EFFORTFUL AND EFFORTLESS LISTENING: HOW AGE-RELATED HEARING LOSS AND COGNITIVE ABILITIES INTERACT AND INFLUENCE MEMORY PERFORMANCE IN OLDER ADULTS

by

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Abstract

This study investigated how age-related-hearing loss (ARHL) might contribute to memory deficits and whether an enhanced auditory message can facilitate memory. According to the effortful listening hypothesis, effortful listening requires cognitive-linguistic and attentional resources for deciphering the message, resulting in fewer resources available for encoding into memory. Auditory perceptual and processing enhancements should reduce the listening effort and free up those resources resulting in better memory performance.

Three experiments were conducted to investigate whether decreasing listening effort facilitates memory performance. In Experiment 1 recall of complex prescription instructions presented in conversational speech and clear speech was tested to see if the enhanced listening (clear) resulted in better memory performance than the non-enhanced listening (conversational) for the two groups of older adults matched for age and hearing loss (Quiet and Noise). In Experiment 2, recall of complex prescription instructions presented in degraded (65% time-compressed speech in babble) and enhanced (120% expanded speech) listening was compared for older adults with particular configurations of hearing loss to younger adults without hearing loss. Experiment 3 was a replication of Experiment 2 comparing a group of 21 older musicians (‘expert listeners’) to non-‘expert listeners’ (two non-musician groups: 20 younger and 20 older adults).

Enhancements of the auditory message during encoding facilitated memory at the time of retrieval for all groups, more so for the hearing-impaired older adults. The older adult musicians demonstrated additional enhancement in listening such that their memory

performance was more similar to the younger non-musicians than to a group of older adults matched for age and hearing ability.

The findings from this study support the effortful listening hypothesis. According to this view, ARHL increases the effort in listening by degrading the message, increasing the distractor effect, and decreasing perceptual learning. These ARHL effects increase the processing load necessary to discern the message for communication at the perceptual, lexical and cognitive levels. These processing loads result in fewer attentional and cognitive-linguistic resources available for elaborate encoding for later recall. Enhancements to the auditory-verbal message in an ecologically valid task demonstrated that memory performance can be improved in older adults with hearing loss. These findings lend support to ARHL as a potential underlying causal mechanism contributing to declining memory performance in the aging adult population.

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Dedication

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Effortful and effortless listening: How age-related hearing loss and cognitive abilities interact and influence memory performance in older adults

The population of adults aged 60 years or older worldwide has doubled since 1980 and is expected to reach 2 billion by 2050. Also, the number of individuals 80 years and older will quadruple by 2050 (World Health Organization, 2012). In Canada, the two age groups that have grown the largest are the 60-64 year olds at 29% growth and the centenarians at 26% growth (Statistics Canada, 2012). The increase in older adults living to enjoy celebrations as centenarians is indeed an indication of improving global health, and is in itself a reason to rejoice (WHO, 2012). However, surviving to this age also presents some challenges. As people live longer, they also experience a higher prevalence of chronic conditions, including hearing loss and cognitive impairments (WHO, 2012).

Both sensory deficits (such as hearing loss) and cognitive impairments (such as memory difficulties) increase as a function of age. In a comprehensive review of the literature, Schneider and Pichora-Fuller (2000) discussed a number of ways in which these sensory and cognitive declines could be related. One possibility they suggested was that poor memory performance could be partially attributed to unclear and/or distorted perceptual information delivered to the cognitive/memory processes; the so-called "information-degradation hypothesis" (Schneider & Pichora-Fuller, 2000). In addition, several researchers (Baldwin & Ash, 2011; Rabbitt, 1968; Rabbitt, 1990; Stewart & Wingfield, 2009; Surprenant, 1999; Surprenant, 2007; Wingfield, Tun, & McCoy, 2005; Wingfield, McCoy, Peelle, Tun, & Cox, 2006) have argued that perceptual effort has an effect on cognitive resources with concomitant influences on memory performance. This is often referred to as the “effortfulness hypothesis”.

The information-degradation and effortfulness hypotheses make specific predictions about the relationship between sensory capabilities (including hearing status) and cognitive performance (including memory). First, if effortful listening arises from age-related hearing changes that affect most older adults, then manipulating the listening environment so that it is difficult or degraded (like older hearing) or easy or enhanced (like younger hearing) should have an effect on learning and memory performance for both younger and older adults (the information-degradation hypothesis). Younger adults should demonstrate learning and memory performance similar to older adults when they ‘listen’ like older adults under difficult or degraded listening conditions. Conversely, older adults should demonstrate learning and memory performance similar to younger adults under easy or enhanced listening conditions. Second, if listening effort for decoding or deciphering the verbal message comes at the cost of cognitive resources that would otherwise be shared with the secondary task of encoding information into memory, then decreasing the listening effort should result in improved memory performance (the effortfulness hypothesis).

The primary purpose of this project was to test these related hypotheses by investigating: 1) how age-related hearing loss (i.e., a degraded auditory-verbal message such as time-compressed or conversational style speech with noise) affects memory, and 2) whether specific enhancements to the auditory verbal message (such as time-expanded speech or a slower-clear speech technique) result in better memory performance. Two additional goals were to demonstrate these effects in an ecologically valid task and to explore whether intensive auditory training, like that obtained by musicians, helps to preserve the auditory fidelity of the sound perceived by the listener. Thus, the experiments in this project investigated how auditory-perceptual processing, and cognitive abilities *interact* to support or hinder memory performance in the aging adult. The functional task that was chosen was listening to, learning, and remembering complex medical prescription instructions, a task that older adults must frequently accomplish.

Ultimately, the goal of this research is to determine how aspects of age-related hearing loss (ARHL) - specifically audibility, spectral-temporal processing, and auditory segmentation - contribute to the listening effort and resultant memory difficulties in the older adult. In addition, I will explore whether particular auditory enhancements directed at maximizing the temporal-spectral processing of the auditory-verbal message facilitate better memory performance. If auditory enhancements can be shown to improve memory, this, in turn, could have a broad practical impact. For example, medical instructions and other important information could be delivered with enhanced messaging to adults with ARHL.

In the following sections, the relevant literatures on age-related hearing loss, including its impact on speech comprehension and age-related cognitive decline are briefly reviewed. Next, the literature on memory and aging is very briefly outlined and the data pointing to a relationship between sensory processing and memory performance, including a consideration of inter-individual variability and possible compensatory mechanisms are summarized. Theories accounting for the association between hearing loss and memory are outlined, including a discussion of the operational definitions of effort and attentional capacity. Finally, I detail the connection between those theories and the current project, including the reasons behind the specific tasks and stimuli that were chosen.

Defining and describing age-related hearing loss (ARHL)

According to the National Institute on Deafness and Communicative Disorders (NIDCD), "(t)here is a strong relationship between age and reported hearing loss: 18 percent of American adults 45-64 years old, 30 percent of adults 65-74 years old, and 47 percent of adults 75 years old or older have a hearing loss" (National Institute on Deafness and Other Communication Disorders (NIDCD), 2010). Age-related hearing loss can be defined as a combination of auditory perceptual and auditory processing deficits. These age-related changes in auditory perception and processing have been demonstrated to occur as early as middle age (e.g., 40-57 years old) (Helfer & Vargo, 2009; Wambacq et al., 2009; Working Group on Speech Understanding and Aging and the Committee on Hearing, Bioacoustics, and Biomechanics (CHABA), 1988). The etiology of ARHL can be attributed to a combination of the auditory stressors that are acquired throughout the life span (e.g., trauma, noise, and otologic diseases) together with genetically controlled aging processes (CHABA, 1988; National Academy on an Aging Society (NAAS), November, 1999).

There is sufficient empirical evidence to conclude that as we age, particularly around the 6th decade of life, our *listening abilities* are less precise and less efficient when compared to younger adults in the 2nd to 3rd decades of life (CHABA, 1988).

These listening difficulties arise from at least three general areas: decreased audibility, slowed temporal processing or adaptation, and difficulty segmenting the target from the competing message.

Audibility. The ubiquitous finding is that as we age our hearing sensitivity thresholds decrease in the higher frequencies, resulting in an attenuation of the signal at those frequencies. In other words, older adults require the sound to be louder, particularly in the higher frequencies, before they can detect, discriminate and identify these sounds (Humes, 2008). In terms of speech understanding, this pattern of loss primarily affects consonant perception and discrimination, particularly those consonants that rely on high frequency cues like frication, such as /s/ or /z/ (Humes, 2008).

The audiometric tests used to characterize this decrease in audibility often report the hearing loss as the average pure tone threshold of the four higher speech frequencies (specifically 0.5 kHz, 1 kHz, 2 kHz, 4 kHz) reported as PTA4 in dB HL (decibels hearing level[1]). The World Health Organization defines hearing impairment as those individuals with a PTA4 greater than 25 dB HL (World Health Organization Prevention of Blindness and Deafness (PBD) Program, 2014).

Temporal processing. In addition to audibility declines, the older adult exhibits a slowing of the spectral-temporal processing of sound demonstrated by latencies in the auditory evoked potentials for complex stimuli (cABR) (Anderson & Kraus, 2013; Anderson, Parbery-Clark, White-Schwoch, & Kraus, 2012; Parbery-Clark, Anderson,

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1 dB HL is the decibel level "with a reference for 'audiometric zero' as the average human threshold at each individual frequency tested" (Valente, 2009, p.12).

Hittner, & Kraus, 2012b), and an increase in the inter-stimulus interval as measured by a gap detection procedure (CHABA, 1988).

One aspect of temporal processing is auditory temporal resolution. Auditory temporal resolution is the ability to detect the relative differences in the duration of the acoustic stimuli over time. A behavioral measure of auditory temporal resolution is a gap detection task (John, Hall, & Kreisman, 2012). John et al. (2012) investigated how age and hearing loss affected performance of a psychoacoustic test for perception of the gap between tones in noise using the Gaps-In-Noise test (Musiek et al., 2005). They compared younger normal hearing adults with two groups of older adults with and without hearing loss. The results demonstrated that when compared to younger adults, the older adults with “essentially normal hearing” required a longer duration of the inter-stimulus interval to perceive the gap (John et al., p. 249). Older adults with hearing loss required even longer durations of the gaps relative to the older adults with essentially normal hearing (John et al., 2012).

Thus, there is evidence from empirical research that older adults have more difficulty in temporal processing of acoustic information. Another behavioral consequence of this decreased ability to detect a silent gap translates to the psychoacoustic perception that the acoustic information is arriving faster than the normal rate in which it is spoken. This seemingly ‘rapid’ speech rate makes it more difficult to segment the auditory stream (Harris, Eckert, Ahlstrom, & Dubno, 2010; Palmer & Musiek, 2013). Additionally, slowed temporal processing has an impact on sub-lexical and lexical speech processing (Walton, 2010).

Temporal processing has a significant effect on the interpretation of those acoustic aspects that allow for speech discrimination such as voicing, manner and prosody cues (Rosen, 1992). For example, the ability to perceive the timing of the onset of voicing is what allows for discrimination of a syllable with a voiceless initial consonant (like ‘pa’) from a syllable with a voiced initial consonant (like ‘ba’). In this example, the voicing in ‘ba’ occurs with the onset of the /b/ consonant and is continuous to the conclusion of the vowel /a/, but in ‘pa’ voicing starts some milliseconds later with the consonant-vowel transition from the /p/ to the /a/. In this example, ‘pa’ meaning father may be confused with ‘ba’ meaning the sound a sheep makes. Another example, with regard to manner of speech, is the detection of the onset and offset of sound (i.e., a silence after a burst of sound versus the continuation of the sound). This timing change is what allows for discrimination between words with a final stop-plosive sound /ch/ versus a continuous fricative sound /s/ in the word ‘patch’ versus ‘pass’. Yet another example is the perception of the silent gap between words or meaningful units. Perceiving the silent gap between two words is what allows for discrimination of the phrases ‘she wants her quarterback’ versus ‘she wants her quarter back’.

In these examples, perception of the timing is relative and not absolute. Therefore, both stable and dynamic temporal resolution abilities are needed in order to adapt to those changes that speakers produce during conversational speech. Perceiving the relative patterns of silent gaps and durations of sounds is one aspect of temporal auditory processing that contributes to the listener’s ability to pick out the targeted speaker from other competing speakers. Also, the dynamic temporal resolution of the listener is how the listener is able to perceive, discriminate and adapt to the variability in the speakers' rate of speech, voice patterns or articulation pattern from an accent or dialect. For the older adult, the temporal processing of the acoustic message is less stable, less dynamic and slower to traverse the auditory pathway (Kraus & Chandrasekaran, 2010). Studies that have investigated behavioral performance on speech perception in noise among those with poorer or less efficient neural temporal processing, such as older adults (Anderson, Parbery-Clark, Yi, & Kraus, 2011) have compared the older adult to those groups with better or more efficient neural temporal processing, such as younger adults (Kraus & Chandrasekeran, 2010), bilinguals (Krizman, Marian, Shook, Skoe, & Kraus, 2012) and musicians (Parbery-Clark, Skoe, & Kraus, 2009). The findings from these studies suggest that more efficient neural processing preserves the integrity of the auditory signal, facilitating discrimination of the target speaker from the background. These studies show that better neural encoding positively correlates with enhanced listening in noise ability.

Speech-in-noise difficulties. Another area in which older adults differ from younger adults is in the understanding of speech in the presence of background noise. Older adults have more difficulty segregating the auditory signal in the presence of background noise and this difficulty is particularly evident if the background noise is competing speech and the competition is as loud or louder than the targeted message (CHABA, 1988). This is often described as "difficulty in picking out the 'to-be-listened-to target' from the 'to-be-ignored background noise'" (Jerger, 2009). Even older adults with normal audiograms require a higher threshold for discriminating words and a more favorable signal-to-noise ratio than younger adults. Older adults with hearing loss require even greater intensity and more favorable signal-to-noise ratios than those without hearing loss (Humes et al., 2012). This listening-in-noise difficulty evident in the older adult may arise from both domain-specific processes such as auditory stream segregation and domain-general cognitive-linguistic processes such as attention, task switching, inhibition, and monitoring capacity (Humes et al., 2012).

The difficulty in spectral-temporal processing of the speech target in competing background noise and its impact on speech understanding is often measured using standardized tests such as the Hearing-in-noise Test (HINT) (Nilsson, Soli, & Sullivan, 1994) or the Quick Speech-in-noise Test (QuickSIN) (Killion, Niquette, Gudmundsen, Revit, & Banerjee, 2004). These tests provide a score that is the signal-to-noise ratio (SNR) or the message-to-competition ratio, in decibels (dB), in which a listener recognizes the speech target correctly for a fixed percentage of the presentations. For example, a score of +7 dB SNR loss on the QuickSIN test indicates that the individual needs the signal to be 7 dB louder than the competing speech noise in order to identify the sentences with 50% accuracy. Higher positive values of dB SNR loss reflect poorer listening-in-noise ability. A QuickSIN score that is equal to or less than +2 dB SNR loss is considered to be an averaged norm in healthy adults, such that listening-in-noise for speech understanding is sufficient for most communication environments. However, even older adults with normal audiograms require higher SNRs (e.g., +3 dB SNR) for listening-in-noise for speech understanding (Killion, 2002).

Furthermore, several studies demonstrate that even mild hearing loss that does not affect speech understanding in quiet listening conditions does have substantial effects in noisy listening conditions (or other adverse listening conditions) for both discriminating words (CHABA, 1988), and for memory of words that were recognized (Mattys, Davis, Bradlow, & Scott, 2012; Ng, Rudner, Lunner, Pedersen, & Rönnberg, 2013; Pichora-Fuller, Schneider, & Daneman, 1995).

Redundancies and context. When audibility, temporal processing, and segregating the message from the competition are not adequate for speech discrimination, the inherent redundancy in the message can be used to understand the meaning. There are redundant aspects in the acoustics, linguistics, and context that are used implicitly and explicitly to decipher or decode the message (Dubno, Dirks, & Morgan, 1984; Ross & Giolas, 1978; Van Rooij & Plomp, 1991; Wingfield, 1975).

In several studies related to perceptual processing of speech, linguistic context (syntactic or semantic) has been shown to moderate the effects that hearing loss has on speech recognition, in that hearing loss has a smaller effect on word recognition in highly contexted predictable sentences (Gordon-Salant & Fitzgibbons, 1997; Mattys et al., 2012; Pichora-Fuller et al., 1995; Wingfield, Poon, Lombardi, & Lowe, 1985). For example, final words in sentences with high context such as *the dog is wagging his tail* are recognized better than low context sentences such as *we need to talk about the tale*. Despite the fact that the final words in these two sentences are homophones, and therefore have highly similar acoustic features, less of the acoustic message is required for word recognition in the first sentence. In fact, *tail* could be appropriately guessed without any acoustic stimuli being detected. The linguistic constraint in the first sentence (tail) suggests that the final word is a noun, it belongs to the dog and it is something that can be wagged. The expected final word may be *tail*, *head*, or *tongue,* to name a few. The number of other final word contenders (items in memory) depends further on the context of the sentence within the conversation. In this way, high redundancy in the linguistic context lowers the need for auditory perceptual processing of the acoustic message. For on-line auditory perceptual speech processing for comprehension, one can make use of the redundant linguistic context to decipher the word *tail* for meaning with minimal acoustic information (e.g., hearing only ail for tail). In contrast, in the second sentence, the word *tale* requires much more of the acoustic information and/or a higher amount of the preceding or following linguistic information to decipher the message. The linguistic constraints in the second sentence do not serve to limit the number of competitors (items from memory). In other words, the successful recognition and understanding of the second sentence potentially requires more cognitive-linguistic resources for the processing of the message preceding and following the word *tale*. Thus, the impact of ARHL will be less significant for recognition of linguistically constrained words in sentences that are predictable. In contrast, ARHL will not only have a more significant impact on understanding less linguistically constrained words, but the cost of success requires even more cognitive-linguistic resources to understand the intended message.

McCoy et al. (2005) were interested in testing the interaction of context and age-related sensori-neural hearing loss in successful word recognition and subsequent recall in the context of the effortfulness hypothesis (Rabbitt, 1968; 1990). They investigated how the effort associated with varied levels of linguistic context affected immediate memory of short word lists (3 items) in older adults with mild-moderate sensori-neural hearing loss. They predicted that if the level of linguistic constraints increased the transitional probabilities of the stimulus words to be recalled, this contextual support would facilitate perception, freeing up those resources for encoding words for later recall. In this way, the effect of ARHL on recall would be reduced or eliminated with greater linguistic constraint (context). In contrast, ARHL would have a greater impact on recall for the manipulation of context that decreased the linguistic constraint. The results showed that when the listening environment was manipulated to decrease the effort in listening for hearing-impaired older adults by increasing linguistic context, memory performance improved (McCoy et al., 2005).

Thus there is empirical support that redundancies, in this case linguistic constraints, facilitate processing of the auditory message for understanding. The more redundancies that exist in the message, the more automatically and effortlessly a message can be decoded. In contrast, the less redundancy in the message, and/or less acoustic information detected, the more that is required in the way of explicit or controlled processes to decode the message. Therefore, recruitment of those top-down cognitive-linguistic processes and increased processing time are required to arrive at the probabilistic best match from long-term memory (Anderson, White-Schwoch, Parbery-Clark, & Kraus, 2013; Mattys et al., 2012; Rönnberg, Rudner, Foo, & Lunner, 2008).

To summarize, age-related changes in the older adult's auditory perceptual and processing ability have been measured in multiple ways that include domain-general processes that engage cognitive abilities (i.e., attention, memory, inhibition), and domain-specific auditory processes (i.e., temporal resolution) that do not require the participant's explicit control. The numerous studies that have examined the changes in the older adult's auditory perception and processing for speech understanding converge on the same finding: the older adult is at a disadvantage for listening as compared to the younger adult.

For the older adult compared to the younger adult, the same speech event will be perceived as less audible, faster than normal, and more difficult to discriminate from the competition. Behaviorally, these difficulties that the older adult experiences in listening are manifested as slower processing, poorer speech understanding in noise, and oft reported complaints of increased effort and fatigue with listening. Further complicating the numerous difficulties that may arise from ARHL are the likely interactions of these factors, which could potentially further compromise listening-ease for communication in the real-world noisy and reverberating environments (Humes et al., 2012; Rönnberg, Rudner, Lunner, & Zekveld, 2010; Rönnberg et al., 2013).

Listening effort: ARHL distortions influence speech comprehension for communication. There are several ways that age-related temporal-spectral processing changes may contribute to listening effort for the older adult with ARHL: 1) the basic aspects of signal processing may contribute to perceptual effort; 2) the ability to perceptually learn the sound patterns evolving over time and map these to meaningful units such as phonemes, words, and phrases may result in additional lexical effort; and 3) the comprehension and recall of the communication event may recruit those additional top-down processes such as working memory, inhibition, monitoring and attention which will result in cognitive-linguistic effort. The following describes the empirical support for the role that perceptual, lexical, and cognitive load plays in listening effort.

Delayed and unstable temporal-spectral processing - perceptual load. Anderson, et al. (2012) investigated the integrity of the subcortical processing of specific speech cues such as timing, frequency and harmonics in a group of older adults aged 60-67 years who were "relatively free of hearing loss" (Anderson et al., 2012 p. 14,156) compared to normal hearing younger adults (18-30 years). The results showed that aging decreases the amplitude and slows the neural response to speech, results in more instability, and reflects less synchrony of the neural-auditory response. Specifically, there was delayed neural timing in the brainstem response to the rapidly changing formant transition of a speech syllable /da/ in older adults compared with the younger adults (cABR: see, (Skoe & Kraus, 2010). They concluded that older adults, even those with normal audiograms, have less precise temporal processing in the subcortical encoding of sound, which may at least partially contribute to older adults' difficulties in decoding speech for understanding (Anderson et al., 2012).

In addition to upstream auditory sensory perceptual processing to decode features for speech and language discrimination (e.g., manner, voicing, prosody), these temporal-spectral processing changes in the older adult also influence adaptation and perceptual learning.

Perceptual learning and adaptation - lexical load. The ability to perceive and understand words in different environments requires that one's auditory perceptual and processing abilities are *stable* and *dynamic*. The listener understands the sounds, words or phrases within the parameters of the individual speaker's accent, voice or articulation ability. For example, as mentioned above, discriminating the sound /pa/ versus /ba/, the word 'patch' from 'pass' or the phrase 'she wants her quarter back' from 'she wants her quarterback' requires lower level auditory sensory-perceptual abilities. These sub-lexical processes decode the incoming auditory stream in the soundscape. The auditory temporal-spectral processes are necessary for discrimination of phonemes, morphemes and the regularities in the speaker's voice and speech pattern. The stability of the acoustic information allows one to detect the regularities of the input over time. The less stable the acoustic information, the more difficult it is to detect regularities and perceptually learn sound to meaning relationships. Optimal auditory perceptual ability requires that one can temporally process and perceptually learn and adapt to the variability of the speaker, even within a single conversation (Mattys et al., 2012)

However, even in the case of disordered speech production (e.g., dysarthria), 'an expert listener' such as a caregiver familiar with the speaker, can perceptually learn or adapt to the dysarthric speech pattern so that the message becomes more easily understood over time. The listener's dynamic and stable auditory perceptual abilities can make better use of the intrinsic and extrinsic redundancy within the acoustic message to more automatically and easily decode the message (Liss, Spitzer, Caviness, Adler, & Edwards, 1998; Liss, Spitzer, Caviness, & Adler, 2002; Stewart, Yetton, & Wingfield, 2008).

Other examples of the ability to adapt to different rate, intonation, and stress patterns are listening to speech spoken either very quickly (e.g., an auctioneer), or listening to heavily accented speech that has a very different rhythm and intonation pattern from one's own language. For example, at first it may be very difficult for native English listeners to understand English spoken by someone whose first language is Mandarin Chinese. However, with repeated exposure to the speaker's pattern, many listeners of all ages will have the ability to adapt to this altered pattern. This quick adaptation translates into discrimination of the speech and ultimately comprehension of the message, albeit with some effort (Cristiá et al., 2012).

Listeners demonstrate varying ability to perceive and adapt to alterations of rate, rhythm, intonation and stress patterns. Some studies that have investigated the ability to adapt to rate have used time-compressed speech at various rates, and then have compared older and younger adult groups with and without hearing loss (Peelle & Wingfield, 2005). Adapting to the variability of a speaker is also described as perceptual learning of the speaker's pattern. The earlier in the communication event that adaptation or perceptual learning takes place, the more automatically and effortlessly the listener can decipher or decode the acoustic message for meaning. In addition, the listener is able to make use of the regularities in the speech and voice pattern to identify the individual speaker amidst background competing speech noise. It then follows that implicit perceptual learning or faster adaptation to an individual's speech and voice production would result in listening-ease. Rapid and automatic perceptual processing requires less explicit top-down cognitive-linguistic processes, freeing up these resources for memory encoding.

Peelle and Wingfield (2005) conducted a series of experiments in which they compared younger and older adults' ability to adapt to degraded speech. They used three types of degraded speech: time-compressed speech, speech in broadband noise, and spectrally-shifted vocoded speech (i.e., speech that has been synthesized in such a way as to reduce the speech signal to limited frequency bandwidths and in this study shifted the spectral information downwards). The groups were equated for overall performance level at the start of the adaptation phase of the experiment. The results demonstrated that neither the younger nor older adults adapted to the speech degraded with broadband noise. However both the younger and older groups adapted similarly to the time-compressed and the spectrally-shifted vocoded speech.

Although older adults adapted to the temporally (compressed) or spectrally (vocoded) degraded speech in a similar way to younger adults, they did not maintain this ability nor did they transfer this learning to new speech rates. It should be noted that the younger and older adults' short term perceptual learning was similar when they were equated for starting accuracy level. However, when younger and older adults heard the sentences at the same compression rate, the younger adults performed significantly better for both recall accuracy and faster rates of perceptual learning.

