiers in Psychology*, *6*, 1-13.

Wingfield, A., Alexander, A. H., & Cavigelli, S. (1994). Does memory constrain utilization of top-down information in spoken word recognition? Evidence from normal aging. *Language and Speech*, *37*(3), 221-235.

Wingfield, A., McCoy, S. L., Peelle, J. E., Tun, P. A., & Cox, C. L. (2006). Effects of adult aging and hearing loss on comprehension of rapid speech varying in syntactic complexity. *Journal of the American Academy of Audiology*, *17*(7), 487-497.

Wingfield, A., & Tun, P. A. (2001). Spoken language comprehension in older adults: Interactions between sensory and cognitive change in normal aging. In *Seminars in Hearing* (Vol. 22, No. 03, pp. 287-302). New York, NY: Thieme Medical Publishers, Inc.

Wingfield, A., Tun, P. A., & McCoy, S. L. (2005). Hearing loss in older adulthood what it is and how it interacts with cognitive performance. *Current Directions in Psychological Science, 14*(3), 144-148.

Wlotko, E. W., Lee, C. L., & Federmeier, K. D. (2010). Language of the Aging Brain: Event‐Related Potential Studies of Comprehension in Older Adults. *Language and Linguistics Compass*, *4*(8), 623-638.

Wynne, D. P., Zeng, F. G., Bhatt, S., Michalewski, H. J., Dimitrijevic, A., & Starr, A. (2013). Loudness adaptation accompanying ribbon synapse and auditory nerve disorders. *Brain*, *136*(5), 1626-1638.

Zacks, R., & Hasher, L. (1997). Cognitive gerontology and attentional inhibition: A reply to Burke and McDowd. *The Journals of Gerontology Series B: Psychological Sciences and Social Sciences*, *52*(6), P274-P283.

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 and hearing*, *32*(4), 498-510.