The authors concluded that there are dissociable components of perceptual learning that are affected differently or uniquely in the normal healthy aging adult. It is possible that one of these components is the presence of age-related auditory acuity and/or auditory processing changes. Perhaps it is the less stable spectral-temporal processes which then interfere with perceptual learning or adaptation. Thus there is evidence to suggest that the older adult may require a longer experience with a novel listening situation in order to adapt to the rate and to learn and remember the information.

Older adults with normal audiograms compared to younger adults with normal hearing have been shown to demonstrate significant difficulty in adapting to excessive rate and variability in intonation and stress patterns, independent of peripheral sensory impairments (Gordon-Salant & Fitzgibbons, 1993; Konkle, Beasley, & Bess, 1977). Thus there is evidence to suggest that even those older adults with clinically normal audiograms demonstrate less *dynamic* temporal processing abilities (i.e., slower to adapt) as compared to younger adults with normal hearing.

Comprehension and recall - cognitive load. In addition to difficulties with rapid consonant-vowel transitions and gap detection that occur on the order of milliseconds, more gross temporal difficulties can be shown in individuals who experience ARHL. For example, Wingfield and Ducharme (1999) presented high and low predictability passages at various time-compressed and time-expanded rates of speech (such as 53%, 67%, and 124%) to younger and older adults. In addition, the participants identified a preferred rate of listening for the passages. The passages were presented at the preferred mean rate selected by the younger and older group. Older adults preferred a significantly slower rate of speech than the younger group. The groups preferred slower rates for the more difficult passages than for the easier passages. Both groups demonstrated that their best recall performance was at the slowest rate and this recall level did not differ significantly from their preferred listening rate. However, the younger adults performed significantly better than the older adults for both passages at all rate levels (Wingfield & Ducharme, 1999).

Wingfield, Tun, Kohl, and Rosen (1999) investigated whether restoring the time to the degraded stimuli facilitated processing in relation to age-related slowing, preserved linguistic ability and short-term conceptual memory. They tested both younger and older adults with clinically normal hearing abilities. Participants listened to and recalled speech passages that were time-compressed to 68% and 55% of the original sound file. Time was restored to the passage either uniformly throughout the passage or at salient linguistic boundaries. They showed that there was a significant main effect of speech rate, time restoration, and an interaction between age and speech rate. There was a differentially greater decline in recall performance at the 55% time-compressed speech rate relative to the 68% rate for the older adults. Mean recall decline for the 68% time-compressed speech relative to the baseline normal rate was the same for the younger and older groups. At the 55% time-compressed rate, the mean recall decline difference from the baseline differed significantly. The older group declined further from baseline than the younger group (Wingfield, Tun, Koh, & Rosen, 1999).

When time was restored to the compressed passage, at salient linguistic boundaries in the passages, recall improved for both younger and older adults. Although younger adults' recall performance fully returned to baseline performance, the older adults' performance remained significantly lower than their baseline performance. The authors suggested two important aspects regarding time restoration for processing of the message and encoding for recall: The amount of time restoration (100% or greater) and the place of that restoration (linguistic boundaries) are important variables to consider for improving recall performance (Wingfield et al., 1999). In addition, the time restorations may have only partially compensated the older adult due to possible auditory perceptual and processing deficits that interact with the rapid or degraded input. The effort expended to accommodate this interaction may indeed be drawing on those cognitive-linguistic recourses that would be allocated for memory encoding (Pichora-Fuller et al., 1995).

Wild et al. (2012) used functional magnetic resonance imaging (fMRI) to determine the degree that spoken sentences were processed under distraction and whether this depends on the intelligibility of the speech message. Participants were 21 younger (19-27 years old) undergraduate students with normal hearing. The task that the participants performed during the fMRI was to attend to one of the cued simultaneously presented stimuli: a speech stimulus (a sentence - in four different speech intelligibility levels); an auditory distractor (chirps - the noise bursts); or a visual distracter (footballs - cross-hatched white ellipses). The four levels of the speech stimuli were: very highly intelligible ‘clear speech’, highly intelligible noise-vocoded speech, low intelligible compressed noise-vocoded speech, and unintelligible rotated noise-vocoded speech. Participants also performed a postscan behavioral recognition task in which they were to indicate whether a sentence presented had been heard during the scan or was a new sentence not heard previously. Analysis of the behavioral recognition task and the fMRI results indicated that clear speech was processed even when not attended to, but that attention greatly improved the processing of the degraded speech. Also the fMRI results indicated that those areas in the frontal regions of the cortex were only engaged when listeners were attending to speech and these regions exhibited elevated responses to degraded compared to the clear speech. While clear speech was processed even when unattended, comprehension of degraded speech appeared to require greater focused attention. The authors suggest that it is this recruitment of the higher-order cognitive mechanisms (e.g., attention processes) that enhanced the processing of the degraded speech (Wild et al., 2012).

To conclude, age-related temporal-spectral processing changes distort the speech signal and this contributes to the listening effort or load at the perceptual, lexical, and cognitive processing levels for communication and recall. This distortion and resultant increased effort is independent of auditory acuity deficits (i.e., PTA4). As the above studies described, the older adults had ‘clinically normal’, or ‘essentially normal’ hearing, or a PTA4 of < 25dB HL. As the previous discussion suggests, enhancing the speech signals in ways that decrease the effects of this distortion should decrease listening effort and effectively increase the ease of listening and consequentially improve memory performance. Listening ease should then allow for the automatic implicit processes to segment the auditory stream, discriminate the sounds, and capture the meaning in the message, while freeing up those cognitive-linguistic resources for encoding for later recall. The experimental manipulations in this project were based on this premise.

In the current study (Experiments 2 and 3), the stimuli were degraded by compressing the stimuli to 65% of the original length, and presenting the stimuli with speech babble noise at +5 dB SNR. In this way, the degraded listening condition was similar to the rates in which the younger and older adults perform similarly for speech recognition and memory tasks when the stimuli were degraded with a combination of both noise and time-compression (Tun, 1998; Wingfield et al., 1999; Wingfield &

Ducharme, 1999). The plan for the current study was to recruit participants with a range of sensori-neural hearing loss, unlike Wingfield et al. (1999) and Tun (1998) who tested participants with more normal audiograms. Therefore, the 65% time-compressed speech rate with the + 5 dB SNR would be slightly more favorable to accommodate those participants with greater hearing loss.

Similarly, in the current study (Experiments 2 and 3), the stimuli were enhanced by expanding the stimuli to 120% of the original length presented in quiet. In this way, the enhanced listening condition would be close to the rate at which the younger and older adults performed similarly and at their best for speech recognition (Wingfield et al., 1999). In addition, this expanded rate of speech was similar to the slow speech rate of the 'clear speech' (Bradlow, Kraus, & Hayes, 2003) enhancement used (Experiment 1) and was at a rate that was within the slow end of normal speech rate (Goldman-Eisler, 1968).

Increased processing time at salient linguistic boundaries is an important factor to facilitate recall in both young and older adults (Wingfield et al., 1999). In the present study, for both the clear speech and time-expanded speech enhancements, these manipulations to the stimuli increased the processing time at the salient linguistic boundaries.

Effects of Aging on Memory Performance

General effects. There is no doubt that older adults perform worse on a variety of different memory tasks. Zacks, Hasher, and Li (2000) summarized the research and indicated that there is an age-related decrement in the ability to learn and remember. However, there is not a universal decline in all types of memory tasks. Some types of memory appear to be either less prone to aging or are differentially affected (Rönnlund, Nyberg, Bäckman, & Nilsson, 2005). Salthouse (2010) reviewed the literature and found inconsistent findings regarding the severity and the pattern of age-related memory decline. He attributed some of these differences in the results to the theoretical framework in which memory and other cognitive functions were assessed and the methods employed (Salthouse, 2010).

One example to illustrate this point is in epidemiological research that uses either cross-sectional or longitudinal methods. In this type of research typically there are large numbers of participants from representative age groups that are assessed one time - cross-sectionally, or repeatedly over many years - longitudinally. The participants are assessed on multiple factors related to health, education and cognition. Often correlational analyses are then used to identify correlations with other factors assessed. This is done to determine relative risk factors or predictors for a particular illness, disease or in this case memory decline in older adults (Salthouse, 2010). Results from cross-sectional versus longitudinal designs sometimes depict different patterns of an age-related memory decline. The different or even conflicting results regarding the severity or pattern of memory decline are often attributed in cross-sectional studies to cohort effects, such as education or health factors. In longitudinal studies, re-test or practice effects are sometimes implicated as the explanation for differences in memory decline (Rönnlund et al., 2005).

As this example demonstrates, different findings regarding the pattern of memory decline as a function of aging is suggested to be an artifact of the different theoretical framework or the specific methodology used in the research design. However, this variability in the findings, attributed to cohort or practice effects, may indeed be the factors acting as moderators and mediators on memory performance. Discovering the differences in memory performance based on possible cohort or practice effects may illuminate those variables that contribute to either preserving memory abilities or the causes for declining memory function in the older adult.

Relevant to the present study, an example of a cohort effect that positively affects auditory working memory performance is musicianship (Parbery-Clark, Strait, Anderson, Hittner, & Kraus, 2011; Strait & Kraus, 2014). Also, examining those variables that have an impact on re-test effects may help to elucidate those factors interfering with experience-dependent perceptual learning or adaptation (Peelle & Wingfield, 2005). Both musicianship and learning effects were considered in the present study as important factors in determining how and why memory performance varies within the aging adult population and differs from the younger adult population.

In addition to variations of memory decline in different tasks with different methodologies, there are large variations in the memory performance on the same task within age groups. Salthouse (2010) demonstrated this variation with a scatter plot of the proportion of words recalled correctly as a function of age. The scatter plot shows, on average, a .3% per year decline for this particular free-recall memory task. However, the scatter plot also demonstrates that some 60 year olds are performing better than the average twenty year old, and that some 20 year olds are performing less well than the average 60 year old (Salthouse, 2010). Although there is agreement in empirical studies that memory declines as a function of age, not all older adults will be similarly affected and not all types of memory abilities will decline to the same degree or with the same pattern (McDaniel, Einstein, & Jacoby, 2008). Understanding the *source* of this variability advances understanding of the causal mechanisms that are underlying the differences in performance between the age groups.

Variability in memory performance. In order to identify those factors that contribute to better or poorer memory performance researchers often examine the individual differences within-subjects on different types of memory tasks. For example, in a 5-year longitudinal study of 829 participants, Rönnlund et al. (2005) examined the influence of aging on *episodic* and *semantic* memory. Episodic memory is the ability to remember specific events and is often tested following a study session of word lists, word-pairs, statements or actions. Semantic memory is described as world knowledge tested without a study session on items such as general knowledge of current events, vocabulary, and verbal fluency (Rönnlund et al., 2005).

Typically the findings in cross-sectional studies is that there is a steady linear decline in episodic memory which starts in the 20s or 30s and declines as much as 2 standard deviations by the 80s. In contrast, Rönnlund et al. (2005) found no decline before age 60 for episodic memory. For semantic memory the cross-sectional data and the longitudinal data both suggest largely stable or even increasing performance between 35-60 years old, with small differences in the oldest old. Overall, compared to the cross-sectional data the age trajectories for episodic and semantic memory in longitudinal data differ. The authors stress the importance of controlling for cohort effects in cross-sectional studies and by using a matched group to control for re-test effects in longitudinal studies (Rönnlund, et al., 2005).

Rönnlund et al. (2005) proposed several explanations for the differential effect of aging on episodic as compared to semantic memory. One explanation is that this variability is due to age-sensitive structures or processes to which both shared (e.g., neural slowing) and unique (e.g., audition or vision) factors contribute. Another explanation for the different patterns of memory change is the relationship that performance may have with a change in basic factors such as biological and structural factors, and processing resources such as speed. It is possible that a decline in those factors has a cascading effect on more complex functioning. In this way, the variability in episodic memory performance can be attributed to compensatory abilities such as the individual's lexical access, education, or knowledge. Further to this point is the suggestion that a decline in some basic factors must reach a certain threshold before it affects the higher-level cognitive function (Rönnlund et al., 2005). Another consideration is the onset of this disruption to the basic factors in relationship to the development of cognitive-linguistic processes.

Biological and structural changes. In relation to the present study, the biological changes that occur earlier in the auditory *system* such as cochlear hair cell loss and neural timing instability may have greater consequences on those higher-level cognitive and memory processes if these basic biological changes occurred earlier in the adult's life span (i.e., middle age). The intermediary processes such as experience-dependent perceptual learning that 'tunes' the listening ability may instead be progressively 'mistuning' the listening ability. Those with mistuned listening would experience increased effortful listening. In contrast, those individuals who have 'tuned' listening ability through extensive listening training or exercises (i.e., musicianship) would have more stable perceptual learning and ease of listening. Therefore, if there is more stability at the base processes then there should be less variability in the mid and higher processes.

Cascading influences top down and bottom up. By way of an analogy, a tree with a large and elaborate network of roots in a solid ground (neural networks) benefits from bottom up and top down processes. The overall health and structure of the tree above ground (mid and higher level cognitive-linguistic processes) has developed due to the support at the base and is consequently less affected by environmental forces (degraded stimuli) at the mid and upper part of the tree.

The above tree analogy illustrates the premise for the current project: The more stable the lower-level processes, such as the spectral-temporal processing (Anderson et al., 2013), the more consistently experience-dependent perceptual learning can function (Peelle & Wingfield, 2005). Stable perceptual learning may contribute to less variability in lexical access for comprehension, which then requires fewer of those cognitive-linguistic processes to discern the meaning (Rönnberg et al., 2008). Furthermore, the greater the stability in those cognitive-linguistic resources recruited to discern the message for meaning such as attention (Lavie, 2005) inhibition (Hasher & Zacks, 1988a) and monitoring (Amichetti, Stanley, White, & Wingfield, 2013) ultimately results in less variability in the elaborate encoding necessary for later recall performance.

The above premise regarding stability of processes and the cascading effects on those mid-level - perceptual learning and linguistic processing, and higher-level - memory-encoding processes, is supported by experimental research.

This approach is one in which the tasks chosen to assess memory are based on a specific theoretical framework. The purpose of the research is to determine how the various aspects of the memory processes differ as a function of age. Typically this type of research compares two relatively extreme age groups. For example, the younger adult group comprised of university students are compared to the older adult group (typically 65+ years old) to discern the dissociable memory processing components that potentially contribute to a decline in memory for the older adult (Salthouse, 2010). Zacks et al. (2000) summarized the theoretical orientations in experimental memory research, which differentiates the older adult's from the younger adult's memory performance. What follows is a brief description of three areas that differentiate the younger from the older adult and how the results from the present study may explain the differences in limited resources, processing speed and inhibitory control (Zacks, Hasher, & Li, 2000).

Limited resources. Older adults are more limited in essential resources or self-initiated processing both at encoding and retrieval (Craik, Anderson, Kerr, & Li, 1995; Hasher & Zacks, 1979; Light, 1991). The limited resources or limited capacity of the older adult theoretically arise from an interaction between internal and external factors. These age-related declines in resource capacity and self-initiated processes are supported by the findings of the differential memory performance of older versus younger adults on the type of memory tasks used. For example, relative to the younger adult, the older adults are most negatively affected by free-recall memory tasks, which require a higher degree of self-initiated processes, compared to recognition memory tasks, which require the lowest degree of self-initiated processes. For the present study, the type of memory task chosen was a free-recall task. If the experimental manipulation to enhance the auditory stimuli (clear speech or time-expanded speech) brings the older and younger adult's learning and memory performance closer together, relative to their performance in the degraded listening (time-compressed or conversational speech in noise), it would suggest that the age differences in free-recall may be partially attributed to the effort in listening which consumes those same resources.

Processing speed. Another area in which the older adult differs relative to the younger adult is in processing speed, with the older adults demonstrating slower processing than the younger adults (Park et al., 1996; Salthouse, 1996; Verhaeghen & Salthouse, 1997). According to Salthouse (1996) the 'limited time mechanism' may explain the relationship between processing speed and age-related changes in memory. In situations in which time is restricted, the time required for the memory processes to rehearse or elaborately encode may be compromised by the earlier processes, consuming the total time available to perform the task.

In relation to the present study, auditory enhancement (time-expanded or clear speech), which facilitates more timely and automatic processes for auditory perception and processing of the message, should free up time for those memory processes to elaborately encode. In this way the auditory enhancements may facilitate faster perceptual learning or adaptation to the speaker's pattern. A larger learning effect (better learning or memory performance on 2nd trial of a task) indicates that the more automatic and timely auditory processing of the message for comprehension has allowed for more time available to rehearse or elaborately encode information for later recall. If learning effects differ by listening condition (degraded or enhanced) for the older adults, this finding suggests that some of the age-related slowing may be attributed to differences in perceptual learning of the speaker's pattern.

Inhibitory control. Older adults have less inhibitory control particularly for attention to the relevant contents of working memory. The increased mental clutter due to poorer inhibitory control increases the likelihood for sources of interference, both at encoding and retrieval (Hasher & Zacks, 1988b; Hasher, Zacks, & May, 1999; Zacks & Hasher, 1994; Zacks & Hasher, 1997). In relation to the present study, the older adult with ARHL may experience an increase in mental clutter from the perceptual and lexical processing loads as previously described. Inhibiting this 'noise' and maintaining attention to the task for both comprehension of the message and encoding into memory requires greater inhibitory control (or executive function) and working memory capacity for successful performance. In this way, the individual's executive control, working memory and short-term memory is taxed more in adverse listening conditions relative to easier listening. Relevant to this study, those individuals with strengths in inhibitory control and working memory capacity should demonstrate better learning and memory performance, particularly for adverse listening condition in which these resources are strained. In this study, the individual's ability in executive control, working memory capacity, short-term memory, and lexical access was assessed. This was done to determine how these characteristics contribute uniquely to their learning and memory performance during the experimental tasks in the two listening conditions.

Individual differences in specific aspects of cognitive-memory processes. Two memory tasks used to assess individual differences in memory function in cognitive research are simple memory span measures (backwards and forward digit spans) to assess short-term memory capacity, and reading span (Daneman & Carpenter, 1980) to assess working memory (Baddeley & Hitch, 1974). Conway et al. (2005) described working memory (WM) and working memory capacity (WMC) as "the multi-component system responsible for the active maintenance of information in the face of ongoing processing or distraction" (Conway et al., 2005) p. 770). Working memory tasks involve both a simultaneous processing aspect (read the sentence for comprehension) and a temporary storage component (remember the last word). Performance on working memory tasks has been positively correlated with complex processes such as reading and language comprehension (Pichora-Fuller et al., 1995).

Since the original reading span paradigm was described by Daneman and Carpenter (1980), there have been many other variations of the reading span paradigm, including the operation span and the listening spans (Conway et al., 2005). These variations of the reading span task have been demonstrated to highly correlate with each other, and are negatively correlated with age. Relative to the younger adult, the older adult demonstrates smaller span measures for both simple spans (backward and forward digits) and more complex working memory spans (Zacks et al., 2000).

In regard to present study, by examining the individual differences in working memory performance (listening span, L-span) and short-term memory (backward digit span), the magnitude of the contribution of this cognitive resource on the performance in the experimental listening conditions can be determined. Similarly, two other cognitive-linguistic measures were used in this study, the Boston Naming Test (Kaplan, Goodglass, & Weintraub, 2001) to assess lexical access, and an executive function task, the FAS: Verbal Fluency test (Mueller & Dollaghan, 2013). In this way the unique contribution of these domain general resources on learning and memory can be partialled out with statistical analysis.

In the present study, if listening effort requires greater cognitive-linguistic resources (working memory, short-term memory, lexical access, executive control) for the primary task (comprehension), then the magnitude of the relationship of these variables and memory performance should be greater in the effortful listening relative to the effortless listening condition. In other words, the individual's cognitive-linguistic abilities should be positively associated with learning and memory performance more so in the effortful listening relative to the effortless listening condition. If these cognitive-linguistic resources are shared and would otherwise be re-allocated to the secondary task of encoding the information for later recall, then learning and recall in this experiment will be poorer in the effortful listening relative to the effortless listening condition.

Variability in memory and cognition for functional performance. Despite the significant medium-to-large effects of age on memory, reasoning and processing speed (Meyer, 2001, summarized in Salthouse, 2010), many older adults over 65 years old continue to function at very high levels. The implicit question posed by this statement is: how are some individuals able to maintain memory performance sufficiently so that they are able to function independently whereas others experience more significant consequence of poorer memory performance that results in a loss of independence? Exploring the factors that predict this variability in memory performance helps to identify the likely causes that serve the phenomenon of better or poorer functional memory performance. As Salthouse (2010) states, “the most convincing evidence that the causes of a phenomenon are understood are results establishing that the phenomenon can be manipulated through interventions” (Salthouse, 2010, p. 157). Indeed this is the intent of the current study. If memory performance improves due to the behavioral intervention (listening enhancements) that manipulates those specific factors that are theoretically hypothesized to cause the phenomenon of poorer memory performance, then results support the hypothesis for causal inference.

Although there is a large variability within age groups on memory tasks, the research findings are inconsistent regarding whether older adults as a group are more variable on cognitive, sensory and motoric performance relative to a group of younger adults (Salthouse, 2010). Perhaps it is an artifact of the fact that as people age they have more variable experiences, education and health factors that result in them becoming less alike. However, the literature does not support a universal increase in variability with age for all measures of cognition. Some studies demonstrate a systematic increase in between-person variability with age, other show no variability in age, and still others reveal decreasing variability with age (Salthouse, 2010). For example, it appears that the specific variables measured by the WAIS III and the Woodcock Johnson III show largely *stable* between-person variability across the age spans (Salthouse, 2010). In other words, the standard deviations for the age groups remain similar from 20 years to 90 years old, so that plotting age on the x-axis and the standard deviations on the y-axis results in a relatively flat line. Despite stable between-person variability across the age spans in some measures of cognitive functions, there is some support for a *smaller* amount of between-person variability with age on other tasks such as spatial relations, block design, and letter number sequence (i.e., standard deviations becoming smaller as age increases). In regard to these metrics, the older adults become more similar as a function of age in spatial relations, block design and letter-number sequence tasks. Similar performance as one ages suggests that age-sensitive processes that are largely shared are the factors that contribute to performance on these measures. Yet still with other measures, there is indeed an increasing variability with age, in that the standard deviations per age group becomes larger as age increases. Cognitive-linguistic tasks that assess verbal comprehension, general information, and picture vocabulary fall into this latter category and generally show that older adults become more variable with age, therefore suggesting that unique factors contribute to performance on these measures (Salthouse, 2010).

This larger variability for older adults in verbal comprehension and delayed recall, particularly starting at approximately 60 years of age, suggests that there may be some causal mechanism that may be operating that contributes to less consistency by age group in these cognitive-linguistic functions. In other words, as people age, verbal comprehension decreases in some individuals and in others verbal comprehension stays the same. For some older adults delayed memory performance remains quite stable. These older adults continue to perform as well as 20 year olds on delayed recall tasks, while others perform substantially less well, and still others perform within a range of performance between these two extremes (McDaniel et al., 2008). Determining those unique individual factors that differentiate performance within the age group may then provide opportunities to prevent the loss of these specific cognitive-linguistic functions. In addition to prevention, understanding the underlying causal mechanism may elucidate opportunities to explore and then target the specific areas most amenable to interventions.

Relationship of ARHL and Cognition

Compensations. One possibility of a causal mechanism is the individual's auditory perceptual and processing abilities, which interact with cognitive capabilities and contribute to the variability in performance of the functional tasks (Schneider & Pichora-Fuller, 2000). According to this argument, the interaction is not evident in the younger population because their sensory capabilities are maximally functioning. It is only when one variable (hearing, for example) starts to come off of ceiling levels that its impact on another variable (memory, for instance) is measurable. This analysis predicts that if we stress the younger adults' perceptual abilities, we may find larger variability on memory measures.

The cognitive and/or sensory-perceptual decline occurring in the older adult population may differentially affect memory performance due to compensatory processes. Bäckman and Dixon (1992) describe a general framework for psychological compensation. This process model depicts how environmental demands, expected performance, and innate skill level interact and create an opportunity for compensation. The individual employs compensations due to awareness of the need to obtain a specific goal. Further, the model explains three forms that compensation may take. One form of compensation is using the same skill with more effort. Another form is using a latent skill typically not employed for this task. Yet another form of compensation is development of a new skill (Bäckman & Dixon, 1992).

As Bäckman and Dixon (1992) explain, psychological compensation may arise from implicit awareness of declining skills with more automatic processes employed to improve task performance. However, factors such as the severity of decline in the skill, or the stability of the individual's ability (cognitive or perceptual), may have an impact on the effectiveness of the compensation. These same factors may also create a need for the individual to switch from implicit awareness and automatic compensations to deliberate and controlled compensations.

In relation to this study the premise is that poorer auditory perceptual and processing abilities may be compensated for with cognitive-linguistic abilities. This compensation is recruited when listening is in either challenging environments or where the expected performance demands (remembering) are higher. The degree to which compensatory mechanisms are more automatic and stable, such that the individual is able to switch efficiently between automatic to deliberate compensations, the more stable and reliable the functional performance of the task.

For example, the older adult with ARHL engaged in conversation in a noisy restaurant will experience more or less listening effort depending on whether appropriate and timely automatic and/or deliberate compensations were employed. One older adult may use automatic compensations by increasing focused attention on the speaker, perhaps even developing rudimentary speech-reading ability. Another may recognize lapses of attention or an incongruent message and then interrupt the speaker and ask for clarification. The above scenarios demonstrate that employing appropriate and timely compensations require various levels of cognitive-linguistic abilities (Bäckman & Dixon, 1992).

Finally, perhaps the factor(s) that influences performance or compensation for the task does so only when that particular factor reaches a specified threshold or results from a specific type of distortion. For example, the noisy listening environment might only negatively affect recognition of speech or memory encoding if the older adult's hearing loss is of a particular degree (e.g., moderate) and of a specified type (e.g., sloping high frequency sensori-neural type versus a flat conductive type) and there are multiple sources of degradation to the stimuli (e.g., rapid speech heard through a hearing aid with a specific type of signal processing).

A study by Jenstad and Souza (2007) further illustrates the above suggestion of specified thresholds and interactions of distortions. Jenstad and Souza (2007) investigated how a specific type of signal processing used in hearing aids (WDRC-wide-dynamic-range compression) affects identification of low context sentences. WDRC is used in hearing aid configurations to increase the audibility of low intensity sounds. WDRC does however distort the auditory temporal envelope. In doing so, some important information such as syllable structure, rhythm, and prosody are altered, which results in a loss of voicing and manner cues for speech perception. The purpose of the study was to determine in which type of listening conditions (normal speech rate, 50% compressed speech rate, and compressed speech with time-restored) are young-old or older-old adults negatively affected by the varying levels of WDRC distortions. Results of this study demonstrated that there was an interaction of level of WDRC distortions and speech rate. The highest level of WDRC distortion had a large effect on speech recognition when the speech rate was time-compressed (fast) compared to the normal rate (Jenstad & Souza, 2007).

Jenstad and Souza (2007) concluded that the detrimental impact of temporal envelope distortions on recognition of low-content speech for older listeners occurs once a certain *threshold of distortion* from the WDRC was reached, particularly in the faster speech rate listening condition. In addition, since there was no improvement in speech recognition in the time-restored compressed speech (fast-restored) condition, they concluded that processing time was not the factor that differentiated the recognition performance. Therefore, they indicated that the source of this variability in performance between normal rate and time-compressed speech was the use of the acoustic redundancy in the normal rate listening condition, which then allowed the participants to *compensate* for the temporal envelope distortion from the WDRC (Jenstad & Souza, 2007).

As the above study demonstrates, poor performance on complex tasks that require both sensory-perceptual and cognitive processes may not necessarily reflect only diminished cognitive functions or only diminished sensory-perceptual difficulties. Other factors including compensations may interact with and serve to moderate or mediate the cognitive processes and therefore contribute to better or poorer performance. Identifying the source of this variability in performance within groups and between groups provides the empirical evidence necessary to understand the causal mechanism underlying the observed memory decline in older adults.

Sensory and cognitive abilities are highly correlated. Understanding the nature of the relationship between cognition and hearing is particularly relevant since ARHL is the 3rd most prevalent chronic disorder among older adults (NAAS, 1999). Importantly, ARHL is correlated with cognitive decline in the older adult population, specifically on tests of memory and executive dysfunction, even when controlling for other co-morbidities (Lin et al., 2011a). For example, in a 5-year longitudinal study Lin et al. (2011b) demonstrated that, when compared to individuals with normal hearing, individuals with mild, moderate, and severe hearing losses, respectively, had approximately a 2-, 3- and 5-times increased risk of developing dementia over the course of the study (Lin et al., 2011b). These studies demonstrated that the more significant the hearing loss, the greater the risk of developing dementia. The findings remained significant even when other conditions associated with dementia such as diabetes and hypertension were ruled out (Lin et al., 2011a; Lin et al., 2011b; Lin, 2012). In addition, greater hearing loss was associated with a *faster rate* of incident cognitive impairment (Lin et al., 2013).

Lin et al. (2013) demonstrated strong relationships between age-related hearing loss and incident cognitive impairments. The aforementioned studies have several strengths including the large sample size, precise measurement of baseline cognitive and hearing status and controlling for confounding factors such as depression and cardiovascular risks (Surprenant & DiDonato, 2013). However, as is the case with any correlational and longitudinal design there are also several limitations in interpreting these findings.

First, coincident changes in the auditory and cognitive processes could contribute to the association of hearing and cognition via a third factor. Although several factors were partialled out such as vascular disease, there could still be another mechanism operating which acts on both the sensory-perceptual abilities as well as the cognitive abilities, a common-cause explanation, (Lindenberger & Baltes, 1994).

In addition, re-test effects may be a factor. It is possible that those with better hearing at baseline compared to older adults with poorer hearing may be more negatively affected on those cognitive task that are more reliant on auditory-verbal skills, and possibly unable to benefit from practice effects for subsequent retests of cognitive functioning. Finally as Lin et al. (2013) indicate, these findings demonstrate associative relationships through correlational analysis and therefore do not imply causal inference.

Baltes and Lindenberger (1997) used the Berlin Aging Study (BASE) to investigate the strong correlational relationship between sensory perceptual loss (hearing and vision) and diminishing intellectual functioning of older adults. They followed 687 individuals, aged 25-103 years old, cross-sectionally. The BASE study used objective measures of visual acuity and auditory thresholds to assess sensory perceptual processes. In addition, they used 14 cognitive tasks to assess 5 areas of intellectual ability (perceptual speed, reasoning, memory, knowledge, and fluency). Baltes and Lindenberger (1997) found that 94% of age-related variance in intellectual functioning was accounted for by perceptual functioning. One explanation for these findings according to Baltes and Linderger (1997) was a common cause that is affecting both sensory and cognitive abilities, suggestive of a widespread neural degeneration. They concluded that the findings of a strong connection between sensory-perceptual and cognitive function in the aging adult requires investigations into the sources, factors and the mechanisms that are common to both domains (Baltes & Lindenberger, 1997).

Although correlational research studies do not imply causation, they are an important first step. Discovery of the correlational relationships leads to development of logical theories to explain how and why the relationship exists. In turn, these theories allow for hypothesis-driven research with experimental manipulations to test opposing theories. For example, determining the potential causal mechanism underlying the relationship between age-related hearing loss and cognitive impairment will inform researchers on the interaction of auditory sensory perceptual and cognitive processes in the aging adult. Ultimately understanding and exploring the nature of that relationship, with controlled experimental manipulations provides opportunities to further test the role that sensory perceptual factors play in cognitive aging.

There is some evidence that hearing loss is related to, and may actually cause decreased memory performance. For example, Cervera, Soler, Dasi, and Ruiz (2009), and Surprenant (2007) found that even mild hearing loss in the young-elderly contributed to decreased working-memory capacity, perhaps by requiring more effort to be devoted to the decoding of the degraded auditory message, leading to less attention being available for remembering the material (Cervera, Soler, Dasi, & Ruiz, 2009; Surprenant, 1999; Surprenant, 2007).

Schneider and Pichora-Fuller (2000) suggested four ways in which the relationship between perceptual deficits and declining cognitive function could logically be described. First, a *deprivation or sensory underload* hypothesis suggests that it is the loss of peripheral - sensory perceptual abilities that permanently change higher level more central - cognitive functioning. Second, a *cognitive load on sensory performance* indicates that a deterioration of higher-level or top-down cognitive abilities influences performance on the sensory abilities due to a loss of control over perceptual systems (e.g., attention, inhibition). Third, the relationship between cognitive abilities and sensory-perceptual abilities is due to a *common cause,* (e.g*.,* widespread neural degeneration) or *multiple causes* such as different age-related factors similarly affecting the sensory systems and the central functioning. Lastly, the *perceptual degradation hypothesis* indicates that the degraded stimuli are delivered to the cognitive processes interfering with optimal performance.

Information degradation hypothesis. The information-degradation hypothesis suggests that the poor memory performance could be attributed to unclear and distorted perceptual information delivered to the cognitive/memory processes. It is the impoverished or inaccurate representations of the stimuli (e.g., due to vision and hearing impairment) as the causal mechanism that interferes with efficient cognitive functioning. A strict information-degradation perspective is that the perceptual errors cascade upward resulting in further disruption to the upper level cognitive processes. Cognitive functioning is not impaired per se, instead, the strong correlations between sensory-perceptual abilities and cognitive functioning exist due to errors in information being sent along the path to the higher level processing resulting in a decline in cognitive performance. Therefore, in this view, only immediate cognitive performance is disrupted but there are no long-term cognitive consequences (Schneider & Pichora-Fuller, 2000). This pure view of information degradation assumes that the perceptual systems and the cognitive systems are modular or encapsulated in such a way that the perceptual and cognitive processes do not affect one another and do not interact.

Another view is related to the information degradation hypothesis but suggests that the systems are integrated and that the perceptual and cognitive processes interact. Several studies (Baldwin & Ash, 2011; Rabbitt, 1968; Rabbitt, 1990; Stewart & Wingfield, 2009; Surprenant, 1999; Surprenant, 2007; Wingfield et al., 2005; Wingfield et al., 2006) conclude that perceptual effort has an effect on cognitive resources with concomitant effects on memory performance, this phenomenon is now often referred to as the “effortfulness hypothesis”.

Effortfulness hypothesis. The effortfulness hypothesis first described by Rabbitt (1968; 1990), and subsequently others (McCoy et al., 2005; Tun, McCoy, & Wingfield, 2009; Tun, O'Kane, & Wingfield, 2002) proposes that when individuals listen to a degraded signal, successful speech discrimination comes at the cost of attentional resources. Under less effortful listening conditions, these limited capacity attentional resources would normally be used for encoding the information for later recall. Instead, they are re-allocated to cognitive processes necessary for understanding speech.

The intelligibility of speech, or the ability to discriminate speech for the purposes of recognition, understanding and communication, may be distorted or degraded by various sources including communication links (e.g., cell phones, public address system in a reverberating room, ‘Skyping’, hearing aids) or as mentioned above by the individual’s hearing loss. The noise in the systems may interfere with intelligibility by simply masking sounds or words and decreasing the number of acoustic bits heard or discriminated. This is referred to as energetic masking (Mattys, Brooks, & Cooke, 2009).

In addition to a ‘masking effect’ the noise may result in the need to recruit higher-level cognitive-linguistic processes to decipher or fill in for missing parts of the signal. However, Rabbitt (1968) showed that even when the noise is not sufficient enough to result in failed identification of the words, the successful discrimination may require more listening effort or resources to decipher what is being said. He tested the hypothesis that if a person is listening in the presence of background noise and is simultaneously required to perform the two tasks of identifying spoken words and then remembering them, the tasks would compete for “channel capacity” resources (Kahneman, 1973) and result in lower performance on the secondary task - remembering.

First, Rabbitt (1968) examined whether items that are difficult to recognize are also harder to remember. Results of this experiment showed that memory performance for digits presented in noise was less than could be accounted for by errors of recognition. In a second experiment, participants heard lists of digits that were presented in clear (quiet) or noise. The results showed significantly better recall of the digits that were presented in clear versus noise, and hearing later words in noise interfered with memory for earlier words in clear. The difficulty in discriminating some digits interfered with the retention of others in the stream, much like the experience of listening to speech in a noisy situation parsing out the relevant information with intermittent noise. In a third experiment, the results revealed that participants' recall of the content of connected discourse presented in quiet (clear) is affected when, before recalling it, a listener is subsequently required to understand and remember speech presented through noise, the participants recalled more in the clear/clear group than those in the clear/noise groups (Rabbitt, 1968).

As Rabbitt (1968) showed in these experiments, effortful listening has an impact on the understanding and recall of an auditory-verbal message in connected discourse. The results of these three experiments suggest that the noise is not just 'masking' the speech. Instead, there is increased difficulty or 'effortfulness' in listening; the effort uses those resources that are shared with the processes required for successful encoding for later recall.

Since Rabbitt's (1968) study, a number of other researchers have shown similar results. For example, Murphy, Craik, Li, and Schneider (2000) investigated the effects of aging and background noise on short-term memory performance as a function of serial position, in a paired associates paradigm. The findings of the experiments showed that when younger adults experienced a degraded listening situation (i.e., moderate amounts of noise, -10dB SNR) the serial position curve resembled that which is seen in the aging adult. The addition of noise to the younger adults mimicked the effects of aging.

The authors concluded that the sensory degradation of the stimuli interfered with encoding for secondary memory as a result of the noise for the young participants and an impoverished perceptual representation in primary memory for the older adult in quiet. However, in addition another possibility and one that is consistent with an effortfulness hypothesis is that aging or noise are associated with a reduction in processing resources and it is this that affects the processes for encoding of the information into secondary memory. Further to this is the impact that this effort has on the final two words, which are unaffected for the younger adult but result in poorer recall for the older adult during the noise condition. Those resources for successful secondary memory encoding in the older adult are consumed, interfering with the primary memory encoding of the final two items (Murphy, Craik, Li, & Schneider, 2000).

In another study, Stewart and Wingfield (2009) investigated how hearing acuity in older adults affected intelligibility functions for words versus sentences of varied complexity. The results showed a significant effect of word versus sentences between young adults with normal and older adults with better and poorer hearing. Increased syntactic complexity required higher amplitudes for successful identification compared to simpler sentences for older adults and even more so for older adults with hearing loss. This study provides further support that effortful listening due to even mild hearing acuity deficits results in re-allocation of those cognitive-linguistic processes, at the cost of those resources needed to comprehend syntactically complex sentences (Stewart & Wingfield, 2009).

The premise for the present study is that ARHL increases listening effort. Listening effort creates inefficiencies or instability for the re-allocation of those limited capacity or scarce resources that are shared between perceptual, lexical and cognitive processing. The variability in the efficiency of trading one resource for another including engaging compensatory processes comes at the cost of fewer resources for other tasks or processes. In this case fewer resources are available to immediately repeat, learn and elaborately encode the message into long-term memory for the recall task.

Attentional resources. One of the enduring criticisms of theories of attention and effort is that they often do not provide a formal definition of those concepts. Although William James famously stated that, "Everyone knows what attention is" (James, 1890, p. 403-404), a specific definition of it has proven elusive (James, 1983). Similarly, the term "effort", which implies by its very nature that there is a limit on the amount of effort available (a mental resource of some sort), is often a vague concept. Given that one of the major hypotheses tested in this thesis is based on the assumptions of variations in cognitive effort, it is important to discuss some of the arguments on this point and describe how this concept will be used in these studies.

Navon (1984) provided a thorough examination of 'resource theory' and its scientific merit. He defined a resource broadly as an internal input essential for processing that at any point may be limited in quantity. He argued that the idea of mental energy is indeed a theoretical claim that must stand up to empirical testing if researchers are to use ‘resources’ as a construct in their experiments. However, he suggested that studies investigating behavioral responses affected by such aspects as task complexity, task difficulty, task distractors or load effects, could use the idea of limited capacity resources even without defining exactly what those resources might be. One could therefore make predictions based on levels of performance when tasks vary on these factors that rely on these “scarce resources” and/or “limited-capacity resources” (Kahnemann, 1973).

Resource theory requires the view that a limitation in information processing is a function inherent to the processing mechanism. In other words, these same resources must at times be re-allocated which may result in inefficiencies in the processing of information for the demands of the task(s) at hand. Thus, processing of acoustic information under ideal conditions allows the use of resources to accomplish the secondary task of encoding the sub-lexical, lexical and conceptual information for later recall. However, when the processing of the acoustic information does not allow for optimal or efficient decoding of the sub-lexical and lexical code, some of those resources that are normally used to decipher the conceptual information are diverted to the primary task, short-changing the secondary task of encoding that information for later recall.

Navon (1984) suggested that in this way, the term “resource” can be used more metaphorically speaking. Specifically, in terms of research on behavioral performance, resource is a term used to express some allocation of processes or trade off between cognitive processes. In other words, what costs might a specific task require in terms of the resources necessary for optimal performance of the primary task. At what expense does the re-allocation of those resources for one task have on concurrent or sequential task performance (i.e., the cost of attentional resources for comprehension of an auditory-verbal message at the expense of the attentional resources for memory encoding processes for later recall of the message)?

This study is not aimed at testing resources as a theoretical concept. But, rather, this study is one that examines the relative level of effort (resource or capacity) that an experimental manipulation with operationally defined constructs (listening effort or listening ease) has on memory performance. If effortful listening is operationally defined as auditory-verbal stimuli that are degraded to mimic how older adults perceive speech, and listening ease is operationally defined as auditory-verbal stimuli that are enhanced in ways that mimic younger adult's perception of speech, then memory performance in these two conditions relative to each other will consume more (in the effortful listening condition) or fewer (in the enhanced and easier listening condition) resources to perform the task. If the effort arises from the experimental manipulation and the cost of difficult listening is to use these same resources (e.g., attention, auditory perceptual processing, inhibition, task switching, and monitoring) that are needed and shared with the memory encoding task and subsequent recall, then freeing up these resources by enhancing the listening by making it a 'super-easy' listening condition should result in better memory performance.

In this way I am using the term resources as Navon (1984) does by way of an analogy likening resource to amperage,

> …we do not ponder whether a concept such as amperage corresponds to some ostensibly defined object or process, as long as it serves as a useful theoretical shortcut for explaining or predicting phenomena of electricity without having to resort to complex models of structure and process. Thus, one does not have to know or model the design of an electrical appliance to be able to predict how it will affect the monthly electricity bill or the likelihood that its operation will short circuit the house supply….It should be judged merely by its success in describing and predicting.…The concept of resource was introduced in the hope of serving a similar function. If trade off among cognitive processes could be successfully expressed in terms of allocation of some hypothetical common currency…" (p. 231).

Listening effort. Listening effort has been previously defined as those attention and cognitive resources required for perceptual processing that supports speech perception for communication (Gosselin & Gagne, 2011).

Other recent considerations of effort and capacity and its relation to speech understanding can be found in the work of Rönnberg and colleagues. Rönnberg et al. (2008) used a working memory model for Ease of Language Understanding (ELU) to explain how perceptual processes interact with cognitive processes for understanding. They proposed that it is the relative fidelity of the speech message that allows for the ease or automaticity of the match between the upstream sub-lexical features (phonology) and the target in the lexicon. In this way, when the fidelity is optimal, the match with the target occurs, at the exclusion of other competing targets in the lexicon, more rapidly and automatically due to implicit processes. When the fidelity of the auditory-verbal message is low or suboptimal, the automatic matching processes of the sub-lexical features to the target in the lexicon is unsuccessful, resulting in a mismatch. The ELU model predicts that controlled processes are then required such that the sub-lexical, lexical and semantic and conceptual representations from long-term memory are needed to further decode the speech signal. In this way, the match occurs by way of explicit processes (Rönnberg et al., 2008; Rönnberg et al., 2010; Rönnberg et al., 2013)

Rudner, Foo, Rönnberg, and Lunner (2009) tested the mismatch hypothesis of the ELU model. When participants listen under taxing conditions, the mismatch hypothesis predicts that language understanding is a function of explicit cognitive capacity, whereas under less taxing conditions it is not. The participants were older experienced hearing aid users with bilateral mild-moderate sensori-neural hearing loss. They performed aided speech recognition in noise with two different types of signal processing used in the hearing aids - fast and slow acting amplitude compression.

Fast and slow acting amplitude compression is used in the signal processing for hearing aids as a method to enhance comfort in hearing aid use. The output of the hearing aid is attenuated based on the input of the signal. In this way, sudden loud sounds (i.e., a car horn or siren) are not increased at the same amplitude level as low-intensity sounds (Quiet speech).

The 'fast' or 'slow' in this signal processing refers to how quickly the signal processing turns on (5-10 msecs) and off (5 to > 200 msecs) the attenuation of sound. Slow-acting amplitude compression relative to fast-acting is less distorting in that the temporal envelope is less altered and the syllable characteristics are preserved. However, in slow-acting amplitude compression, the Quiet speech following loud sounds would be less audible, degrading the speech differently from the fast-acting amplitude compression. Rudner et al. (2009) hypothesized that the experience of extended use of either fast or slow acting amplitude compression would allow the participants to acclimate or perceptually learn to process the speech by using the new acoustical form of speech and therefore establish new phonological representations in long-term memory.

Participants were randomly assigned to a nine-week experience with either fast-acting or slow-acting amplitude compression. After this period of experience, aided speech recognition in noise was then re-tested in both the *experienced* listening (match to assigned condition) and the *novel* listening condition (the mismatch to the assigned condition). In addition, two cognitive tests, reading span and a letter number test, were used to measure explicit cognitive capacity. Comparisons of aided word recognition in noise were made between the novel (mismatch) versus the experienced (match) amplitude compression listening condition. Multiple regression analyses revealed that reading span performance predicted 43% of the variance in the post-experienced mismatched condition for speech recognition performance in noise.

When participants experienced novel listening due to the change in the hearing aid configuration (for example by changing the hearing aid configuration from the experienced fast-acting amplitude compression rate to a novel slow-acting amplitude compression rate or visa versa), speech recognition performance in noise was best predicted by reading span, an explicit cognitive capacity metric. The letter matching cognitive metric did not predict performance. Results of this study were in support of the mismatch hypothesis of the ELU. The novel listening (mismatch) speech recognition in noise is predicted by the explicit cognitive capacity - as measured by reading span (Rudner, Foo, Rönnberg, & Lunner, 2009). Thus, this experiment suggests that when older adults perceptually learn or acclimate to speech processing with one type of signal distortion, listening effort increases for speech processing with a different or novel distortion and positive performance is predicted by strengths in cognitive capacity.

Quantifying listening effort. There is sufficient evidence to suggest that the listening conditions for segregating, discriminating and understanding speech will potentially result in more *listening effort* for older adults relative to younger adults, even while listening in the same environment. The older adults with ARHL potentially experience a highly variable speech signal, which would translate more often to a novel listening condition. The different sources of distortion arising from the signal processing in hearing aids, the internal distortion due to the individual's ARHL, or the external distortion from the environment (speaker issues, reverberation and noise) potentially act together to disrupt speech processing. Empirical support for the existence of increased listening effort in the older adult relative to the younger adult and a quantification of this listening effort has been demonstrated with both pupillometry (Kuchinsky et al., 2013) and with a dual task paradigm (Gosselin & Gagne, 2011; Tun et al., 2009).

A dual task is a method used to quantify the degree that performance differs when two tasks are combined versus when either task is performed separately. In this way, the dual task *cost* can be quantified based on the difference between one task performed alone and the two tasks performed concurrently. Gosselin and Gagne (2011) used a dual-task paradigm to quantify listening effort expended in adverse listening conditions. The proportion of dual task cost (pDTC) was calculated by the difference between the single and dual task, divided by the single task. The (pDTC) scores were used to compare younger adults with normal hearing and older adult groups with normal audiograms. Participants performed a primary task, a sentence recognition task in which they identified the subject, verb, and compliment of a sentence, and a secondary task, a tactile-pattern recognition task, to identify long and short pulses. The findings from this study demonstrated that the older group performed proportionally worse in the dual task condition thus indicating that they expended more listening effort relative to the younger adult group (Gosselin & Gagne, 2011).

Similarly, Tun et al. (2009) used an auditory word recognition task as the primary task, and a visual tracking task as the secondary task, to explore the effect of age and hearing loss on effortful listening. The dual task *cost* was a difference score between the single task visual tracking and the dual task visual tracking. Four groups of participants were used, two younger (good and poorer hearing) and two older (good and poorer hearing). Results revealed that although the participant groups had been matched for correct word identification abilities at the start of the experiment, the older adults with hearing loss demonstrated the largest secondary task cost while recalling the word lists (Tun et al., 2009).

The findings in these two studies suggest that listening effort can be quantified with a dual-task paradigm. Also the findings demonstrate that the older adults with hearing loss expended more effort than the older adults without hearing loss, and the older adults with normal audiograms expended more effort relative to the younger groups (with or without hearing loss).

Consequences of listening effort. Listening in these taxing and effortful situations results in failures of speech perception, language understanding and communication, more often for the older adult than the younger adult (CHABA, 1988). However, in the situation in which speech discrimination, language understanding and the resultant communications were successful, was there a consequence of this increased listening effort for the older adult?

Successful communication in a difficult listening environment for the older adult comes at a greater cost for performance on the secondary task. In the Gosselin and Gagne (2010) study the secondary task was a vibro-tacile task requiring those processes necessary to identify one of four pulse patterns. The secondary task in the Tun et al. (2009) study was a visual-tracking task, which engaged those processes necessary to track a visual stimulus on a screen. However, a more common and relevant secondary task for communication pertaining to the older adult is those processes required for elaborative encoding for later recall. The recruitment of those cognitive-linguistic processes as a compensation (Bäckman & Dixon, 1992) in order to perform the primary task (understanding speech) comes at the cost of the secondary task (encoding into memory) and can be best explained by the effortfulness hypothesis (Rabbitt, 1968; 1990).

Adherence to Medication Instructions

As noted above, a secondary aim of this study was to test the perceptual degradation and effortfulness hypotheses using more ecologically valid stimuli than have been used in the past. To create ecological valid stimuli for this study, a more functional and relevant task was sought, one that younger and older participants might encounter for listening to complex information. Fictional medical prescription instructions were created. The decision to use fictionalized but somewhat familiar medical prescription instructions was based on the intention to design the stimuli to be pragmatically relevant to all adults.

Studies demonstrate that medical adherence is problematic for the older adult population and that working memory and attention contribute to this difficulty (Liu & Park, 2004). For example, Stilley, Bender, Dunbar-Jacob, Sereika, and Ryan (2010) compared findings of three longitudinal studies. Samples of adult patients taking once daily lipid-lowering medication, diabetic patients with co-morbid conditions on complex regimens and early stage breast cancer patients on hormonal therapy all completed similar batteries of standardized, valid, neuropsychological tests at baseline. The secondary analysis of these three studies revealed that medical non-adherence was prevalent in all studies. Deficits in attention, mental flexibility, and working memory predicted non-adherence in all studies (Stilley, Bender, Dunbar-Jacob, Sereika, & Ryan, 2010). However, these authors did not investigate the role of hearing loss as either a mediating or causal factor in working memory decline. The sensory-perceptual abilities were not considered to either directly or indirectly influence medical adherence.

In another study, Campbell et al. (2012) conducted a systematic evidence-based review of medical adherence in the cognitively impaired older adult. The purpose was to identify barriers to medication adherence and the interventions used to improve adherence in this population. Results of this analysis identified barriers to adherence as understanding new directions, living alone, scheduling medication administration into the daily routine, and using potentially inappropriate medications. Although only three studies met inclusion criteria for interventions used with this population, the authors concluded that successful interventions for improved medical adherence in this population resulted from frequent human communication as reminder systems more so than non-human reminders (Campbell et al., 2012). Thus, these findings suggest that optimizing the communication of medical instructions for older adult with ARHL appears to be an important factor in medical adherence.

Using fictional medical prescriptions instructions as the complex ecologically valid stimuli for this study accomplished two goals. It allows one first to examine both the role of ARHL on memory, and second, to measure how much the listening environment affects memory performance for a functional activity of daily living (i.e., medical adherence) that is relevant to an aging adult population.

Musical Experience and Aging

A final aspect of the current research was to investigate whether certain types of training or experience help to preserve the older adult's encoding of sound that may then potentially decrease the effort in listening. A cohort of 'trained listeners' who have been shown to demonstrate enhanced auditory-neural encoding of sound are musicians. When compared to non-musicians, musicians demonstrate higher fidelity of the auditory signal arriving at the auditory cortex. These superior auditory skills have been demonstrated in both the music domain as well as the speech domain (Kraus & Chandrasekaran, 2010; Zendel & Alain, 2012; Zendel & Alain, 2013; Zendel & Alain, 2014).

The heightened auditory skill of musicians is explained by the OPERA hypothesis (Patel, 2011). OPERA is an acronym for overlap, precision, emotion, repetition and attention, which refer to the five aspects of musical training that may lead to this identified superior auditory temporal-spectral processing of sound.

According to Patel (2011), specialized musical training influences speech perception because there is *overlap* of the anatomy and physiology of the auditory system for speech and music. Music is a temporal art, in that the meaning of the acoustic information is conveyed and expressed over time. Speech for the purposes of communication is processed in a similar way. The meaning of the acoustic information becomes evident as the various acoustic patterns change relative to each other over time. Patel (2011), suggests that there is more *precision* required for music processing for performance purposes than for speech perception for communication purposes. Thus, musicians are more finely tuning their listening for those slight changes in timing, frequency and amplitude of the acoustic information, more so than that which is required for speech perception, except for when speech is perceived in adverse conditions. In turn, the perceptual learning of the acoustic patterns for speech perception and mapping to phonemes is also more finely ‘tuned’. The strong *emotions* evoked by music may induce plasticity by way of the brain’s reward centers. The *repetition* of active listening, through frequent practice, tunes the auditory systems, perhaps by strengthening the neural network. Lastly, the focused *attention* to the details of sound for playing an instrument particularly in the context of others (i.e., in a band or orchestra) facilitates auditory stream segregation Auditory stream segregation is an aspect of temporal processing that is important for listening to speech in noise (Kraus & Chandrasekaran, 2010; Parbery-Clark et al., 2012b; Strait & Kraus, 2014). (For further discussion of the OPERA hypothesis as well as alternate views, see, Levitin, 2013.)

Kraus and colleagues have found consistent enhanced auditory perceptual and processing abilities in musicians' abilities to process complex sounds. As mentioned above, musicians demonstrate this enhanced auditory-neural signature not only for music but also for processing of speech and language. Musicians demonstrate better acoustic abilities relative to non-musicians in three areas: *pitch*, synonymous with the perceptual aspect of frequency; *timing*, synonymous with the temporal acoustic ability referring to the perception of onset and offsets of sound in relationship to the ongoing auditory stream; and the *timbre*, synonymous with the complex perception of quality of sound and refers to the spectral and temporal aspects of the acoustic message (Kraus & Chandrasekeran, 2010).

Musicians' listening training and their enhanced auditory processing abilities have been shown to reflect better listening-in-noise abilities in several age groups such as school-aged children (Skoe & Kraus, 2013; Strait, Parbery-Clark, Hittner, & Kraus, 2012), young adults (Parbery-Clark, Skoe, Lam, & Kraus, 2009), middle-aged adults (Parbery-Clark, Anderson, Hittner, & Kraus, 2012a) and older adults (Anderson et al., 2011; Parbery-Clark et al., 2012b; Parbery-Clark et al., 2009; Strait & Kraus, 2014). In contrast to older non-musician adults with declines in both auditory acuity and temporal-spectral processing (i.e., delayed neural timing, decreases in spectral encoding and neural consistency of sound), the older musicians demonstrate preserved auditory temporal processing abilities that are more similar to younger adults. If this preserved temporal processing in the older musician contributes to listening ease, then the older adult musicians should perform more similarly to the younger adult, and demonstrate significantly better memory performance compared to the non-musician older adults. These findings would support the effortful listening hypothesis, and suggest that those spectral and temporal processing aspects preserved in older musicians may act as an enhancement in listening by decreasing the effort for decoding of the message, so that these same cognitive resources are available for encoding for later recall.

Present Experiments

The purpose of this study was to further examine and test the perceptual degradation and effortfulness hypotheses with ecologically valid complex auditory-verbal stimuli. If the effortful listening arises from those age-related hearing changes that affect older adults, then manipulating the listening condition so that it is difficult-degraded (like older hearing) and easy-enhanced (like younger hearing) should affect the learning and memory performance for younger and older adults. Younger adults should demonstrate learning and memory performance similar to older adults when they ‘listen’ like older adults in the degraded condition. Conversely, older adults should demonstrate learning and memory performance similar to younger adults when listening in the enhanced condition.

Older adults with hearing impairment should benefit more than younger adults from the enhancements (time-expanded or clear speech technique) to the listening condition. Enhancements to the acoustic information specifically to mimic the younger adult's better auditory perception and temporal-spectral processing should improve the older adults' learning and memory performance. If the listening effort arises from those same age-related auditory perceptual and processing changes, then older adults' learning and memory performance in the enhanced condition should be more similar to the younger adults' learning and memory performance.

In contrast, degrading (time-compressed or conversational speech in noise) the acoustic information specifically in ways that resemble older adults' listening should also result in younger adults performing more similarly to older adults. Finally, the learning efficiency and learning patterns, immediate and delayed memory performance of the younger adults in the degraded listening (mimicked older adult listening) compared to the older adults in the enhanced listening (mimicked younger adult listening), will become more similar to each other. That is, perhaps the patterns of learning for the younger and older adult will resemble each other, narrowing the gap between the groups in learning and memory performance and possibly reaching a point in which these learning and memory performance scores are not significantly different from each other.

Specifically, in Experiment 1, two groups of older adults listened to a passage of medical instructions presented in either Quiet or Noise and recalled the complex prescription information in the two listening conditions, one presented at a normal conversational speech rate and a second one presented with a clear speech technique. In

Experiment 2, two age groups (younger and older adults) listened to and recalled complex prescription information. One set of the instructions was acoustically enhanced (time-expanded in quiet) and the other set was degraded (time-compressed in noise). Finally in Experiment 3, the same variables were compared among groups of younger non-musicians, older non-musicians, and older musicians. In all experiments, learning efficiency performance (the number of critical units reported for all learning trials divided by the number of trials to learn), immediate memory (the total of the critical units reported immediately during any of the listen-recall trials to the maximum of 37) and delayed memory (the total number of the critical units reported after a 20 minute delay) were measured.

Experiment 1

Rationale

The purpose of this experiment was twofold: 1) to examine whether a specific type of auditory enhancement, a message spoken with clear speech technique, reduces the listening effort relative to normal conversational speech and results in better learning efficiency, immediate and delayed memory performance (Bradlow et al., 2003) and; 2) to investigate whether the irrelevant distractor (e.g., speech babble noise) increases the listening effort and decreases the learning and memory performance similarly in both the conversational and clear speech listening conditions.

The temporal and acoustic manipulation of the stimuli. The stimuli in this experiment were the medical prescription instructions created for this study spoken at their original-conversational rate, 192.5 syllables per minute (spm). Then these same vignettes were spoken using a slower hyper-articulated 'clear speech' technique (Baker & Bradlow, 2009).

The 'clear speech technique' is one in which the talker is instructed to produce the speech as if speaking to someone who is either hearing impaired or to one who is not a native speaker of the language (Ferguson & Kewley-Port, 2007). These were indeed the instructions provided to the male speaker who produced the stimuli for this experiment. This 'clear speech' technique resulted in an average speaking rate of 145 spm. Relative to the original-conversational rate of the vignettes (average rate of 192.5 spm), this clear speech rate was on the slower end of the normal speech rate (Goldman-Eisier, 1968).

However, in addition to a slower rate of speech, there were other acoustic dimensions that changed as a result of using the 'clear speech' technique. Studies that investigate how 'clear speech' differs from 'conversational speech' report other significant changes in the acoustic characteristics that make clear speech more easily understood. This ability to understand clear speech more easily than conversational speech is referred to as an intelligibility benefit. The acoustic characteristics that have been identified are increased duration of vowels, longer and more frequent pauses, a larger consonant-vowel ratio, increased size of vowel space, decreased alveolar flapping, increased stop-plosive release, more variable voice fundamental frequency (F0), and greater variability in vocal intensity (Ferguson & Kewley-Port, 2007). Many of these changes in the acoustic dimensions that are produced in *clear speech* versus *conversational speech* have been identified as the parameters contributing to the intelligibility benefit that promotes ease of understanding (Bradlow et al., 2003).

The *clear speech* and the *conversational speech* vignettes in this experiment were subjected to acoustic analysis using Praat version 5.3.63 computer program (Boersma & Weenink, 2014). This acoustic analysis was done to ensure that the style of speech was consistent with the previous research, and that the experimental manipulation in which the speaker used 'conversational' versus 'clear speech' technique was appropriately reflecting the acoustic parameters differentiating the two styles of speech.

Similar to the study by Bradlow et al. (2003), the following acoustic characteristics were examined: total sentence duration, total number of pauses, average pause duration, F0 mean (Hz), F0 range (Hz), and the average vowel space range in F1 (mels) and F2 (mels).

The use of ‘clear speech’ as the experimental manipulation to enhance the listening condition compared to the original recordings of the stimuli in the ‘conversational speech’ style was confirmed by the differences in these acoustic parameters. When the male speaker used a ‘clear speech’ technique this resulted in the expected increase in the overall duration, the number of pauses, a change in F0 mean and range, and increase in vowel space relative to when he used the conversational style speech technique. In this manner, the clear speech vignettes reflect a temporal spectral enhancement relative to the conversational speech vignettes (see Table 1 for the characteristics of each vignette for conversation vs. clear speech).

Table 1

Acoustic Characteristics of Conversational (Conv.) and Clear Speech Sentences for Medipatch and Puffer Vignettes

	Medipatch			Puffer		
Acoustic Measurement	Conv.	Clear	Difference	Conv.	Clear	Difference
Avg. passage duration(s)	48.30	62.20	13.90	47.00	64.00	17.00
Total # of pauses	12.00	18.00	6.00	10.00	25.00	15.00
Avg. pause duration[a]	7.6	7.5	.10	7.10	9.50	2.40
FO mean (Hz)	113.36	126.02	12.66	114.05	121.84	7.79
Vowel space F1 (mels)[b]	748.02	775.53	27.51	655.32	690.49	35.17
FO range (Hz)	233.25	308.00	74.74	317.22	356.39	39.17
Vowel space F2 (mels)[b]	1368.41	1426.52	58.11	1442.81	1517.00	74.19

Note. Methods for acoustic analysis were based on those described in Baker, Bradlow, and Kraus (2003). Praat version 5.3.63 was the computer program used (Boersma & Weenink, 2014). [a] Average durations in milliseconds (ms). [b] Converted from Hz to mel scale that is defined as the perceptually motivated mel scale (Fant, 1973) calculated by the equation (1000/log2)log[(F/1000) + 1].

Hypothesis and predictions

In this experiment older adults listened to medical instructions either in quiet or in the presence of background babble. Half of the sentences were presented in conversational speech and half in clear speech.

If the hypotheses for this study are confirmed then there should be a main effect of listening condition. Relative to the conversational speech the enhanced listening condition ‘clear speech’ will result in more efficient learning and better immediate and delayed memory performance (i.e., a larger number of critical units reported). If the irrelevant speech-babble noise further interferes with processing of the target then the expectation is that there would be a main effect of speech babble noise and a significant interaction of the listening condition and group (Quiet vs. Noise). Participants in the Noise group will have poorer learning and memory performance compared to the Quiet group. The difference in memory performance between the two groups may be due to both energetic masking (Heinrich, Schneider, & Craik, 2008) of the stimuli and/or a distractor effect (Lavie & DeFockert, 2003; Lavie, 2005). The interaction of the group and listening condition will result in a larger negative effect of noise on the conversational than the clear speech listening condition.

Methods

Participants

A total of 48 older adults were recruited and participated. Participants were randomly assigned to either the Quiet or Noise group (see Table 2 for participant characteristics means and standard deviations; see Figure 1 for audiogram data).

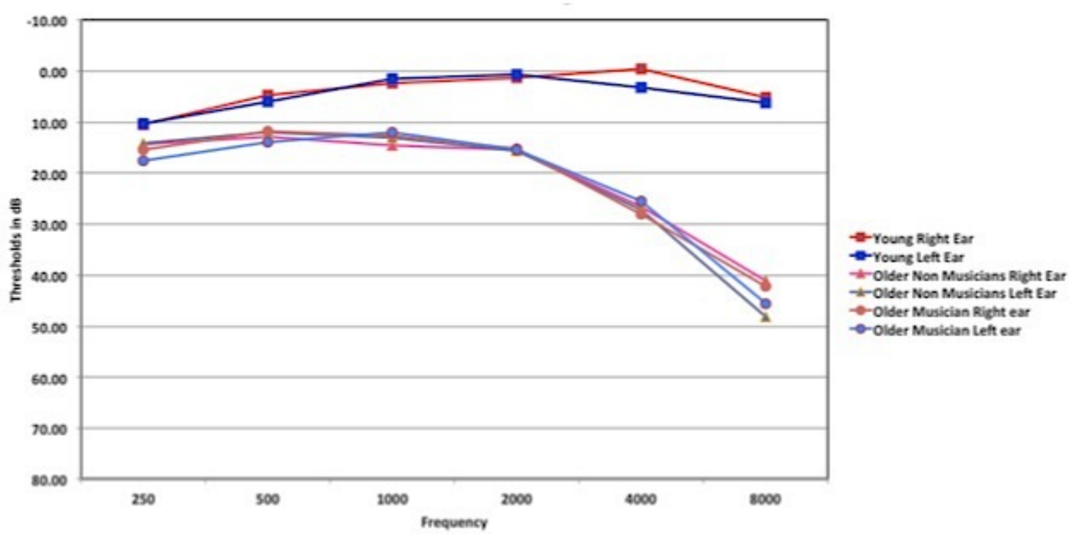

Figure 1. Mean audiogram profile of all participants in the three experiments in this study (n = 133). Young: younger participants from Experiment 2 and 3 (n = 32); Older Non-Musician: older participants (Quiet and Noise groups) from Experiment 1 (n = 48), and the older non-musician participants from Experiment 2 and 3 (n = 32); Older Musician: older musician participants from Experiment 3 (n = 21).

Table 2

Experiment 1: Demographics, Hearing, and Cognitive Characteristics Means and Standard Deviations for Quiet and Noise Groups

	Quiet Group		Noise Group		
Characteristics	*M*	(*SD*)	*M*	(*SD*)	
Demographic Variables					
Age (years)	65.29	(6.16)	64.79	(6.94)	
Education[a]	3.71	(1.04)	3.92	(1.06)	
Health[b]	3.88	(0.74)	4.00	(0.83)	
Hearing Characteristics					
QuickSIN[c]	1.33	(1.39)	2.38	(1.64)	*
HHIA Survey[d]	8.92	(12.62)	6.92	(10.27)	
RPTA4 (dB)	16.04	(11.25)	20.99	(16.54)	
LPTA4 (dB)	19.90	(14.60)	20.05	(14.25)	
Cognitive Characteristics					
FAS (words)[e]	43.04	(12.17)	42.63	(13.87)	
BNT (words)[f]	56.79	(3.74)	55.00	(8.02)	
BackDigit Span[g]	5.00	(0.93)	4.16	(1.30)	*
L-Span	18.13	(10.07)	17.04	(9.06)	

Note. [a] Education - by self reported category 1 = some High School, 2 = High School diploma, 3 = some University/College, 4 = University/College degree, 5 = graduate/professional degree. [b] Health - by self reported category 1 = very poor, 2 = poor, 3 = good, 4 = very good, 5 = excellent. [c] QuickSIN = Quick Speech-in-noise measurement that provides a signal-to-noise ratio loss expressed as dB SNR loss, higher numbers indicate poorer abilities to understand speech in noise. Normal value = < +3 dB SNR loss (Killion, 2002). [d] HHIA - Hearing Handicap Inventory for Adults is a self-assessment; higher scores indicate greater perception of hearing loss handicap. [e] FAS - verbal fluency executive function task, higher number of words generated is better performance. [f] BNT-Boston Naming Test, naming vocabulary test, higher number of words correctly named is better performance. [g] BackDigit Span - backwards digit span, indicates number of digits reported, higher number is better performance.
*$p < .05$ **$p < .01$

The Quiet group consisted of 24 older community-dwelling adults, 56-81 years old (*M* = 65.29, *SD* = 6.2, 10 males, 14 females) with musicianship scores *M* = 2.21, SD = 2.67. Handedness: 18 were right-handed and six were left-handed. Hearing aid use: two participants wore hearing aids, one female participant wore a hearing aid in the right ear only; a second female participant wore bilateral hearing aids.

The Noise group consisted of 24 older community-dwelling adults, 55-77 years old (*M* = 66.79, *SD* = 6.9, 12 males, 12 females) with musicianship scores *M* = 1.46, *SD* = 2.13. Handedness: 23 were right-handed and one was left-handed. Hearing aid use: one male participant wore a hearing aid in the right ear only.

Recruitment. Community-dwelling older adults from the greater St. John's area were recruited by announcements and posters at various senior activity/community centers, athletic facilities, and local businesses close to the Memorial University campus. Only healthy adults without known medical events that may affect memory (e.g., cardiovascular event, neurological event or disease) were invited to participate. All participants were ambulatory and physically able to step up into the testing sound booth.

All participants received $10 an hour for their participation. In addition, participants were provided with an option of free proximal parking on the Memorial University Campus.

Ethics. Ethics clearance and approvals were obtained from Memorial University's Interdisciplinary Committee on Ethics in Human Research (ICEHR) in accordance with the Tri-Council Policy Statement on Ethical Conduct involving Humans (TCPS-2).

All participants gave their informed consent before participating in accordance with Memorial University's Interdisciplinary Committee on Ethics in Human Research (ICEHR).

Research Design

There was one between-subjects variable, competition (Quiet vs. Noise) and two within-subjects variables, listening condition (conversational vs. clear speech) and time of memory recall (immediate vs. delayed).

This study used a modification of the learn-relearn paradigm (Keisler & Willingham, 2007). Participants listened to, immediately repeated what they had heard (immediate memory), and learned the vignettes as precisely as they could over a series of trials (learning efficiency). Participants then recalled the vignettes after the completion of 20 minutes of filler tasks (delayed memory).

Participants experienced both stimuli passages (i.e., medipatch and puffer), both listening conditions (i.e., conversational and clear), and all preliminary measures and filler/interference tasks (i.e., set A and set B). This resulted in eight different combinations of order conditions for these sets of variables. The order in which the participants performed the listening conditions, passages, or tasks (set A and B) was counterbalanced and participants were randomly assigned to one of the order conditions. An example of one of the orders is *EmA/DpB*. In this example, the participant experienced the relatively *Enhanced* listening condition first (clear speech through insertion ear phones) with the *medipatch* passage, completed the interference/filler *tasks set A* (see "Interference/filler tasks and assessments - Task set A" below for the complete list of tasks in this set). At completion of the timer the participant then returned to the sound booth to recall the medipatch passage. This ended the first half of the experiment. There was a five-minute break (/) between the first and second listening condition. Then the participant experienced the second listening condition, the relatively *Degraded* listening condition (conversational speech through the speaker in soundfield) with the *puffer-inhaler* passage, completed the interference/filler *task set B* (see "Interference/filler tasks and assessments - Task set B" below for the complete list of tasks in this set). Again at completion of the timer the participant then returned to the sound booth to recall the puffer-inhaler passage. The seven other possible orders to complete the experiment were: *EmB/DpA; EpB/DmA; EpA/DmB; DmA/EpB; DmB/EpA; DpB/EmA; DpA/EmB*.

The participants completed the study in two sessions on two separate days. In the first session they completed the vision screening, audiometric tests and the listening span (L-span). In the second session they completed the experiment as well as the other measures of hearing-listening and cognitive-linguistic abilities (which were included in the task sets A and B).

The Auditory-Verbal Stimuli

Stimuli characteristics. Fictionalized medical prescription vignettes were created for this study. The vignettes were thematic in nature in that they described the multiple steps needed in relationship to how to use the specific medical prescription (see Appendix A for the two vignettes: medipatch and puffer-inhaler). These vignettes were matched on many linguistic and non-linguistic aspects of speech to equate them as much as possible on the complexity of the stimuli and memory for items, while at the same time maintaining the ecological validity of the vignettes (see Table 3 for characteristics of the two vignettes).

Table 3

Linguistic Aspects of the Fictional Medical Prescription Instructions: Medipatch and Puffer Vignettes

	Medipatch	Puffer
Linguistic Features		
Total words + (carrier)	100 (15)	89 (24)
Function Words/vignette	25	26
Content words/vignette	75	63
# Syllables critical units[a]	73	73
Max # syllables/sentence	21	21
Min # syllables/sentence	3	4
Imperative phrases	11	12
Total # sentences /(units)	10 / (37)	10 / (37)

Note. [a] the critical unit recalled that conveyed the salient meaning of the message may be a single word, compound word or multiple words (e.g. breathe out, out of reach).

Both sets of prescription instructions were comprised of 10 sentences, with 37 critical units to report. The 37 critical units identified a priori were the content words within each phrase that carried the most important salient meaning for the practical purpose of using these fictional medications. The vignettes were similar in sentence structure and the number of embedded clauses. For example, there were similar numbers of imperative phrases, 12 for the puffer-inhaler vignette and 11 for the medipatch vignette. There were similar ranges of the number of syllables per sentences 4 to 21 for puffer-inhaler and 3 to 21 for medipatch. The number of syllables of the content words that comprised the critical units for recall were 73 for both medipatch and puffer-inhaler. The distribution of the critical units throughout the vignette, were constructed so that each third of the vignettes had similar numbers and distribution of items to recall. (For the full description of how these stimuli were created and recorded for this study see Appendix B.)

Presentation of the auditory condition. The intensity level of the stimuli was set at each individual participant's PB max-Most Comfortable Loudness level (PB max-MCL) obtained during the audiometric testing. The PB max-MCL is the intensity level measured in decibels in Hearing Level (dB HL), for which the participants achieved the highest accuracy for repeating phonetically-balanced word lists. This individualized audibility level is consistent with an intensity level that reflects their best performance for discriminating and repeating a list of open-set words in quiet in a sound attenuated chamber.

The rationale for using MCL in dB HL for each individual participant, as the presentation level for the listening conditions, was to equate the groups for optimal performance level for speech discrimination. However, another possible option for presentation level would have been to deliver the stimuli at a specified sensation level (i.e., 35dB SL). For example, a presentation level of 35dB SL means that the participant would experience the stimuli at 35 dB HL above their speech reception threshold (SRT).

SRT is the threshold level in dB HL that one is able to repeat a closed set of two syllable words with 50% accuracy. If a specified sensation level had been used this would have equated the groups on an absolute sensation level (i.e., the level in which they perceive the intensity of the stimuli would have been precisely matched for all participants in the experiments). Another option would be to equate the groups on absolute hearing levels. If this last method had been chosen, the presentation level of the stimuli would have been set at an identified absolute hearing level (e.g., 70 dB HL as is done for the QuickSIN test). Although each of these alternatives have merit, for the purposes of this study, it was important to equate the groups on their best performance level for accuracy of speech discrimination in order to compare their learning and memory performances on the two listening conditions. One advantage of using MCL in dB HL as the intensity level in which the stimuli were presented for this study was to ensure both audibility and comfort. A set *sensation level* (e.g., 35dB SL) may not have been equally comfortable (i.e., too loud) for some of the older adults or not sufficiently audible (i.e., too quiet) for others due to the nature of age-related sensori-neural hearing loss. These differences in comfort and audibility would have been even more pronounced if a set *hearing level* (e.g., 70 dB HL) had been used, and therefore less likely to sufficiently equate the groups for maximum performance on speech discrimination. The expectation was that indeed the specific intensity levels in dB HL that the participants heard the stimuli (which was based on their individualized MCL) would vary within and between the groups (particularly those groups that were significantly different in auditory acuity such as the younger and older adults). Furthermore, the expectation was that if other measures of ARHL correlated with learning and memory performance in the listening conditions, then the presentation levels in dB HL would also significantly correlate with performance as it would reflect their individual hearing-listening levels.

Despite the advantage of using MCL in dB HL, the actual sensation levels for the presentation of the stimuli may have significantly varied by group and this may have influenced the experiment. In order to examine this possibility, first, the sensation level that the participants perceived the stimuli was calculated for all participants in all groups in the three experiments (subtracting the SRT in dB HL from the MCL in dB HL indicates the dB SL). Second, to examine this relationship between sensation levels by group, a series of ANOVAs were conducted to determine if the sensation levels for the presentation of the stimuli differed among the groups for each experiment. There were no significant differences among the groups in all three experiments as follows: Experiment 1, there were no significant differences between the Quiet and Noise groups for the sensation level presentation, $F(1, 47) = 2.98$, $p = .09$; Experiment 2, there were no significant differences between the Younger and Older groups for the sensation level presentation, $F(1, 63) = 0.75$, $p = .39$; and Experiment 3 there were no significant differences among the Younger non-musicians, the Older musicians and the Older non-musicians for sensation level, $F(1, 60) = 1.02$, $p = .37$.

Furthermore, as expected the MCL in dB HL (in which the stimuli were presented) did not differ between the groups when the groups were not significantly different in measured age-related auditory acuity deficits (PTA4). For example, in Experiment 1, there were no significant differences between the Quiet and Noise groups for the MCL in dB HL, F (1, 47) = 0.96, p = .33. However, it was expected that the MCL in dB HL would differ if the groups differed in auditory acuity ability (PTA4). This was indeed the case, in Experiment 2, there were significant differences between the Younger and Older groups for the MCL in dB HL, F (1, 63) = 26.51, p < .001; and in Experiment 3, there were significant differences among the groups for the MCL in dB HL, F (1, 60) = 0.96, p < .001. The differences in MCL in dB HL were only between the Younger non-musicians and Older adult groups (musician and non-musicians), and not between the two groups of older adults (p = 1). (See Table 4 for means and standard deviations for each group in all three experiments.)

Table 4

Intensity level of stimuli presentation during the experiments for both listening conditions

Experiment 1	Older Quiet		Older Noise			
Sensation Level[a]	45.63	(6.81)	41.88	(8.18)		
MCL in dBHL[b]	58.96	(6.08)	61.04	(8.47)		
Experiment 2	**Younger**		**Older**			
Sensation Level[a]	44.69	(3.80)	43.44	(7.23)		
MCL in dBHL[b]	49.38	(4.16)	57.19	(7.51) **		
Experiment 3	**Younger**		**Older Musician**		**Older Non-Musician**	
Sensation Level[a]	45.00	(3.63)	42.14	(9.30)	44.50	(6.26)
MCL in dBHL[b]	49.50	(4.26)	58.81	(4.15)	57.75	(6.78)**

Note. Means and (standard deviations in parenthesis) displayed for the intensity level of the stimuli in the degraded (i.e., conversational or compressed speech) and enhanced (i.e., clear or expanded speech) listening condition. [a] Sensation Level (SL) is the difference in decibels (dB) of the individual participant's speech reception threshold (SRT) and the presentation level in dB Hearing Level (HL) of the stimuli. This dB SL level reflects the intensity level of the stimuli perceived by the participant. [b] Most Comfortable Loudness listening level (MCL) determined during the audiometric testing as the hearing threshold level (in dB HL) in which the participants reported phonetically balanced word lists with their maximum performance. This MCL in dB HL level is the presentation level in which the auditory-verbal stimuli were delivered to the speaker in sound field or to the insert earphones.
$^{**}p < .01$

Conversational speech condition. The conversational speech was presented binaurally via a sound field speaker calibrated to a 1Khz tone. The decision to use a sound field presentation of the stimuli for this listening condition was to mimic listening in more natural listening environments. Participants were comfortably seated and positioned 1 meter distance and 0 degree azimuth to the speaker. To ensure that all participants were positioned appropriately, tape marking on the floor indicated the appropriate position of the chair.

The Noise group. The conversational speech vignette and competing speech babble noise at + 5 dB SNR were routed to the speaker.

The Quiet group. The conversational speech vignette was routed to the speaker in quiet (i.e., no speech babble).

Clear speech listening condition. The participants were seated as they were in the conversational condition. The clear speech stimuli were presented binaurally (routed to the left and right ears) via disposable 3A E.A.R.tone™ insert earphones. The presentation of the stimuli with insertion earphones directly to the right and left ear canal was with the intended purpose to further enhance the listening in a way that may be easily captured in the natural environment (i.e., heard with either a personal FM system, head phones, or through a hearing aid).

The Noise group. The clear speech vignette and competing speech babble noise at + 5 dB SNR were presented simultaneously to the insert earphones binaurally.

The Quiet group. The clear speech vignette was presented without speech babble noise to the insert earphones binaurally.

Procedures

Figure 2 illustrates the procedures for the second session, when the participant performed the experiment in two listening conditions.

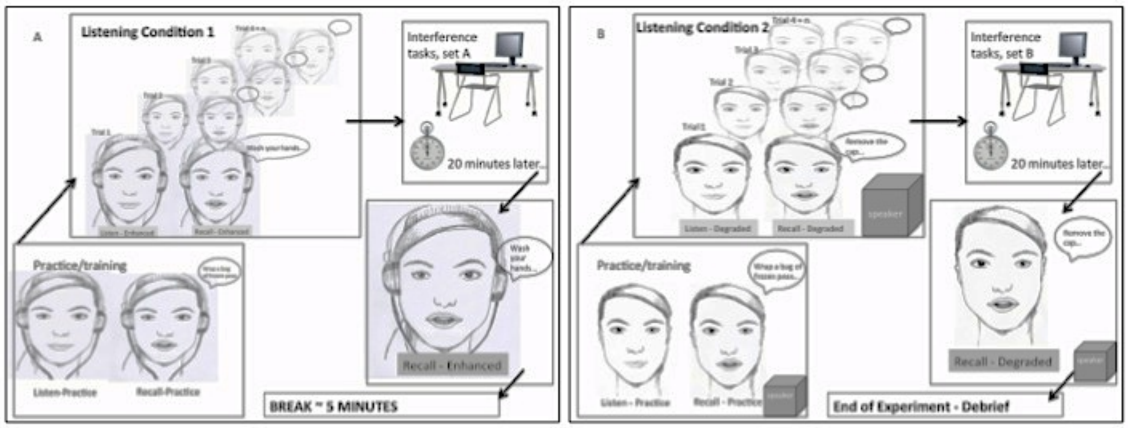

Figure 2. Procedures for Experiments 1-3, illustration of session 2: (A) Listening Condition 1 (enhanced), via insert earphones. Participant instructed and practice session. Trials of listening and recall x 4 (or criteria for learning). Move to experiment room for 20 minutes of interference/filler tasks (set A). Move back to booth for delayed recall. Five minutes break. (B) Listening Condition 2 (degraded) via speaker. Participant re-instructed and practice session repeated. Trials of listening and recall x 4 (or criteria for learning). Move to experiment room for 20 minutes of interference/filler tasks (set B). Move back to booth for delayed recall, end of experiment, debriefing.

Preliminary measures. The purpose of the preliminary measures was to determine if an individual should be excluded from the study due to uncorrected visual impairment that may interfere with performing the tasks for the experiment, a pre-existing cognitive impairment, or a severe to profound hearing loss which would exceed the capacity of the loudspeakers in the sound booth (90 dBA). In addition, the preliminary measures were used to identify aspects of hearing-listening ability that would not be captured solely by the audiometric measures. Also the measures of cognitive-linguistic functions were obtained to determine how the individual's unique hearing-listening and cognitive-linguistic characteristics may have interacted with and affected their performance during the experiment.

Demographic questionnaire. The questionnaire included questions regarding age, education, occupation, health, medication use, musical experience and language(s) spoken. The musicianship score was calculated based on the responses to the questions regarding musical experience (see Appendix C for the demographic questionnaire).

Vision screening. All participants had their vision screened to ensure that vision was adequate to perform the tasks on the computer, to see the pictures, to read, and to complete surveys. Vision was screened with the optical correction (e.g., glasses or contacts) that was to be worn during the experiments, with both eyes open and examined together. The Stereo Optical device (Optec 2000) was used to assess vision according to the manufacturer's instruction manual specification (Stereo Optical Company, 1995). Near and far vision and eye dominance was determined for all participants.

Normal vision is 20/20 feet or 6/6 meters. Therefore, an individual with normal vision is able to see and decipher at 20 feet away or 6 meters away, the letter (as per Snellen Chart), or identify the Landolt ring without the gap or unbroken (as per Stereo Optical) at the same distance as the average person. According to the Canadian Medical Association the requirement for minimal vision for private, non-commercial drivers is 20/50 feet or 6/15 meters (Yazdan-Ashoori & Ten Hove, 2010). When an individual's vision is reported as 20/50 feet, or 6/15 meters this indicates that the average person can see from 50 feet (15 meters), what this individual needs to be as close as 20 feet (6 meters) in order to see or decipher as well. In other words, a person with 20/50 sees less well than a person with 20/20 vision.

All participants demonstrated adequate corrected vision to continue in the experiment: $M_{\text{Far vision}} = 27.46$, $SD = 16.53$; $M_{\text{Near vision}} = 26.88$ $SD = 13.77$. In order to determine if the two groups differed in vision an independent sample t-test was conducted. There were no significant differences between the Quiet and Noise groups for far vision, t (46) = 0.782, p = .77 (M $_{\text{Quiet far vision}}$ = 29.33, SD = 19.62, M $_{\text{Noise far vision}}$ = 25.58 SD = 12.89), or for near vision, t (46) = 0.282, p = .44; ($M_{\text{Quiet near vision}}$ = 27.46, SD = 13.43; $M_{\text{Noise near vision}}$ = 26.28, SD = 14.37.

Mini-Mental Status Examination (MMSE: (Folstein, Folstein, & McHugh, 1975)**.** The Mini-Mental Status Examination is a widely used screening tool for dementia. It is used both clinically and in research to screen cognitive status. Areas assessed include orientation, praxis, language and memory. The purpose of the MMSE was to determine if any participant exhibited pre-existing dementia. All participants scored well within the normal range according to their age and education on the Mini-Mental Status Examination. A passing score on the MMSE is >23 out of 30 (Crum, Anthony, Bassett, & Folstein, 1993). The scores for Experiment 1 ranged from a minimum score of 27 to a maximum score of 30.

Therefore, no participant was excluded from this study due to identified pre-existing dementia or cognitive impairment (Chatfield, Matthews, & Brayne, 2007). In order to determine if the two groups differed in their performance on the MMSE an independent sample t-test was conducted. There was no significant difference between the Quiet and Noise groups for this cognitive screening metric, t (46) = 0.76, p = .45 (M_{Quiet} = 29.00, SD = .88, M_{Noise} = 29.21 SD = 1.02).

Audiometric tests. The audiometric tests were conducted in a single-walled sound attenuated chamber inside a private air-conditioned office. The *Grason Stadler Instruments* Audiometer model GSI-61 was the audiometer used during the audiometric tests and during the experiments. The GSI-61 audiometer, the Telephonics TDH50P headphones, the E.a.r.Tone^{TM} 3A insert earphones and the free-field speakers within the sound booth were calibrated to specification (American National Standards Institute ANSI S3.62004, 2004). All participants completed all audiometric tests.

Pure-tones hearing thresholds used to obtain Right (R) and Left (L) Pure tone average (PTA4). A modified Hughson-Westlake procedure was used to obtain pure-tone thresholds (Carhart & Jerger, 1959). Pure-tone air and bone conduction thresholds measured in decibels (dB HL) were obtained for the speech frequency spectrum 250, 500, 1k, 2k, 4k, and 8k Hz for the right and left ear with standardized procedures for appropriate masking levels to isolate the ears as indicated (Valente, 2009). The pure tone threshold for a specific frequency is the presentation level in dB HL, in which an individual is able to detect the tone at that specific frequency with 50% accuracy (Katz, 1978).

Pure tone averages (PTA4) were obtained for each participant by calculating the average of 0.5k Hz, 1k Hz, 2k Hz, and 4k Hz thresholds for the right RPTA4 and left ear LPTA4 separately. RPTA4 and LPTA4 were used as the measure of the degree of age-related auditory acuity deficit. This method is consistent with other studies investigating hearing acuity deficit and its impact on speech understanding and memory (Tun et al., 2009). (See Table 2 for Hearing characteristics means and standard deviations.)

Speech reception thresholds. Speech reception threshold (SRT) is the presentation level in dB HL, in which an individual is able to identify a closed set of two syllable words with 50% accuracy. SRT is also commonly referred to as a threshold of intelligibility (Newby, 1979). The standard Central Institute for the Deaf (CID W-2) word lists were used for this measure. The words were presented with live voice under TDH-50P earphones for both ears separately. The individual's SRT is highly correlated with the pure tone average (PTA) of 0.5k, 1k, and 2k Hz. The SRT was used as confirmation that the participant's PTA was reliably assessed, and as the reference point in which to present the words for speech discrimination.

Speech discrimination. The standard procedure for assessment of speech discrimination was used (Katz, 1978; (Newby, 1979). Live voice presentation of the phonetically-balanced word lists (CID W-22 word lists) were presented at 35 dB sensation level (SL) above the individual's SRT to assess accuracy for speech discrimination in the left and right ear. This measure was conducted within the sound booth under TDH-50P headphones.

PB max. To determine the decibel level referred to as *PB max* (i.e., phonetically-balanced words reported with the maximum accuracy) in dB HL, the individual hears and repeats an open set of words (CID W-22) and the accuracy is calculated for that specific listening threshold level. If the accuracy for repeating the words reaches 100% and the individual reports that this was a comfortable listening level, then this is the hearing threshold level identified as PB max in dB HL as most comfortable loudness level (MCL).

However, if accuracy is less than 100%, a new word list is used and the intensity level is either increased or decreased accordingly. Repeated testing at various intensity levels with new word lists is done until the individual repeats with their maximum accuracy at the most comfortable loudness level. In this way, a performance-intensity function (PI-function curve) is created for the individual (Jerger, 1973). The point at which the individual achieves their PB max-most comfortable loudness level is at the intensity level in dB HL in which they have repeated with the highest accuracy at a most comfortable listening level (Newby, 1979). This PB max-most comfortable loudness level (PB max-MCL) was obtained for each participant.

The PB max-MCL was confirmed during the practice-training items to ensure that PB max-MCL obtained for words in quiet remained comfortable for the presentation of the experimental stimuli. Each participant was asked to confirm that this level was sufficiently loud but not too loud for listening during the practice. If any adjustment to the PB max-MCL level during the practice item was made, this new PB max-MCL level was used for both listening conditions during the experiment.

An otoscopic examination (visual inspection of the external ear canal and tympanic membrane) was completed by the researcher, as necessary, based on audiometric findings and/or otologic complaints by the participant. No participant was excluded from this study based on audiometric or otoscopic examination. All participant's PB max-MCL was below 90 dB HL (the limits of the loudspeakers in the sound booth), so no participant was excluded from the study.

Hearing-listening measures. In addition to audiometric tests to assess auditory acuity as described above, other measures were used to examine listening abilities. The following measures were conducted to evaluate the individual listening ability differences that may contribute to listening effort and memory performance.

The Quick Speech-In-Noise test (QuickSIN: Etymotic Research, Elk Grove, IL; (Killion et al., 2004)**.** This listening-in-noise measure is a standardized assessment of the ability to repeat/recall sentences from a target speaker (a female voice) in the presence of multi-talker babble (three female voices and one male voice) at various levels of speech-in-noise ratios (SNRs).

The six sentences in each list are at a signal-to-noise ratio (SNR) presentation level starting at 25 dB (i.e., the target sentence is 25 dB louder than the background babble noise), and then decreasing SNRs by 5 dB for each subsequent sentence as follows, 20 dB, 15 dB, 10 dB, 5 dB, and 0 dB (i.e., for the last sentence the target speech and background noise are at the same intensity levels). The signal intensity level remains constant at 70 dB HL and the noise is increased to decrease the difference between the signal to noise ratio. There are 5 key words in each sentence, with 6 sentences in a list for a total of 30 words for each list.

The QuickSIN was administered and scored according to the manual instructions. The participants were seated in the sound booth, at 0 degrees azimuth to the speaker. The 3 lists that were selected for this experiment were practice list #21 and test lists #3 and #4. All participants were instructed on how to perform the task (see Appendix D, for the standardized instructions read to each participant and the practice and test sentences used). The target sentences were routed through the GSI-61 audiometer's external channel at 70dB HL (IEC, 1992) via the speaker. The participants' responses were scored on line and the dB SNR loss was calculated for each participant, according to the QuickSIN manual instructions (Killion et al., 2004).

The QuickSIN score for each participant was the metric used to assess the individuals' listening-in-noise ability. This score was used later in the analysis of how listening-in-noise ability affected the memory performance in the two listening conditions.

The Hearing Handicap Inventory for Adults HHIA (Newman, Weinstein, Jacobson, & Hug, 1991)**.** This self-assessment scale is a standardized and normed test used clinically to determine the individual's self-perception of the degree in which they experience a handicap due to hearing loss (adapted from Hearing Handicap Inventory for the Elderly, HHIE (Ventry & Weinstein, 1982). The 25 questions reflect both the social/situational (12 questions) and emotional consequence (13 questions) of hearing loss. An example of the social/situational question is, *"Does a hearing problem cause you to use the phone less often than you would like?"* An example of the emotional question is, *"Does a hearing problem cause you to feel embarrassed when meeting new people?"* (Newman et al., 1991, p. 357). The individual's response is yes (4 points), sometimes (2 points), or no (0 points). The score is the sum total of all the responses. The higher value reflects a greater perception of hearing handicap. "The HHIA test has high internal consistency reliability, excellent test-retest reliability and low standard error with associative critical difference of 95%, making it an excellent tool for monitoring rehabilitation outcome." (Newman et al., 1991, p. 357). It is used for aural rehabilitation purposes to assess suitability of hearing aid fittings.

For this study, it was important to determine whether the perception of hearing handicap influenced listening ability in the experiment. Those participants with perception of significant hearing handicap may be indicating with higher HHIA scores that they experienced more effort in listening. Higher HHIA could be an indirect measure of greater effort level, and would therefore be expected to be negatively associated with memory performance, particularly in the conversational listening condition.

The musicianship score. The musicianship classification score created for this study was an interval scale in which a higher value reflected more experience with music. This interval scale was created to have a metric to determine level of musicianship and possibly an indirect metric for temporal-spectral processing ability of each participant. The participants answered a series of questions regarding the exposure to music in early education, age of onset of formal music training, duration in years of musical performance, and the extent to which they were engaged in musical practice (e.g. numbers of hours/days per week that they were currently active in musical performance).

The musicianship questions on this survey were consistent with other studies that examine musical training and its relationship with auditory perceptual and processing abilities in behavioral and electrophysiological studies (Kraus & Chandrasekaran, 2010). These selected questions targeted the specific information in which there was empirical support regarding the relationship between the level of musicianship and enhanced listening ability. For example, there is a stronger correlation with enhanced auditory representation in the cortex with earlier age of onset of music training and with the extent of musical practice (Pantev et al., 1998; Trainor, 2005).

A composite score was calculated so that participants had a musicianship score from 0-10. A minimum score of 0 would translate to no early music education, no formal lessons, and no instrumental or vocal performance presently or in the past. Maximum score of 10 translates to those individuals who considers themselves currently to be a musician (not necessarily professionally), had started music education by 10 years of age or younger, had been musically active throughout their lifetime, had performed 12 years or greater, and currently perform on average at a minimum of six hours weekly.

Cognitive-linguistic measures. The following cognitive-linguistic tests were conducted in order to obtain measures of the individual differences in cognitive performance that may contribute to listening effort and memory performance.

The role that ARHL plays for making speech difficult to understand is a complex one involving peripheral and central auditory processes as well as cognitive function (Humes et al., 2012). Therefore it was important to obtain not only individual measures of hearing-listening abilities, but cognitive-linguistic functioning as well. Then, planned statistical analysis could be used to partial out how these variables interacted or contributed to the variance in the memory performance during the two listening conditions in the experiment. In this way it can be determined if individual variability in hearing-listening and cognitive-linguistic ability contributed to their memory performance.

Listening span (L-span). L-span is an auditory working memory task that is similar to the reading span measure (Daneman & Carpenter, 1980). The rationale for using a WM span tasks in this study was that this type of span task is highly predictive for complex cognitive behaviors across domains such as understanding spoken language and reading comprehension (Just & Carpenter, 1992; St Clair-Thompson & Sykes, 2010). There is empirical support that the predictive ability of the WM span task is due to the domain general demands (e.g., executive attention) as opposed to the domain specific demands of the task (e.g., auditory processing, visual processing). The reading span, operation span, counting span and listening span tasks are highly correlated, and demonstrate good test-retest reliabilities (see Conway et al., 2005, for review).

For the purposes of this study, a metric that predicts complex cognitive behavior, primarily in relationship to the executive attention demands of the task, would provide another parameter of how individual differences in this specific aspect of cognitive ability contributed to memory performance in the two listening conditions.

The L-span task was presented on a computer. The participants were seated in front of a computer monitor. The standardized instructions for the task appeared on the computer screen. The participants heard a sentence through headphones presented at 70 dB SPL and had to indicate whether the last word in the sentence was predictable or not predictable by using a mouse and clicking on the respective boxes labeled as *predictable* or *unpredictable*. At the same time that they heard the sentence, they saw a letter on the computer screen. The letter was 24 point Helvetica font, with black print on a white background. They were instructed to pay attention to this letter for later recall. After a series of sentences and the corresponding letters, the response buttons on the computer screen become active with letters. The participant’s task was to recreate the letter sequence by clicking on the response buttons in the order in which the letters appeared.

The scoring method of L-span used for this study was on an all-or-none basis similar to operation span. For example, if the list length was three letters for recall, the participant would receive a score of 3 for that trial only if they recalled all three items in the correct order otherwise they would receive a score of 0. The total score for each participant was the sum total of all the list lengths which were correctly recalled. A larger numeric score would reflect better listening span and therefore indicate better working memory. This L-span score was used in the analysis to determine the relationship between the participants' working memory and recall performance for the two listening conditions.

Backward digit span (Wechsler, 1981). Backward digit span is a short term memory (STM) task that correlates with other measures of cognitive function such as working memory capacity, but not so strongly that it is suggested to measure the same construct (Conway et al., 2005; St Clair-Thompson, 2010). This STM task requires the participant to listen to a set of to-be-recalled items and then recall them. There is no additional type of processing required at the time of encoding, between item lists or prior to recall. The participant was required to report back the digits that they just heard, in the reverse order or backwards to how the items were presented.

The backward digit span was presented on a computer. The standardized instructions for the task appeared on the computer screen. The participants heard a list of digits through headphones presented at 70 dB SPL. Following the presentation of the list of digits the participant was cued with "recall items" on the computer screen, and an array of 9 digits displayed similarly to a telephone keypad were illuminated. The digits were 24 point Helvetica font, with black print on a white background. The participants recreated the 'backwards' order of the digits by clicking on the response buttons in reverse of how they had been presented to them. The initial list length was 2; if the participant responded correctly then the list length increased by 1 but if the participant responded incorrectly the list length decreased by 1. There were 20 trials. The minimal span score that could have been obtained during this task was 1 and the maximum was 18. All participants started with 2-item lists. The score for backwards digit span was the mean. The mean was based on the average of the list lengths correctly recalled during the last 10 trials for the task. This was the value reported as the backwards digit span used in the analysis to determine the relationship between the participants' auditory short-term memory and recall performance for the two listening conditions.

During the course of this study, the researcher identified an error in the calculation of the correctly recalled lists for one of the participants. The participant was presented with longer lists as if he had correctly recalled all the items, when instead the participant was entering only the last few digit(s) correctly recalled and omitting other digits he could not remember for that trial. This resulted in no errors in the responses in his list that he had recreated. Since the 'error' response triggered the program to decrease the length, without an error the lengths continued to increase. Once this problem was identified, the computer program was amended so that the list length presented decreased appropriately.

However, it was important to determine if other participants used the strategy of entering only the items they remembered correctly and not entering an error response. Therefore, all the participants' recorded backward digit span performance were re-examined to determine if the correct scoring applied to their backwards digit span values. In this study there were some backward digits scores that had been incorrectly calculated;

these values were not entered in the analysis. In Experiment 1, there were nine missing values for this measure.

In regards to the relationship between STM (i.e., backward digit spans) and memory performance during the two listening conditions, only those participants whose backwards digit span score was correctly calculated the first time were used in the correlational analysis for this cognitive measure. The participants with missing backward digit span values were not completely excluded from the study, however they were excluded from the correlational analysis using this cognitive measure.

The rationale for only using those participants who were correctly scored initially is that the incorrect scoring resulted in the participants experiencing a different task than those participants whose score were calculated correctly (i.e., trials increased length even when performance was poor).

Boston Naming Test (BNT). The BNT is a subtest of the Boston Diagnostic Aphasia Examination (BDAE) (Kaplan et al., 2001). This test is used extensively with a clinical population for the purposes of identifying word-retrieval and naming abilities. The BNT is a standardized and normed confrontation picture-naming task. The test consists of 60 line drawings, in which participants name the picture and receive 1 point for each correctly named item. The BNT has been found to have good internal consistency and high reliability (Goodglass, Kaplan, & Barresi, 2001).

The participants were instructed and responses were scored according to the test manual instructions. Participants were shown 60 pictures and were instructed to name each picture as accurately as possible with a single word. Participants were cued with a semantic cue (i.e., “it is something you eat”) if they misinterpreted the line drawing of the item, or did not respond after 30 seconds. In addition, as is permitted in the administration of the testing, they were provided with a phonemic cue “it starts with a /b/”, or a choice of 4 words to select the correct name. Only the correct spontaneous responses and those following the semantic cue were scored as correct (1 point), any incorrect responses, or those correct responses requiring a phonemic cue or the forced-choice were scored as incorrect (0 points). The total score is the sum of each item correctly named, for a maximum of 60 points (Goodglass et al., 2001).

The BNT scores were used in the analysis to determine the relationship between lexical abilities (i.e., word-retrieval or picture naming) and memory performance for the two listening conditions.

Verbal fluency measure (FAS). The FAS measure correlates with other metrics that measure executive function. Scores reflect the individual’s cognitive flexibility, inhibition and response generation (Mueller & Dollaghan, 2013). The participant was instructed to generate as many words as possible beginning with the letter “F”, “A” and “S”, given 1 minute for each letter (see Appendix E for instructions read to the participants). The score for this test was calculated as the combined total number of responses for each letter in which they generated new words without violating the prescribed rules (e.g., no repetitions of words, no proper nouns). The FAS score was used in the analysis to determine the relationship between executive functioning and recall performance for the two listening conditions.

The Philadelphia naming test (Roach, Schwartz, Martin, Grewal, & Brecher, 1996). This task is a 175 item picture-naming task. It was developed for research purposes to assess naming ability in aphasic individuals. The PNT naming task differs from the BNT in that it is highly correlated with measures of aphasia, however unlike the BNT, the PNT is only weakly correlated with demographic variables (Roach et al., 1996). Large line drawn pictures were presented on the computer screen. The participants were instructed to name each picture as quickly as they could with one word. The participants used the mouse to advance the pictures on the screen. In this study the purpose of the PNT was to provide an additional filler task to separate the two memory events in time so that the two task sets A and B were equal in time lengths (i.e., 20 minutes).

Instructions. Each participant was seated comfortably in a chair in the sound booth facing the speaker at 0 degree azimuth, as they had been for all hearing testing in the initial session. They were instructed to continue to look at the yellow sticker in the center of the top of the speaker, to ensure that the head position remained central so that the sound from the speaker to each ear was of equal intensity and timing. They were told that they were being video monitored to ensure that they complied with the instructions, stayed alert, performed the tasks and were comfortable during the experiment.

The participants were informed of the experimental tasks with a written script (see Appendix F for script read to participants) that was read aloud to them, while they read along. Answers to questions and redirections to the written instructions were provided prior to and during the training/practice item.

The participants were instructed that they would have multiple trials to learn the vignettes. The goal was to capture as much of the critical information (37 units) that they could glean, and repeat all that they had heard and remembered after each trial of listening. Participants were instructed that gist reporting was acceptable but were encouraged to use as close to verbatim as possible.

Training/practice. A training item was created so that the participants could understand the nature of the task with specific feedback provided during the training task. In addition, the training/practice item provided an opportunity to perform the task prior to the experimental condition to confirm that the intensity level determined during the audiometric testing as PB max-MCL was comfortably loud but not too loud. Participants could also become familiar with the speaker's voice and speech rate for the targeted message prior to the two experimental listening conditions.

The content of the training item was the exact same 2-sentence vignettes (see Appendix A for the training vignette). However, the training conditions matched the experimental listening condition. For example, the practice vignette was presented as it was to be in the experimental listening, so that the training item was presented twice for each participant, once prior to the conversational and again prior to the clear listening condition.

Learning and immediate memory. After the participants listened to the entire 10-sentence vignette, they were then prompted to recall immediately those ten sentences that were just heard as precisely as they could in the order in which they heard them. The participants were not under any time constraint. The participants' responses were said aloud and the responses were audio-recorded. All participant responses were recorded into a sound file designated with a coded participant number and letter (e.g., #14A and #14B) for the two listening conditions. Each trial of listening and then recall of the vignette was recorded on to separate tracks directly into GarageBand 11' on a Macintosh computer for later transcription and off-line scoring by a research assistant blinded to the listening condition.

Trials for completion of learning. All participants experienced four trials of listening-learning for the conversational listening condition, and four trials in the clear listening conditions. The rationale to set the trials to learn the vignettes at a fixed number of trials was based on the intention to prevent ceiling and floor effects. That is the intention was to prevent a result in which there were no differences in the performance between the two listening conditions because the experiment was either so easy that the participants performed at maximum levels for both listening conditions, or so difficult such that the participants could not do the experiment in either listening condition.

The choice to use four trials for learning the vignette was based on the results of a short pilot of the experiment in which three participants similar in ages to the targeted group: 61, 71, and 80 years old performed the experiment. In the pilot the participants learned the vignettes (both the conversational and clear listening conditions) to either a maximum of 100% of the 37 units to report, or until there was no increase in learning after three consecutive trials of learning. The average number of trials for learning was 4.8 trials. No participant performed at ceiling (37 units). The mean was 32.8 units, with a range from 30-36 units. Therefore 4 trials to learn both the conversational and clear speech vignettes was expected to control for ceiling effects of the best learners (i.e., perhaps those with less ARHL in the clear speech listening condition), but also prevent floor effects of the worst learners performing the tasks (i.e., perhaps those with greater ARHL in the conversational listening condition).

Interference/Filler tasks and assessments. After completion of the four learning recall trials, a timer was set for 20 minutes. The participants moved to a separate experiment room to perform other tasks. There were two different sets of tasks (set A and set B). The tasks performed had two purposes: 1) to provide a delay between listening and delayed recall and a filler activity so that the participants could not rehearse the information they just heard; and 2) to assess the participants on various cognitive and linguistic measures that were later used in the correlation analyses to examine the individual differences in relationship to memory performance.

The filler tasks within the sets (A or B) were always administered in the same order. If the participant had not completed all the interference/filler tasks within the allotted time frame (20 minutes), the final items of each set (i.e., set A, demographic questionnaire or set B, Hearing Handicap Inventory for Adults, HHIA) were completed at the end of the experiment before the debriefing.

Tasks set A. The tasks that were included in this set were administered in the following order: the verbal fluency executive function task (FAS), the backward digit span task, the Philadelphia naming test items 1-87, and a demographic questionnaire.

Tasks set B. The tasks that were included in this set were administered in the following order: the Philadelphia naming test items 88-175, the Boston Naming test, the Mini-Mental Status Exam, and the Hearing Handicap Inventory for Adults (HHIA).

Delayed memory. At the completion of the timer (20 minutes), the participant was directed to return to the seat in the sound booth, and the microphone was re-checked for the correct position. The participants were instructed to again recall the same vignette that they had heard immediately prior to the interference/filler tasks (prompted with the title of the vignette). The participants were reminded to report all of the information that they heard, in the order that they heard it, as precisely as they could, as close to verbatim as possible. Participants reported this information aloud and it was recorded into the sound file as the last trial.

Dependent measures. There were three measures that were obtained for the two listening conditions (conversational or clear) for hypothesis testing as follows:

Learning efficiency. Learning efficiency performance was operationally defined as the mean number of critical units learned per trial. This was calculated using the total sum of the number of critical units reported at each of the four trials of learning divided by the number of trials (4). In this way there was a single value for the learning efficiency during the conversational listening, and a single value for the learning efficiency during the clear condition. Fewer critical units learned on average per trial would reflect less efficient learning performance. More critical units learned on average per trial would reflect more efficient learning or a faster rate that participants learned the passage for that listening condition.

Immediate memory. Immediate memory performance was operationally defined as the sum total of the critical units that had been reported during any of the learning trials for that listening condition, to the maximum of a possible total of 37 units. For example, for each trial of listening-recall the total sum of 'new' critical units reported were tallied. The summed total of each 'new' critical unit reported during any of the trials resulted in the immediate memory performance for that listening condition. For example, the sum of the first trial listen-recall (18 units) reported, plus the second trial (5) new units reported, plus the third trial (1) new unit reported, plus the fourth trial (1) new unit reported is a total of 25 critical units recalled immediately of a total possible of 37. This 25 is then the immediate memory performance score for that listening condition). By calculating the immediate memory performance in this way this variable then reflects how much of the message (i.e., the total number of the possible 37 critical units in the vignette) had been heard well enough during the listening-learning trials so that it could be recalled immediately.

Delayed memory. Delayed memory performance was operationally defined as the number of reported critical units on the trial after the filler tasks for that listening condition, to the maximum of 37 critical units.

Scoring of participant responses. A research assistant, who was blinded to the listening condition, scored all participant sound files, giving credit for each critical unit reported correctly. The critical units were the content words of the passages that conveyed the meaning of these medical instructions.

Gist and verbatim recall. When determining recall accuracy the participant was given credit for each of the critical units reported either verbatim or with a gist synonym. The acceptable gist synonyms for each critical unit had been identified as one that captured the meaning of the critical unit in the context of the phrase (see Appendix G). For example, if a participant reported ‘clean’ instead of ‘wash’ in the phrase “wash your hands”, it was identified as an acceptable gist response and was counted as correct.

These scoring criteria were adopted so that both the participants’ use of verbatim and gist recall could be captured. Since previous studies indicate that older adults use gist-based recall more often than younger adults (Tun, Wingfield, Rosen, & Blanchard, 1998; Wingfield et al., 1999), it was important to determine the proportion of gist recall to verbatim recall. In this way, an increase in the use of gist responses may reflect recall ability more consistent with an older adult’s listening, similarly an increase in verbatim responses may reflect recall ability more consistent with a younger adult’s listening. If the two listening conditions differentially affected the use of gist or verbatim recall, this finding could provide further support that the use of verbatim or gist arises from the ease or effort in listening.

Comparing groups on hearing and cognitive measures. A series of ANOVAs were used to determine if the two groups differed in age, musicianship scores, and hearing as measured by LPTA4 and RPTA4, QuickSIN and HHIA scores. Results indicated that there was no significant difference between the Quiet and Noise participant groups for age, F (1, 47) = 0.07, p = .79; musicianship score, F (1, 47) = 1.16, p = .29; or hearing in the right ear, RPTA4, F (1, 47) = 1.47, p = .23, or the left ear LPTA4, F (1, 47)

= 0.001, *p* = .97; or perception of hearing handicap (HHIA) *F* (1, 47) = 0.36, *p* = .55. (Table 2 for means and standard deviations.)

There was a significant difference for QuickSIN scores, *F* (1, 47) = 5.65, *p* = .02, the Quiet participant group demonstrated better listening-in-noise abilities, M_{Quiet} = 1.33, *SD* = 1.39, compared to the Noise participant group M_{Noise} = 2.38, *SD* = 1.64.

In order to determine if there was a significant difference in hearing between the right and left ears, a paired samples t-test was conducted separately for each group. Paired samples t-test indicated that there were no significant differences between the right and left PTA4 for the Quiet group participants, *t* (23) = 1.521, *p* = .14; or the Noise group participants, *t* (23) = -0.554, *p* = .59. (see Table 2 for RPTA4 and LPTA4 means and standard deviations; see Figure 1 for audiometric profile data.)

Self reported health and education were also examined to determine if the groups differed on these variables. There were no significant differences between the Quiet and Noise groups on health, χ^2 (2, *N* = 48) = 1.17, p = .56 or education, χ^2 (2, *N* = 48) = .84, *p* = .84 (see Table 2 for means and standard deviations on demographic, hearing-listening and cognitive-linguistic characteristics.)

A series of ANOVAs were used to determine if the two groups differed in cognitive linguistic abilities such as, working memory as measured by L-span, executive function as measured by FAS, short-term memory as measured by backwards digit span, and lexical access as measured by BNT. Results indicated that there were no significant differences between the Quiet and Noise participant groups for L-span scores, *F* (1, 47)

= .15, p = .70; FAS scores, F (1, 47) = .01, p = .91; or BNT scores, F (1, 47) = .98, p = .33.

However, there was a significant difference between the Quiet and Noise participant groups for the backward digit span measure, F (1, 38) = 5.36, p = .03 (see Table 2 for means and *SD*). The Quiet group demonstrated longer backward digit span values $M_{\text{Quiet}} = 5.00$, $SD = .93$, compared to the Noise group $M_{\text{Noise}} = 4.16$, $SD = 1.30$. However, it should be noted that the backward digit span score was the metric in which 5 participants from the Quiet group and 4 from the Noise group did not have valid scores due to a computer error. This unequal number of obtained valid span scores for the two groups may be affecting this comparison. Furthermore, it is likely that the missing span values represent poorer scores, since the computer error was a function of entering only the last few digits and omitting digits that could not be remembered. One fewer poor backward digit span value in the Quiet group could artificially inflate the Quiet group's mean compared to the Noise group's mean.

Although the groups were randomly assigned there were unexpected a priori differences between the groups on variables that may have an impact on the results. One is the QuickSIN, with the Quiet group demonstrating significantly better listening-in-noise ability as compared to the Noise group. The other variable is the backward digit span, again with the Quiet group performing better on this metric. If experimental differences exist between the two groups, for the memory performance in the two listening conditions, these variables must be considered and understood in terms of their impact on the results. The interpretation of the data must take into consideration the potential differences in listening-in-noise ability, which may reflect better temporal-spectral processing abilities. In addition, cognitive (short-term memory) functioning may reflect greater capacity or resource for remembering during the experimental listening conditions. The Quiet group with both better temporal-spectral processing and short-term memory, may experience less effort in listening, relative to the Noise group independent of the noise condition. The Quiet group may have better learning and memory performance during both listening conditions (conversational and clear). The magnitude of the effect of conversational versus clear listening on memory performance may be less significant in the Quiet group, relative to the Noise group, independent of the between subject variable (i.e., speech babble noise).

Results

Accuracy and Consistency of Scoring of Participant Responses

To determine the consistency and accuracy of the coding of the participant sound files for the reported critical units, one research assistant, blinded to the listening condition, coded all the participant sound files and then re-coded 21% of the total of the participant files randomly selected from the experiment. A total of 10 participant sound files from Experiment 1 (5 from the Quiet group and 5 from the Noise group) were re-coded. To ensure that the coding had been done consistently and did not become increasingly strict or lax, of the 10 participants selected, five participant sound files were selected from the first half, and 5 from the second half of the previously coded files. An intra-rater reliability analysis was performed to assess the degree that the coding and re-coding of the sound file responses for each participant was consistently captured for the critical units reported. Generally speaking, an intraclass correlation coefficient (ICC) value between .75-1.00 is considered excellent (Hallgren, 2012).

Intra-rater reliability. Intra-rater reliabilities for coding of blinded scoring were assessed using intra-class correlation coefficient with a two-way mixed effects model and absolute agreement type (Shrout & Fleiss, 1979). The ICC for single measures for the reported-recalled critical units for each trial was .98 for Experiment 1.

Inter-rater reliability. An inter-rater reliability analysis for coding of blinded scoring was performed to assess the degree that the coding and re-coding of the sound file responses for each participant could be easily and consistently captured by a second rater. To determine the consistency of the coding of the participants' sound files for the reported critical units, a second research assistant, blinded to the listening condition, coded 12% or six participants of the total of the participant files from Experiment 1. None of the re-coded sound files used for the intra-rater reliability were used for this analysis. The intraclass correlation coefficient (ICC) for single measures for the reported-recalled critical units for each trial was .92 for Experiment 1.

The ICC values reported above are between .92-.99, therefore the intra-rater and inter-rater reliability analysis demonstrates excellent consistency in coding (Cicchetti, 1994). The high ICC for both the intra-rater and inter-rater reliabilities suggests that minimal amount of measurement error is introduced by the coding of the participants' sound files. The original scores for the participants were therefore considered appropriate for use in the hypothesis tests for this study.

Order of the Experiment Effects

There were 8 different orders in which the participants completed the experiment (i.e., EmA/DpB; EmB/DpA; EpB/DmA; EpA/DmB; DmA/EpB; DmB/EpA; DpB/EmA; DpA/EmB as explained previously). Participants were randomly assigned to one of the counterbalanced orders. To determine whether the order of the experiment affected the participant's learning efficiency, immediate, and delayed memory performance, a series of mixed design ANOVAs were conducted.

Learning efficiency performance was analyzed with a 2 (listening condition: conversational vs. clear) x 2 (listen order: conversational first vs. clear first) x 2 (passage order: medipatch first vs. puffer first) x 2 (interference/filler task set order: Set A first vs. Set B first) mixed factors ANOVA, with listening condition as a within-subjects factor, and the three order variables as between-subjects factors. This was conducted for each of the dependent variables separately (i.e., learning efficiency, immediate memory and delayed memory). By conducting the analysis in this way all two, three and four-way interactions could be determined (see Table 5 for all F and p values).

Table 5

Experiment 1: Order of Experiment Effects and Interactions

Variables	*F (1,40)*	*p*
Learn Efficiency		
Listening Condition	3.63	.06
Listening Condition*Listening Order	10.68	***.002**
Listening Condition* Passage Order	0.14	.72
Listening Condition*Interference Order	1.33	.26
Listening Condition*Passage Order* Listen Order	0.87	.36
Listening Condition*Passage Order*Interference Order	3.05	.09
Listening Condition*Listen Order *Interference Order	0.31	.58
Listening Condition*Passage Order*Listen Order*Interference Order	0.10	.75
Immediate Memory		
Listening Condition	1.63	.21
Listening Condition * Listen Order	5.91	***.02**
Listening Condition * Passage Order	2.13	.15
Listening Condition *Interference Order	0.09	.76
Listening Condition *Listen Order*Passage Order	0.63	.43
Listening Condition *Listen Order*Interference Order	0.02	.90
Listening Condition *Listen Order*Passage Order	5.91	***.02**
Listening Condition *Listen Order*Passage Order*Interference Order	0.00	.95
Delayed Memory		
Listening Condition	1.60	.21
Listening Condition *Listen Order	4.04	***.05**
Listening Condition *Passage Order	0.05	.82
Listening Condition *Interference Order	3.59	.07
Listening Condition *Listen Order*Passage Order	0.40	.53
Listening Condition *Listen Order*Interference Order	0.00	1.00
Listening Condition *Passage Order*Interference Order	0.16	.69
Listening Condition*Listen Order*Passage Order*Interference Order	0.21	.65

Note. * ***p*** value bolded denotes significant

Order of experiment effects – learning efficiency. Learning efficiency was operationally defined and calculated as the number of critical units learned-per-trial, calculated for each participant by summing the total amount of the critical units reported at each of the trials, divided by the number of trials to learn (4 trials). In this way there was a single value for the learning efficiency during the conversational listening, and a single value for the learning efficiency during the clear condition. More efficient learning was reflected as a higher value, in which more of the units were learned over fewer trials.

There was no significant effect of order or interactions for passage (e.g., medipatch vs. puffer) or filler task set (e.g., Set A vs. Set B) on Learning efficiency (see Table 5).

However, there was a significant 2-way interaction between listening condition order (conversational-clear vs. clear-conversational) and listening condition on learning efficiency, F (1, 40) = 10.68, p = .002. The learning was more efficient during the second listening condition compared to the first listening condition in both the conversational listening condition, $M_{\text{first conversational}} = 19.66$, $SD = 5.81$, $M_{\text{second conversational}} = 21.94$, $SD = 5.40$; and the clear listening condition, $M_{\text{first clear}} = 21.03$, $SD = 6.75$, $M_{\text{second clear}} = 23.09$, $SD = 5.73$. The interaction is such that performance is always better in the second listening task, regardless of which task was second. This is evidence for general learning/practice effects. As a result of the significant interaction between order of listening condition and listening condition for learning efficiency, listening order was entered as a covariate for further hypothesis testing for the differences of learning efficiency between the two groups (Quiet and Noise) in the conversational and clear listening conditions.

Order of experiment effects - immediate memory performance. Immediate memory performance was operationally defined and calculated as the sum of the critical units immediately reported for any of the trials of listening-recall prior to the filler tasks for each listening condition (i.e., the total sum of ‘new’ critical units reported were tallied for the four trials). The summed total of each ‘new’ critical unit reported during all of the trials resulted in the immediate memory performance for that listening condition. The maximum possible for recall was 37 critical units for each passage.

There was a significant 2-way interaction between listening condition order (conversational-clear vs. clear-conversational) and listening condition on immediate memory, F (1,40) = 5.91, p = .02; as well as a 3-way interaction between passage (medipatch-puffer), interference/filler task (set A or B) and listening condition on immediate memory performance, F (1, 40) = 5.91, p = .02.

The two-way interaction between listening order and listening condition on immediate memory performance demonstrated that the groups had better memory performance (i.e., more critical units recalled) during the second listening condition compared to the first listening condition. The immediate memory performance was greater during the second listening condition compared to the first listening condition in both the conversational listening condition, $M_{\text{first conversational}} = 28.79$, $SD = 5.38$, $M_{\text{second conversational}} = 30.42$, $SD = 4.51$; and the clear listening condition, $M_{\text{first clear}} = 29.63$, $SD = 5.79$, $M_{\text{second clear}} = 31.33$, $SD = 4.43$.

The three-way interaction reflected that, the participants who had the conversational puffer passage with the interference task set A, immediately recalled more units, $M_{\text{conversational puffer-set A}}$ = 32.75, *SD* = 3.47, than the other 3 passage x interference task combinations for the conversational speech listening conditions, $M_{\text{conversational puffer-set B}}$ = 28.50, *SD* = 5.33, $M_{\text{conversational medi-set A}}$ = 27.67, *SD* = 5.69, $M_{\text{conversational medi-set B}}$ = 29.50, *SD* = 4.10.

As a result of the significant interactions noted above, listening condition order, passage order, and interference task order, were entered as covariates for further hypothesis testing for the differences of immediate memory between the groups (Quiet and Noise) in the conversational and clear listening conditions.

Order of experiment effects - delayed memory performance. Delayed memory performance was operationally defined and calculated as the total number of the critical units reported after completion of the interference/filler tasks (20 minutes). The maximum possible for recall was 37 critical units for each passage.

There was no significant effect of order or interactions for passage (e.g. medipatch vs. puffer) or interference/filler task set (e.g. Set A vs. Set B) on Delayed memory performance (see Table 5 for *F* and *p* values).

However, results indicated there was a significant 2-way interaction between listening condition order (conversational-clear vs. clear-conversational) and listening condition on delayed memory, $F(1,40) = 4.04$, $p = .05$. The delayed recall was greater during the second listening condition compared to the first listening condition in both the conversational listening condition, $M_{\text{first conversational}}$ = 22.83, *SD* = 5.85, $M_{\text{second conversational}}$ = 25.08, *SD* = 6.01; and the clear listening condition, $M_{\text{first clear}}$ = 24.54, *SD* = 6.73, $M_{\text{second clear}}$ = 25.21, *SD* = 6.38. Again, this interaction indicates a practice/learn effect. The delayed memory performance for the second listening task performing better regardless of listening condition when compared to the delayed memory performance of the first listening task.

As a result of the significant interaction between listening-order and listening condition on delayed memory performance, listening order was entered as a covariate for further hypothesis testing for delayed memory performance between the Quiet and Noise groups in the conversational and clear listening conditions.

Conversational and clear listening the effect on learning and memory performance by group

Learning efficiency performance. In order to evaluate how the conversational and clear listening conditions affected learning efficiency and whether the listening condition differentially affected the learning efficiency of the two groups (Quiet and Noise), a mixed design repeated measures ANOVA was used. The variable listening-order identified above as having a significant effect on learning efficiency was entered as a covariant.

The learning efficiency scores were analyzed with a 2 (group: Quiet, Noise) X 2 (listening condition: conversation, clear speech) mixed design ANOVA in which listening condition was entered as the repeated measure within-subject variable and group was a between-subject variable. There was a significant main effect of listening condition, F (1, 45) = 13.48, p = .001. Conversational listening resulted in less efficient learning, $M_{conversation}$ = 20.8, SD = 5.67 relative to the higher number of critical units learned per trial in the clear listening, M_{clear} = 22.06, SD = 6.28. These results indicate that listening enhancements improved learning efficiency on average by 1.26 critical units learned per trial. There was no significant main effect of the between-subject variable (i.e., speech babble noise), F (1, 45) = 0.03, p = .86. There was no significant interaction of listening condition by group, F (1, 45) = 0.03, p = .87.

Immediate memory performance. In order to evaluate how the conversational and clear listening condition affected immediate memory and whether the listening condition differentially affected the immediate memory performance of the two groups (Quiet and Noise), a mixed design repeated measures ANOVA was used. The three variables identified above as having a significant effect on immediate memory performance (listen-order, passage-order and interference task-order) were entered as covariates.

The immediate memory scores were analyzed with a 2 (group: Quiet, Noise) X 2 (listening condition: conversation, clear speech) mixed design ANOVA in which listening condition was entered as the repeated measure within-subject variable and group was a between-subject variable.

There was a significant main effect of listening condition, F (1, 43) = 6.35, p = .02. Conversational listening resulted in fewer recalled critical units $M_{conversation}$ = 29.60, SD = 4.98 relative to the higher number of critical units recalled in the clear listening M_{clear} = 30.48, SD = 5.17. Listening enhancements improved immediate recall on average by approximately 1 critical unit. There was no significant main effect of the between-subject variable (i.e., speech babble noise), F (1, 43) = 0.30, p = .59. There was no significant interaction of listening condition by group, F (1, 43) = 0.06, p = .82.

Delayed memory performance. In order to evaluate how the conversational and clear listening condition affected delayed memory and whether the listening condition differentially affected delayed memory performance of the two groups (Quiet and Noise), a mixed design repeated measures ANOVA was used. The variable listening-order identified above as having a significant effect on delayed memory performance was entered as a covariant.

The delayed memory scores were analyzed with a 2 (group: Quiet, Noise) X 2 (listening condition: conversation, clear speech) mixed design ANOVA in which listening condition was entered as the repeated measure within-subject variable and noise was a between-subject variable.

There was a significant main effect of listening condition, F (1, 45) = 5.51, p = .02. Conversational listening resulted in fewer recalled critical units $M_{conversation}$ = 23.96, SD = 5.98 relative to the higher number of critical units recalled in the clear listening M_{clear} = 24.88, SD = 6.50, demonstrating that the ‘clear’ speech listening enhancements improved delayed recall on average by approximately 1 critical unit relative to the ‘conversational speech’ listening condition. There was no significant main effect of the between-subject variable (i.e., speech babble noise), F (1, 45) = 0.33, p = .57. There was no significant interaction of listening condition by group, F (1, 45) = 0.99, p = .33. (See Table 6 for means and standard deviations.)

Table 6

Experiment 1: Quiet and Noise groups for Learning Efficiency, Immediate and Delayed Memory performance in conversational and clear listening conditions. Means and Standard Deviations

	Quiet		Noise[c]		Total	
Dependent variable	*M*	(*SD*)	*M*	(*SD*)	*M*	(*SD*)
Learning Efficiency						
Conversation[a]	20.99	(6.34)	20.60	(5.03)	20.80	(5.67)
Clear[b]	22.15	(5.92)	21.98	(6.75)	22.06	(6.28)
Immediate Memory						
Conversation[a]	29.88	(5.15)	29.33	(4.90)	29.60	(4.90)
Clear[b]	30.92	(5.59)	30.04	(4.80)	30.48	(5.17)
Delayed Memory						
Conversation[a]	24.79	(6.81)	23.13	(5.01)	23.96	(5.97)
Clear[b]	25.00	(6.25)	24.75	(6.87)	24.88	(6.50)

Note. [a] The number of critical units reported when listening during the conversational speech rate, the original recordings, at an average rate of 192.5 syllables per minute (spm). [b] The number of critical units reported when listening during the clear speech technique, hyper-articulated with meaningful pauses, at an average rate of 145.5 syllables per minute (spm). [c] Noise – speech babble noise at +5 dB SNR.

The Quiet and the Noise groups were similarly affected by the ‘clear’ speech enhancement to the listening condition (see Figure 3). When the speech was manipulated so that it was sufficiently discriminable in that it could be easily segregated into meaningful units (i.e., the clear speech technique with a slower rate), the presence or absence of the irrelevant distractor - speech babble noise did not differentially affect memory performance.

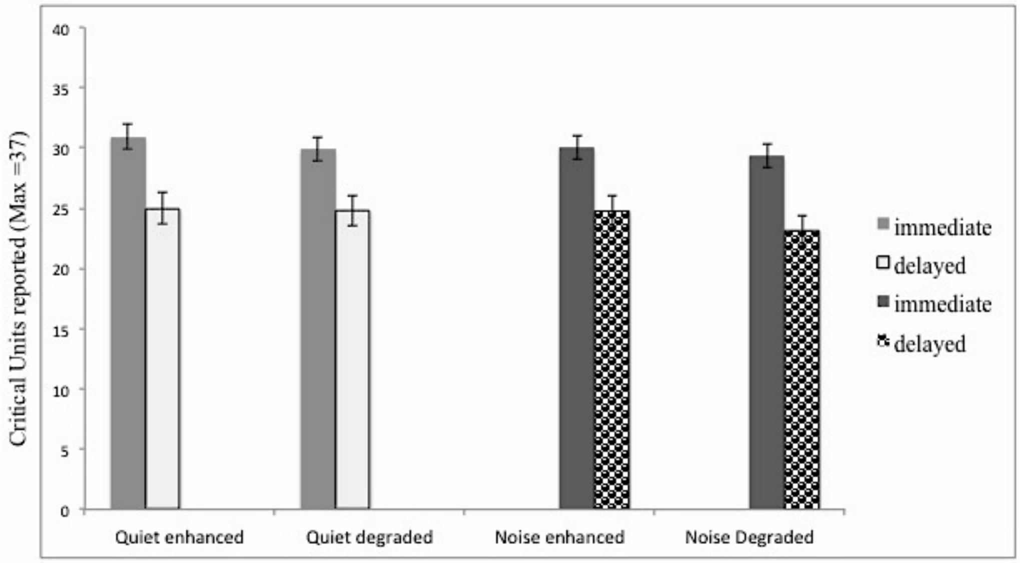

Figure 3. Experiment 1 Results: Immediate and delayed memory performance in the degraded (conversation) and enhanced listening (clear speech) condition for the Quiet and Noise groups. Error bars are standard error.

Delayed memory performance and the relationship with hearing-listening and cognitive-linguistic abilities

Correlation analyses were conducted to further explore the unique contribution of the individual's hearing-listening and cognitive-linguistic abilities on delayed memory performance in the conversational and clear speech listening conditions for the two groups (Quiet and Noise) separately. The rationale to conduct this analysis for only the delayed memory performance variable was based on the following. First, all three dependent variables show similar patterns: the clear speech technique relative to the conversational listening condition resulted in better performance for learning efficiency, immediate and delayed memory performances (approximately one additional critical unit reported). Second, these dependent variables were significantly and highly correlated with each other (see Table 7 for correlation matrix of the dependent variables). Finally and perhaps most important for this study, the delayed memory variable was the metric that was the most ecologically valid for functional memory performance relevant to medical adherence.

Table 7

Experiment 1: Correlations between dependent variables for conversational and clear listening - Both Groups

	Delayed Conv.	Delayed Clear	Immediate Conv.	Immediate Clear	Learn Conv.	Learn Clear
Delayed Clear	.67**					
Immediate Conv.	.84**	.68**				
Immediate Clear	.52**	.84**	.49**			
Learn Conv.	.84**	.73**	.87**	.58**		
Learn Clear	.62**	.93**	.57**	.91**	.65**	-

Note. Delayed = delayed memory performance, Immediate = immediate memory performance, Learn = learn efficiency performance, Conv. = conversational speech listening, Clear = clear speech listening.
** $p < .01$.

The variables that reflected the hearing-listening ability as it relates to ARHL included in this analysis were LPTA4 and RPTA4, QuickSIN scores, HHIA and musicianship score.

The variables that reflected the cognitive-linguistic characteristics included in this analysis were as follows: auditory working memory as measured by L-span; executive function measured by verbal fluency task (FAS), lexical ability as measured by the word retrieval-picture naming task (BNT), and auditory short-term memory as measured by the backwards digit span.

The memory measures that were included in these correlation analyses were the delayed memory performance in the conversational and in the clear listening condition. These relationships were examined separately for the Quiet and the Noise groups.

Hearing-listening characteristics. The results of correlation analysis for the relationship between delayed memory performance and each of the individual variables that may contribute to listening effort are described below.

LPTA4 and RPTA4: Left and right ARHL and delayed memory performance. There were no significant correlations for LPTA4 or for the RPTA4 ARHL and delayed memory performance in the conversational and clear listening conditions in either the Quiet group or the Noise group when these groups are examined separately. When the two groups are examined together, there were still no significant correlations for LPTA4 or for the RPTA4 and delayed memory performance in the conversational and clear listening conditions (see correlation Tables 8, 9, 10).

Table 8

Correlation analysis between delayed memory performance and hearing and cognitive abilities - Experiment 1 Both Groups

	Del.Mem.Deg	Del.Mem.Enh	LPTA4	RPTA4	HHIA	QuickSIN	Musician	L_Span	Digits_Back	FAS
Del.Mem.Enh	.67**									
LPTA4	-.17	-.17								
RPTA4	.06	-.13	.63**							
HHIA	-.06	-.07	.56**	.32*						
QuickSIN	-.24	-.27	.23	.24	.18					
Musician	.17	.20	-.02	.05	-.14	-.45**				
L_Span	.39**	.28	-.24	-.26	-.19	-.26	.28			
Digits_Back	.48**	.47**	-.12	-.04	.08	-.48**	.25	.43**		
FAS	.53**	.44**	-.17	-.32**	-.15	-.27	.20	.52**	.29	
BNT	.56**	.55**	-.04	-.05	-.04	-.34*	.18	.30*	.30	.36*

Note. Del.Mem.Deg = Delayed Memory performance in the relatively degraded listening (conversational speech), Del.Mem.Enh = Delayed Memory performance in the relatively enhanced listening (clear speech), HHIA = Hearing Handicapped Inventory for Adults (HHIA), Digit Back = Backward Digit Span. **p* < .05, ***p* < .01

HHIA: Self-perception of hearing handicap and delayed memory performance. The Hearing Handicap Inventory for Adults (HHIA) may capture aspects of hearing beyond poor auditory acuity, such as listening effort, cognitive abilities and self-efficacy for hearing handicap (CHABA, 1988).

First, a correlation analysis was used to determine if the perception of hearing handicap measured by the HHIA, significantly correlated with QuickSIN and LPTA4 and RPTA4 in the entire group in this experiment. Results indicated that HHIA scores did not significantly correlate with QuickSIN, $r = .18$, $p = .24$. However there were significant correlations with LPTA4, $r = .56$, $p < .001$; and with RPTA4, $r = .32$, $p = .03$ and self-perception of hearing handicap (HHIA).

To determine if perception of hearing handicap (HHIA) was correlated with delayed memory performance a correlation analysis was used. There were no significant correlations between the HHIA scores and delayed memory performance for the entire group in the conversational, $r = -.06$, $p = .70$, or for the clear, $r = -.06$, $p = .66$ listening condition.

Whether examined as one entire group or examined separately by group (Quiet or Noise) there were no significant correlations of perception of hearing handicap and delayed memory performance in either the conversational or clear listening condition (see correlation Tables 8, 9, 10).

Table 9

Correlation analysis between delayed memory performance and hearing and cognitive abilities - Experiment 1 Quiet Group

	Del.Mem.Deg	Del.Mem.Enh	LPTA4	RPTA4	HHIA	QuickSIN	Musician	L_Span	Digits_Back	FAS
Del.Mem.Enh	.61**									
LPTA4	-.25	-.14								
RPTA4	-.07	-.28	.57**							
HHIA	-.08	-.08	.75**	.20						
QuickSIN	-.09	-.18	.07	.17	.16					
Musician	.05	.22	.13	.27	-.11	-.50*				
L_Span	.36	.28	-.23	-.28	-.13	-.45*	.44*			
Digits_Back	.44	.20	.19	.27	.04	-.16	.43	.30		
FAS	.63**	.43*	-.10	-.19	-.05	-.31	.09	.43*	.47*	
BNT	.64**	.77**	-.17	-.33	.10	-.29	.21	.39	.54*	.51*

Note. Del.Mem.Deg = Delayed Memory performance in the relatively degraded listening (conversational speech), Del.Mem.Enh = Delayed Memory performance in the relatively enhanced listening (clear speech), HHIA = Hearing Handicapped Inventory for Adults (HHIA), Digit Back = Backward Digit Span.
*$p < .05$, **$p < .01$

Table 10

Correlation analysis between delayed memory performance and hearing and cognitive abilities - Experiment 1 Noise Group

	Del.Mem.Deg	Del.Mem.Enh	LPTA4	RPTA4	HHIA	QuickSIN	Musician	L_Span	Digits_Back	FAS
Del.Mem.Enh	.78**									
LPTA4	-.08	-.19								
RPTA4	.24	-.03	.72**							
HHIA	-.06	-.06	.33	.49*						
QuickSIN	-.34	-.35	.39	.22	.29					
Musician	.33	.18	-.21	-.08	-.22	-.36				
L_Span	.44*	.27	-.25	-.25	-.28	-.07	.04			
Digits_Back	.49*	.59**	-.34	-.05	.10	-.51*	.01	.44		
FAS	.46*	.44*	-.23	-.40	-.27	-.26	.33	.61	.13	
BNT	.62**	.50*	.03	.08	-.002	-.33	.16	.28	.21	.33

Note. Del.Mem.Deg = Delayed Memory performance in the relatively degraded listening (conversational speech), Del.Mem.Enh = Delayed Memory performance in the relatively enhanced listening (clear speech), HHIA = Hearing Handicapped Inventory for Adults (HHIA), Digit Back = Backward Digit Span.
*$p < .05$, **$p < .01$

QuickSIN: Listening-in-noise ability and delayed memory performance. There were no significant correlations for the QuickSIN scores and delayed memory performance in the conversational or the clear condition for either the Quiet or Noise group (see Table 9, 10 for r, and p values).

Musicianship score: musicianship and delayed memory performance. When the entire group was analyzed there were no significant correlations for musicianship and delayed memory performance in the conversational listening, $r = .17$, $p = .25$, or the clear listening, $r = .20$ $p = .17$ condition. When the groups were examined separately for the relationship between musicianship and delayed memory performance the results showed that there were no significant correlations for delayed recall performance in both the Quiet group in the conversational, $r = .05$, $p = .83$, or the clear, $r = .22$ $p = .30$ listening condition, or for the Noise group in the conversational, $r = .33$ $p = .11$ or the clear, $r = .18$ $p = .40$ listening condition. For Experiment 1, there were no significant relationships of musicianship score and the delayed memory performance in either group in either listening condition.

When the entire sample was analyzed there was a significant positive correlation of musicianship and listening-in-noise ability (QuickSIN), $r = -.45$, $p = .001$. Higher musicianship scores correlated with lower QuickSIN scores or better listening-in noise abilities. This is consistent with studies that examine the relationship of degree of musicianship and perception of speech-in-noise (Parbery-Clark et al., 2009; Parbery-Clark et al., 2012b; Parbery-Clark et al., 2009). Those with more musical training, for longer periods of time, starting at a younger age, demonstrate superior temporal processing, which supports better listening-in-noise abilities (Kraus & Chandrasekeran, 2010).

When considering the operationalized values of effect size as recommended by Cohen (1992), in which correlations > .1 are considered small in effect size, >. 3 are considered medium in effect size, and >.5 are considered large in effect size (Cohen, 1992) the above significant value (r = -.45) would be considered medium in effect size.

The findings in this experiment therefore indicate that higher musicianship scores were significantly correlated with the expected better listening-in-noise abilities (QuickSIN scores) in the two groups of participants. This finding of superior listening-in-noise ability as a function of musicianship training would suggest that indeed, the musicianship score in these two groups reflect better temporal-spectral processing. However the higher musicianship score, and correlated better temporal processing, was not the variable that contributed to the variance in delayed memory performance for these two groups of older adults.

Since musicianship scores in this experiment were not related to delayed memory performance, this finding suggests that the better temporal processing was not the variable that contributed to ease of speech understanding.

Perhaps this is because when the male speaker produced the vignettes he did so in such a way that the vignettes were not sufficiently different from each other in the temporal manipulation. In other words, the original-normal rate and style used for the conversational speech vignettes was already sufficiently clear. This is despite the fact that in the acoustic analysis the two styles had exhibited the expected changes, which have been previously attributed to promoting ‘clearer’ speech (see Table 1). The suggestion here is that the two listening conditions for this experiment may be better described as ‘clear’ and ‘clearer’ versus ‘conversational’ and ‘clear’.

The superior temporal processing ability, may not be essential to efficiently process ‘clear’ versus ‘clearer’ speech. For example, if one already has sufficient temporal processing ability to detect the silent gap between “quarter” and “back” as meaning ‘money returned’, and not “quarterback” as in “football player,” then further increasing the gap between the words does not further enhance speech understanding of these words in the context of the phrase ‘she wants her quarter back’.

Summary of hearing-listening abilities and memory performance in the conversational and clear listening for the Quiet and Noise groups. When the entire sample was analyzed, as well as when the two groups were analyzed separately, there were no significant correlations among the hearing-listening measures and the delayed memory performance for the conversational and clear speech listening conditions. Although these hearing-listening abilities were not significant, generally the direction of the weak relationship of ARHL and memory performance was in the expected negative direction.

The hearing-listening measures did significantly correlate with each other in the expected ways. For example, there were large effects sizes for the relationship between left and right ARHL and perception of hearing handicap, and a medium-large effect size of the relationship of musicianship and listening-in-noise abilities (Cohen, 1992).

It should be noted that it was still possible that by presenting the stimuli at the individualized MCL in dB HL instead of a presentation level fixed at an absolute sensation level (e.g., 35 dB SL), may have influenced the results of the delayed memory performance, even though there were no differences in calculated sensation levels (dB SL) between the Quiet and Noise groups. Those individuals with lower sensation levels may be demonstrating that they cannot tolerate the greater signal intensity (i.e., the sound is uncomfortably loud) and consequently required the stimuli to be at a quieter level than was optimal for one listening condition but not both listening conditions. If this was the case than the expectation would be that the sensation level should significantly correlate with the delayed memory performance with one or both of the listening conditions. To further examine this possibility a correlation analyses between the sensation levels in dB SL and delayed memory performance in the degraded and enhanced listening condition were conducted for the entire sample. There were no significant correlations between sensation level presentation of the stimuli and delayed memory performance in either the conversational or clear speech listening for the participants in this experiment. Additionally, there were no significant correlations between the MCL in dB HL and delayed memory performance in the conversational or clear speech listening for the participants in this experiment (see Table 11 for *r* and *p* values).

Table 11

Correlation analysis between delayed memory performance and intensity level of stimuli presentation – Experiments 1-3 in relatively degraded and relatively enhanced listening

	Delayed Memory Degraded	Delayed Memory Enhanced
Experiment 1	Conversational Speech	Clear Speech
Sensation Level[a]	-.129	-.059
MCL in dBHL[b]	-.041	-.140
Experiment 2	65% Compressed Speech in Noise	120% Expanded Speech in Quiet
Sensation Level[a]	.122	.226
MCL in dBHL[b]	-.584**	-.494**
Experiment 3	65% Compressed Speech in Noise	120% Expanded Speech in Quiet
Sensation Level[a]	.170	-.039
MCL in dBHL[b]	-.412**	-.335**

Note. Delayed Memory Degraded is memory performance during the conversational or compressed speech listening condition presented in sound field. Delayed Memory Enhanced is memory performance during the clear or expanded speech listening condition with insertion earphones. [a] Sensation Level (SL) is the difference in decibels (dB) of the individual participant's speech reception threshold (SRT) and the presentation level in dB Hearing Level (HL) of the stimuli. [b] Most Comfortable Loudness listening level (MCL) determined during the audiometric testing as the hearing threshold level (in dB HL) in which the participants reported with their maximum performance. $^{**}p < .01$

It appears from these results that when the targeted messages were sufficiently audible and discriminable such that the two listening conditions may be better described as ‘clear’ and ‘clearer’, even in the presence of competing noise, the magnitude of the relationship between hearing-listening abilities and delayed memory performance was less striking and not significant. In other words, perhaps once the stimuli were sufficiently audible, the level of temporal degrading did not reach a threshold or tipping point in which the added distortion from ARHL interacts with the processing of the message for successful recognition. Or perhaps instead it is the cognitive-linguistic abilities that are recruited as a compensatory process for successful recognition and encoding for later recall (Bäckman & Dixon, 1992; Wild et al., 2012). If the latter is the case then cognitive-linguistic scores will be significantly positively correlated with delayed memory performance, perhaps more so in the conversational listening condition.

Cognitive-linguistic abilities and delayed memory performance. The results of the correlation analysis for the relationship between delayed memory performance and each of the individual variables that may contribute to listening effort are described below.

L-span: working memory ability and delayed memory performance. There was a significant positive correlation for the L-span scores and delayed memory performance for the Noise group in the conversational, $r = .44$, $p = .03$, but not in the clear, $r = .27$, $p = .20$ listening condition. There were no significant correlations for the L-span scores and delayed memory performance for the Quiet group for the conversational, $r = .36$, $p = .08$, and for the clear, $r = .28$, $p = .18$ listening condition.

The above significant values would be considered a medium effect size (Cohen, 1992). However, note that the magnitude of that effect decreased when the listening condition was more favorable for the groups as in the clear speech without the competing noise, in which it became non-significant.

Backward digit spans: short-term memory ability and delayed memory performance. In view of the fact that there were missing backward digit span scores, which most likely reflected poorer values, these results should be considered with some caution. There were significant positive correlations for the backward digit span scores and the delayed memory performance for the Noise group in the conversational, $r = .49$, $p = .03$, and for the clear, $r = .59$, $p = .006$ listening condition. There were no significant correlations for the backward digit span scores and delayed memory performance for the Quiet group for either the conversational $r = .44$, $p = .06$, or the clear, $r = .20$, $p = .41$, listening conditions.

When the entire sample was examined, there were significant positive correlations between backward digits spans and memory performance for both the conversational, $r = .49$, $p = .002$, and the clear, $r = .47$, $p = .003$, listening conditions.

All the above significant values would be considered a medium-large effect size (Cohen, 1992). The magnitude of the relationship between short-term memory and delayed memory performance became smaller when the listening condition was more favorable as in the clear listening or without competing noise.

FAS: Executive function ability and delayed memory performance. There were significant positive correlations of the FAS scores and delayed memory performance for the Noise group in the conversational, $r = .46$, $p = .02$, and for the clear, $r = .44$, $p = .03$ listening condition. There were significant positive correlation of the FAS scores and delayed memory performance for the Quiet group in the conversational, $r = .63$, $p = .001$ and the clear listening, $r = .43$, $p = .04$.

Thus there is a medium to large effect size (Cohen, 1992). The magnitude of that effect became smaller when the listening condition was more favorable in the clear speech listening condition.

However it is interesting to note that the magnitude of the relationship of executive function and delayed memory performance was the greatest in the Quiet group in the conversational listening condition, which is an unexpected finding.

Boston Naming Test (BNT): Lexical ability (naming/verbal fluency) and delayed memory performance. There were significant positive correlations for the BNT scores and delayed memory performance for the Noise group in the conversational, $r = .62$, $p = .001$, and the clear, $r = .50$, p = .01 listening condition. There were significant correlations for the BNT scores and delayed memory performance for the Quiet group in the conversational, $r = .64$, $p = .001$, and the clear, $r = .77$, $p < .001$ listening condition.

The above values would be considered a large effect size (Cohen, 1992). The magnitude of that effect became *greater* when the listening condition was most favorable, that is in the clear speech listening condition without competing noise.

Summary of Cognitive-linguistic abilities and delayed memory performance in the conversational and clear listening for the Quiet and Noise groups. When the entire sample (i.e., both groups) was analyzed, as well as when the two groups (Quiet and Noise) were analyzed separately, there were medium to large effects of the cognitive-linguistic measures on the delayed memory performance for the conversational and clear speech listening conditions. The magnitude of these effects generally became smaller when the listening condition was more favorable as in the Quiet group or in the clear speech enhancement.

Discussion

Learning-practice effects: Order of listening condition and learning and memory performance

The significant interactions between the order of the presentation of the listening condition (i.e., conversational-clear vs. clear-conversational) and listening condition on the learning efficiency, immediate and delayed memory performance, are consistent with the extant literature describing a *learning-practice effect* and the related *learning curve*.

A practice or learning effect is described as more positive scores (e.g., faster, more accurate, higher consistency, more efficient) with experience of task over time (i.e., subsequent trials of the same type of task or test). This learning-practice effect and the classic s-shaped learning curve (progress plotted on the y axis as a function of time/trials on the x axis) has been described to occur on the simplest perceptual-motor tasks as well as complex cognitive tasks (Ritter & Schooler, 2001). It is evident in educational testing, clinical neuropsychological tests, and in research with test-retest experimental designs (Hausknect, Halpert, DiPaolo, & Moriarty, 2006).

Learning effects may be affected by familiarity with task, decreased anxiety with repeated trials, and employment of strategies learned and transferred to the subsequent trials (Ritter, Reifers, Klein, Quigley, & Schoelles, 2004), for review).

The order in which the participant experienced the listening condition interacted with the performance during the two listening conditions. The two listening conditions in this experiment were relatively degraded (conversational speech in sound field) or enhanced (clear speech heard through insertion earphones) by this temporal-spectral manipulation. The main effect of listening condition suggested that the conversational speech style resulted in a relative *degradation effect* and the clear speech resulted in a relative *enhancement effect.* The interaction of order of the listening condition with this degradation or enhancement effect is suggestive of a learning effect. Specifically, there was less of a degradation effect of the conversational speech when it was experienced as the 2nd listening condition (i.e., the second task for listening) and larger enhancement effect of clear speech when it was experienced as the 2nd listening condition (i.e., the second task for listening).

For example, when the subgroup of participants experienced the conversational listening condition as their 2nd listening condition, the practice/learning effect reduced the degradation effect in that they performed better (i.e., more critical units reported) than the subgroup of participants who had experienced the conversational listening as their first listening condition (i.e., the first task for listening and first experience with the experiment). The practice/learning effect may be attributable to the fact that this subgroup of participants who had the second listening task as the conversational speech listening condition had the benefit of learning how to do the task first in their first listening condition (i.e., clear listening condition). Additionally, perhaps were able to perceptually learn the speaker's voice and speech characteristics more easily in that first clear listening condition. As well, perhaps, these participants had become less anxious, and were then able to employ a strategy for learning and remembering for this 2nd listening condition. Similarly, when the clear speech listening condition is experienced as the 2nd listening condition, the learning effect further increased the enhancement effect, as those participants had both an enhancement effect and the extra benefit of the practice/learning effect as well (see Figure 4).

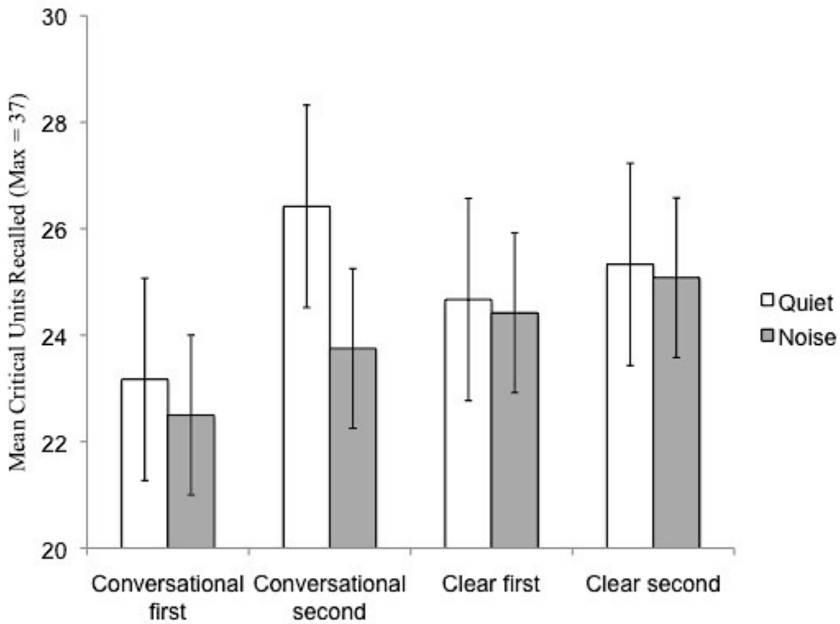

Figure 4. Experiment 1: Comparing learning effects in conversational speech and clear speech listening conditions in Quiet and Noise groups. First/second indicates the order in which the participant performed the experimental listening conditions. Error bars are standard error of the mean.

Learning effect benefit on delayed memory performance in noise and in quiet

Learning effect is defined and quantified as the difference in recall performance, between the 2nd listening condition and the 1st listening condition. If one examines the delayed memory performance of the two groups (Quiet and Noise) separately in relationship to the practice/learning effect benefit for the two listening conditions (conversational and clear), an interesting pattern emerges. Figure 4 depicts this relationship of learning effects in the two listening conditions in the Quiet group and in the Noise group. Enhancements to listening (clear speech) allow greater perceptual learning to operate in both the Quiet and Noise groups, but more so in the Quiet group.

Conversational listening decreases the learning benefit, with learning benefits becoming much smaller.

Perceptual learning effect (clear speech). In the Quiet group, the learning effect is the difference in delayed memory performance in the clear speech listening condition of the subgroup of participants that had the benefit of the clear speech in the second listening condition $M_{\text{clear 2nd}} = 25.33$, as compared to the subgroup of participants that had clear speech in the first listening condition $M_{\text{clear 1st}} = 24.67$, (Clear 2nd – Clear 1st). This demonstrates the learning effect benefit for the clear speech listening condition as an increase of .66 critical units. Similarly, in the Noise group, the difference of the delayed memory performance of the subgroup of participants in the clear speech listening condition in the second listening condition, $M_{\text{clear 2nd}} = 25.08$, compared to the delayed memory performance of the subgroup in the clear speech listening condition in the first listening condition, $M_{\text{clear 1st}} = 24.42$, reveals a learning effect benefit of .66 more units recalled. In both the Quiet and Noise groups, when the subgroups of participants who listened first in the conversation speech condition as their first task or experience with the experiment, the learning/practice effect was the same .66 more units recalled when compared to the delayed memory performance of the subgroups of participants who listened first in the clear speech listening (with and without noise).

Perceptual learning effect (conversational) In the Quiet group, the delayed memory performance for those in the subgroup that had the conversational speech as the second listening condition, $M_{\text{conversational 2nd}} = 26.42$, compared to the subgroup of participants that had the conversational speech in the first listening condition $M_{\text{conversational}}$

$_{1st}$ = 23.17, (Conversation 2nd – Conversation 1st) demonstrated a learning effect benefit for the conversational speech as an increase of 3.25 critical units recalled. When participants had the benefit of listening to the male speaker's voice and speech patterns in quiet with clear speech listening technique as their first experience with the task, their performance for the 2nd listening condition (conversation) in quiet, demonstrated the largest learning effect. This suggests that when participants first listened in quiet, the participant had an additional benefit of perceptual learning of the speaker's pattern (as a result of the experience with the task during the first clear speech listening condition), which then provided a perceptual learning enhancement in addition to a more general practice effect of learning the experimental task. This resulted in a substantial perceptual learning/practice effect (i.e., 3.25 more units recalled).

However, in the Noise group, the difference of the delayed memory performance for the subgroup who experienced the conversational listening condition as the second listening condition, $M_{\text{conversational 2nd}} = 23.75$, compared to the subgroup of participants who had the conversational listening as their first listening condition, $M_{\text{conversational 1st}} = 22.50$, revealed a learning effect benefit of 1.25 more units recalled. In the Noise group, there was still some benefit of the clear speech listening as the first experience with the experimental task, which potentially facilitated perceptual learning of the speaker's voice and speech and added to a practice effect, but somewhat *less* so compared to the Quiet group.

These results suggest two interesting findings: 1) The 'clear' speech relative to conversational speech promotes an additional perceptual learning of the speaker's voice and speech pattern, this increases the overall learning benefit even in the noise conditions, perhaps by the high perceptual load mitigating the distractor effect of the noise. 2) Noise reduces the perceptual learning of the speaker's voice and speech pattern (i.e., the decrease in the perceptual learning/practice effect from 3.25 more critical units learned in quiet compared to 1.25 more critical units learned in noise).

The results of Experiment 1 demonstrated that when older adults listened to complex medical prescription instructions with 'clear speech,' (presented at audible levels through insertion earphones) their learning efficiency, immediate and delayed memory performance improved relative to their performance when they listened with a normal conversational speech rate (presented at audible levels in sound field). This better learning and memory performance for clear speech listening was maintained even in the Noise group. There was a weakly associated negative relationship between ARHL and delayed memory performance in this experiment. There was a medium to large positive association between delayed memory performance and working memory, executive control and lexical abilities; however, the magnitude of that effect was larger in the conversational listening compared to the clear listening condition.

The results support the hypothesis that the auditory verbal stimuli in the conversational speech listening condition demand more cognitive-linguistic resources to achieve successful decoding of the signal than the clear speech listening condition. As a result, fewer resources are available for learning and encoding for later recall (effortfulness hypothesis). In addition, the decrease in the practice/learning effect in the Noise group compared to the Quiet group for conversational speech but not clear speech supports the hypothesis that a high perceptual load decreases the distractor effect, where a high perceptual load spoken with *conversational* style does not (Lavie, 2005). Perhaps then when older adults listen to conversational speech rate that is degraded by ARHL, the high perceptual load does not mitigate the distractor effect, which then interferes with the on-line processing of the acoustic message. Results suggest that it is this distraction (even milliseconds) from the online auditory temporal-spectral processing of the message that then requires those cognitive resources to decode the message, so that fewer resources are available for encoding for later recall.

Although the findings in this Experiment 1 were significant for the main effect of listening condition (conversational and clear) on learning and memory performance, the expectation was that the groups (Noise and Quiet) would be differentially affected by the listening condition resulting in an interaction of group with listening condition. This was not evident in this experiment, most likely since the noise (speech babble) was a between group variable and there were large variances in performance within the groups.

In addition, the expectation was that the age-related auditory acuity deficit would be more strongly correlated with learning and memory performance for the two listening conditions. The expectation was that there would be a large negative effect of ARHL - acuity deficit on learning and memory performance, with the magnitude of that effect being larger in the conversational listening compared to the clear listening.

Perhaps the relative temporal-spectral manipulation of these two listening conditions was not sufficiently different, in that the listening conditions were too similar to each other. Perhaps this is why the relative degradation of the stimuli did not interact with the ARHL acuity deficit as expected.

For example, the conversational speech style in this first experiment, although spoken at an average rate of speech (192.5 spm) was sufficiently clear in other ways. Furthermore, the speech samples were RMS equated for amplitude, which potentially made them even more similar to each other. The temporal-spectral degrading of more typically produced conversational speech may not have been captured by this speaker's rendition. Since he was instructed to use articulation, rate and prosody for optimal clarity even for the original-conversation recording, and as a professionally trained singer and speaker, his normal conversational style is most likely comparable to citation-style speech. As Lam, Tjaden, and Wilding (2012) demonstrated the instructions given to the speaker for the production of the passages affects the acoustic aspects and the intelligibility benefit (Krause & Braida, 2004; Krause & Braida, 2009; Lam, Tjaden, & Wilding, 2012). Citation–style speech production has been demonstrated to provide a larger intelligibility benefit than typically produced conversational speech and potentially only slightly less so from 'clear speech technique' (Ferguson & Kewley-Port, 2007).

Despite the possibility that the conversational speech was more likely 'clear', and the clear speech, may be best described as 'clearer', there was still a main effect of listening condition for Experiment 1. However, the 3-way interaction with passage order, interference task, and listening condition on immediate memory was also a concern in that one passage may have lent itself to be spoken more 'clearly' than another. Again perhaps this may be an artifact of how these two passages were spoken by this male speaker. For this reason, in Experiment 2 and 3, the spectral temporal enhancement to the stimuli was created with a time-expansion technique. To determine if a more substantial manipulation of the temporal-spectral aspect of the stimuli interacts with age-related hearing loss, and whether another type of enhancement in listening (time-expanded speech) results in better learning and memory performance, the experimental manipulation used for Experiment 2 and 3 in present study was time-compressed and time-expanded speech.

Additionally, the speech babble noise at +5 dB SNR was used as a within group variable in the degraded (time-compressed) listening condition for Experiments 2 and 3. In this way, this experimental manipulation more closely resembles the experience that the older adult has for listening in adverse conditions. The irrelevant distractor (speech babble noise) as a within-subject variable may help to capture the degree to which the ARHL interacts with the noise and further increases listening effort.

Also, the expanded speech in quiet more closely resembles the experience that the younger adult has for listening. By comparing the younger and older participant group's learning and memory performance, in the two listening conditions (time-compressed with noise and time-expanded in quiet), those aspects that mimic age-related hearing loss should result in poorer learning and memory performance, and those that mimic younger listening should result in better learning and memory performance for both groups. Similar to Experiment 1, as a within-subject research design one can then examine the relationships of hearing-listening factors and cognitive-linguistic characteristics on the learning and memory performance during the two listening conditions.

Experiment 2

Rationale

The purpose of this experiment was twofold: 1) to examine whether a different type of auditory enhancement, time-expanded speech (Wingfield & Ducharme, 1999), promotes listening ease in a similar way as clear speech technique and results in better learning efficiency, immediate and delayed memory performance; and 2) to investigate whether an interaction of ARHL and the degraded target stimuli (time-compressed speech) and the irrelevant distractor (speech babble noise) increases the listening effort and decreases the learning and memory performance. Fundamentally the research question is, if older adults can listen like younger adults will they remember more similarly to the younger adult? Also, if younger adults listen like older adults will they remember more similarly to the older adult?

The temporal-spectral and acoustic manipulations of the stimuli: individual variability. The methods used in Experiment 2 were designed with the intention of creating a degraded listening condition that mimics those aspects of listening that have been previously identified as problematic for the older adult with hearing loss. In addition, the intention was to create enhancements to the listening condition that not only mimic those aspects of listening that the younger adult without hearing loss experiences, but, also provide an intelligibility benefit promoting listening ease. The ultimate purpose was to determine if these manipulated auditory perception and processing aspects contribute to memory difficulties and whether enhancements allow the older adult to hear, listen, learn and remember more similarly to younger adults.

This experimental manipulation required that the participants' experience of the two listening conditions were to be as similarly degraded and similarly enhanced as possible. Specifically, the experimental manipulations of the verbal stimuli were created in such a way to equate the listeners in relation to the audibility of the stimuli for speech discrimination, the level of difficulty for segregating and discriminating the message-in-competition, and the level of ability to temporally process a time-compressed or time-expanded verbal message. First the intention was to equate the groups' performance on these tasks in a manner that is ecologically feasible. Therefore the degraded listening was created to be more similar to an adverse listening situation that may be typically experienced (e.g., a large pharmacy or a noisy hospital ward). So the degraded stimuli were created to be comfortably loud, but somewhat faster speech rate, in a noisy environment. In addition, the enhanced listening condition was created to be one that could be reasonably obtained when one is providing medical instructions to older adults. So the enhancements were created to be comfortably loud in a quiet room and at a somewhat slower rate. Second, it was important to avoid ceiling effects of the best performers (younger adults) and floor effects of the poorest performers (older adults with ARHL). By creating the stimuli in this manner and then conducting the experiment as a within-subject design, one can examine how the individual differences in these variables affect learning and memory performance for this functional memory task. The following describes the rationale for how the stimuli were manipulated, and the predictions in the context of these manipulations.

Equating for audibility of the message. The intensity level of the verbal stimuli was set at each individual participant's PB max-Most Comfortable Loudness level (PB max-MCL) obtained during the audiometric testing. The PB max-MCL is the intensity level measured in decibels (dB), in which the participant achieved the highest accuracy for repeating phonetically-balanced word lists. This individualized audibility level is consistent with an intensity level that reflects their best performance for discriminating and repeating a list of open-set words in quiet in a sound attenuated chamber. As previously described, the rationale for using the individual's PB max-MCL in dB HL was to equate the audibility for performance accuracy for speech discrimination. The expectation was again that the sensation levels in which the stimuli were presented during the experiments might vary slightly between the groups. However, there were no significant differences in sensation levels between the younger and older groups in this experiment (see Table 4). Also, the expectation was that the absolute MCL in dB HL in which the stimuli had been presented during the experiment would be significantly different between the younger and older adults. This would be as a consequence of the significant differences in the hearing acuity levels between the groups. For example, younger adults with normal hearing (SRT of 10 dB HL) may require the stimuli to be presented at 45 dB HL (or 35 dB SL) for maximum speech discrimination performance; whereas the older adults with moderate ARHL (SRT of 30 dB) may need the stimuli presented at 65 dB HL (or 35 dB SL) to perform equally in speech discrimination at their maximum levels. As expected the MCL in dB HL in which the stimuli were presented were significantly different between the younger and older groups in Experiment 2, $F = 26.50$, $p < .001$ (Table 4 for means and standard deviations).

The presentation of the stimuli at the individual's PBmax-MCL level, routed through the GSI-61 audiometer would be similar to the experience of turning up the volume, or using a prescribed hearing aid with a 'flat' or linear response. A hearing aid that is configured so that the output or 'gain' is flat or linear is one that increases the intensity of the acoustic information equally throughout the speech frequency spectrum. Although many individuals with hearing loss may benefit from hearing amplification that provides a relatively flat response (such as a personal FM system-which the insertion earphones would simulate), more often finer tuning of the hearing aid is required for optimal speech discrimination and comfort. For example, modern digital programmable hearing aids can now be configured so that they spectrally shape the speech signal, attenuating or dampening the intensity at the lower speech frequencies and increasing the intensity in the higher frequencies (Humes, Busey, Craig, & Kewley-Port, 2013). However, since configuring the increased sound intensity to the shape of the person's hearing loss would not be typically available in most listening situations, instead, in order to equate the audibility in an ecologically valid manner, the loudness level was set at the individual's most comfortably loud-listening level. Additionally, as was done in Experiment 1, for the enhanced listening condition, the use of insertion earphones and delivering the stimuli binaurally directly to the right and left ear canals was intentionally done to further enhance the listening in a way that would be considered ecological valid in the real-world noisy and reverberating listening environments.

However, the use of the individual's PBmax-MCL intensity level may not have equated the groups for audibility of these experimentally more complex auditory-verbal vignettes in noise, since the PB max-MCL is obtained for single words in quiet.

Further, those participants with an audiometric configuration reflecting a precipitously sloping-hearing loss in the higher speech frequencies, may also experience the stimuli as less audible for at least three reasons. First, since this increase in intensity level is delivered equally throughout the speech spectrum, the intensity level may not be sufficiently loud in the area of greater hearing loss, such as in the higher speech frequency which are required for discriminating consonants (Humes et al., 2013).

Second, the increased intensity of the low-frequency acoustic information, can mask over the high frequency acoustic information resulting in less audibility, this phenomenon is referred to as the *upward spread of masking* (Newby, 1979).

Third, those individuals with sensorineural hearing loss may have associated hearing difficulties that may further distort the acoustic information and influence listening ability. Examples of associated hearing phenomena that may affect listening ability are oversensitivity to sound referred to as *hyperacusis*, abnormal growth of loudness referred to as *recruitment,* and noises or sounds in the ear referred to as *tinnitus*.

Recruitment of sound is a phenomenon in which the individual experiences the auditory stimuli as barely audible and then with only a small increment of increased intensity, the acoustic information is perceived as 'too loud' (DeWeese & Saunders, 1977). Tinnitus is defined as noises or sound experienced in the ear of an individual in the absence of external acoustic stimulation (Rossiter, Stevens, & Walker, 2006).

These special auditory phenomena, recruitment of sound and tinnitus, are felt to arise from a sensori-neural hearing loss and create distortions, which could further degrade the audibility of the acoustic information (DeWeese & Saunders, 1977; Katz, 1978(Rossiter et al., 2006). The presence of these related auditory difficulties are highly correlated with each other, for example the majority of individuals that reported hyperacusis also reported tinnitus (Eggermont, 2012).

Despite the inability to precisely equate for audibility, as a within-subject repeated measures design, the prediction was that the individual's learning efficiency, immediate and delayed memory performance should be relatively either enhanced or degraded by the listening condition, recognizing that the participants' specific hearing, listening and cognitive abilities would contribute uniquely to this performance.

However, planned follow up correlational analysis was used to determine the relationship of ARHL and delayed memory performance. High frequency ARHL is also significantly correlated with tinnitus and recruitment of sound (Zarenoe & Ledin, 2013). Therefore the older adult with more significant ARHL (PTA4), and its related auditory phenomenon, would experience more distortion of the signal, more difficulty in listening and potentially expend more effort relative to a more normal hearing cohort. The predictions consistent with the effortfulness hypothesis would demonstrate then that the greater ARHL (as measured by LPTA4 and RPTA4) would contribute significantly and predict poorer memory performance.

Equating for Listening-in-noise ability using Signal-to-Noise Ratio (SNR). The +5 dB Signal-to-Noise Ratio (SNR) was used as the message-to-competition ratio in an attempt to make the degraded listening condition ecologically valid. This SNR was based on what one may encounter in everyday real world listening environments. Also, it would be consistent with creating a sufficiently 'noisy' listening environment, but slightly more favorable one, relative to the average listening-in-noise abilities for adults (Tun, 1998).

Tun (1998) conducted a study in which participants listened to and reported back time-compressed sentences in various SNRs (e.g., most difficult -9 dB to easiest +21 dB in 3 dB increments). She compared a group of younger and older adults on percentage of correctly reported sentences at three speech rates, normal, medium fast (compressed to 80% of original rate), and fast (compressed to 60% of original rate). The results demonstrated that when older and younger adults listened to fast speech with between +3 to +6 dB SNRs, the older adult group achieved approximately 75% and the younger adult group achieved approximately 85% correctly recalled sentences.

The +5 dB SNR presentation level used was selected based on the findings from the Tun (1998) study in which she used noisy and fast speech. The +5 dB SNR will theoretically permit the older adults to achieve a high enough accuracy for these lengthier complex vignettes and at the same time the younger adults will not achieve maximum scores at this SNR level, effectively preventing floor effects for the older adults and ceiling effects for the younger adults.

Lower QuickSIN scores reflect better listening-in-noise abilities. Scores that are less than or equal to +3 dB SNR loss are considered to reflect normal listening in noise ability (Killion, 2002). This +3 dB SNR loss indicates that one is able to repeat sentences with 50% accuracy when the sentences are only 3 dB louder than the background speech babble competition. A +5 dB SNR presentation level (i.e., the message 5 dB louder than the competing speech babble) was selected as being appropriately more favorable relative to the average QuickSIN values for healthy adults and more favorable than what is considered the averaged-norm (e.g., Experiment 1 the QuickSIN M_{group} = 1.85, SD 1.59; Experiment 2 the QuickSIN M_{older} = 1.64, SD= 2.0; in Experiment 3 the QuickSIN $M_{\text{older musicians}}$ = 1.76, SD= 2.0).

The message-to-competition ratio was not individually adjusted to the participants' QuickSIN scores, and it therefore does not completely equate the participants for ability of listening-in-noise. For example, +5 dB SNR presentation level may be more or less degrading of the listening situation relative to the individual's unique ability to discriminate speech-in-noise.

Therefore correlational analyses were used to determine the relationship of the individual's ability to discriminate speech-in-noise, as measured by QuickSIN in dB SNR loss, and their delayed memory performance. In addition, this analysis is used to identify how the effort arising from difficulties for listening-in-noise may influence delayed memory performance.

Equating for the temporal processing of auditory verbal stimuli with expansion and compression of the original passages. The verbal stimuli were manipulated in such a way as to resemble naturally fast speech. To do this, the speech was time-compressed to 65% of the original passage. The verbal stimuli were manipulated to resemble naturally slow speech; to do so, the speech was time-expanded to 120% of the original passage.

These manipulations alter the temporal-spectral aspect of the acoustic stimuli in such a way that the result is that the speech is perceived to be faster or slower but naturally so.

In the present study the manipulation of the original sound files, creating a faster rate of speech, was done to mimic the older adult's degraded or distorted perception of normal speech rate. The older adults' listening to a normal rate of speech, with auditory temporal-spectral processing that is slowed and highly variable, would result in the perception that the speech was 'too fast' to allow for the rapid perceptual processing and comprehension of the message.

An enhanced listening situation in which the speech is expanded and therefore perceptually slowed would potentially be perceived more like the 'normal rate' in which a younger adult experiences sound. This slower rate would conceivably be more easily perceptually processed, perhaps due to the longer durations of the acoustic stimuli over time (i.e., larger gaps, increase duration of voicing, increase vowel space). It would follow then that there would be less effort for discrimination and comprehension of the spoken message.

The two listening conditions were manipulated in this manner in order to resemble the perception that the older adult would have with normal speech as being 'too fast'. That is the speech vignette was compressed to 65% of the original sound file for the degraded listening condition. Also, the speech vignette was manipulated to mimic the perception that the younger adult would have as being normal rate, the speech was expanded to 120% of the original sound file so that it was relatively enhanced and a less effortful speech rate for discrimination and comprehension.

Enhancements of the stimuli. The degree of time-expansion (120%) to simulate slower speech was based on the research on the effects of age on listening-rate preferences and recall performance in younger and older adults (Wingfield & Ducharme, 1999).

Since the intention of this study was to create ecological valid stimuli, the 120% time-expansion was consistent with capturing a rate that would be likely to maximize recall performance but closer to a preferred rate of listening. Since recall performance was best at the slower rate for both younger and older groups in the Wingfield and Ducharme (1999) study, this rate was consistent with the goal to enhance the auditory stimuli in this way.

Additionally, the expansion of the vignette to 120% of the original rate increased the silent pauses similarly throughout the passage. This effectively increased the duration of the silent pauses that occurs at the linguistic boundaries in which they were originally produced. This is similar to the study by Wingfield et al. (1999) in which improved recall was obtained for time-compressed speech when time was restored to 125% at salient linguistic boundaries (Wingfield et al., 1999).

Expanding the original sound files for this study to 120%, resulted in the speech rate (162 spm) falling well within the low end of the normal rate of speech (i.e., 138-258 spm) (Goldman-Eisier, 1968). Also this 120% time-expanded speech rate was aligned with the speech rate obtained when the passages had been produced with the 'clear' speech technique (146 spm) in Experiment 1 (Bradlow et al., 2003). Aligning the time-expanded speech rate with the 'clear speech rate' was important for further comparisons of this time-expanded speech enhancement to *clear speech* enhancements used in other studies and was consistent in creating a more ecologically valid stimulus. In addition, by comparing the clear speech technique used in Experiment 1 to the time-expanded speech used in Experiment 2 and 3 in the present study, the feasibility of using particular types of signal processing (e.g., hearing amplification) to enhance listening could be explored.

Degradation of the stimuli. The degree of time-compression (65% of the original passage) to simulate faster speech was based on several studies in which time-compressed speech was used with younger and older adults (Peelle & Wingfield, 2005; Tun, 1998; Wingfield et al., 1999). It was important to identify the level of time-compression that would be consistent with creating ecologically valid stimuli and at the same time avoid ceiling and floor effects. This ability-to-process and/or ability-to-adapt to speech rate would vary within the participant groups similarly to the *audibility* and *listening-in-noise* ability. It was the intention to equate the groups for the ability to *temporally process*. It was particularly important to select a time-compressed speech rate level that would be favorable enough for the participants with potentially the poorest temporal processing and/or the slowest-to-adapt-to-rate, as one would expect for the older adult group with significant hearing loss (i.e., floor performance). At the same time it was important to have a sufficiently fast or dis-favorable rate for the younger adult with normal hearing (i.e., ceiling performance). The 65% time-compression speech rate was perceptually and sufficiently fast, and it met the criteria as a rate that one may encounter in his or her listening environment (Tun, 1998; Wingfield & Ducharme, 1999).

Unlike *audibility* and *listening-in-noise levels,* there was no individual measure obtained in the audiometric testing, such as *'temporal processing threshold'* that could then be used in a correlation analysis to determine how the unique contribution of temporal processing contributed to effort and memory performance.

Instead, a classification of *musicianship* was used as a factor to indirectly capture the participants' unique contribution for temporal processing of speech. The rationale for this as a factor is supported with empirical findings demonstrating that young and older musicians have better temporal processing as compared to peers matched for age, education and hearing ability (see Kraus & Chandrasekaran, 2010 for review).

Therefore, planned follow up tests with correlation analyses were conducted to determine the contribution of the individual's ability to temporally process speech, on learning efficiency, immediate and delayed memory performance. In this way, this analysis was used to identify how the individual's ability to temporally process and/or adapt to the time-compressed rate, or benefit from the time-expanded rate resulted in effortful or effortless listening and how this effort level then influenced memory performance.

The adults with lower musicianship scores would have less preserved temporal-spectral processing and would likely experience more effort in listening relative to the more "expert" temporal-spectral processing cohort (e.g., higher musicianship scores). The expectation would then be that the results would show that lower musicianship scores would be associated with poorer delayed memory performance in the degraded condition. If the results indicate that lower musicianship is related to poorer delayed memory performance then this finding supports the effortfulness hypothesis. Effortful listening, when due to poorer abilities in temporal-spectral processing of complex passages, comes at the cost of those cognitive resources required to encode the information for later recall.

Hypothesis and Predictions

According to the effortfulness hypothesis (Rabbitt, 1968, 1990), the degrading of the acoustic stimuli as a result of ARHL increases listening effort. Decoding the message in these effortful listening conditions then consumes the resources that would otherwise be allocated for elaborate encoding of the information for later recall. In this way the direct cost of difficult or effortful listening is fewer resources for those processes needed for memory encoding. Those individuals who either experience less effort in listening and/or have more cognitive-linguistic resources available to be shared with the two processes (comprehension and recall) will perform better than those who experience more effort in listening and/or have fewer cognitive-linguistic resources.

If the hypothesis for this study are confirmed then results of Experiment 2 should show the following: There will be a main effect of listening condition, enhanced listening (time-expanded speech in quiet presented) resulting in more efficient learning, better immediate and delayed memory performance relative to degraded speech (time-compressed with speech babble noise) for both the younger and older adults. If the ARHL further interferes with auditory processing of the target then the expectation is that there would be a main effect of age and a significant interaction of the listening condition by group. The two groups will be differentially affected by the two listening conditions.

The older participants will have significantly poorer learning and memory performance compared to the younger group in the degraded listening conditions and/or perhaps benefit more so from the enhanced listening condition. The individual variables that measured aspects of ARHL (PTA4, QuickSIN, HHIA) will be negatively related to memory performance with the magnitude of that effect greater in the degraded listening condition. However, higher musicianship scores, as a potential indirect measure of preserved temporal-spectral processing, will be positively related to delayed memory performance. The individual variables that measured aspects of cognitive-linguistic abilities (L-span, backwards digit span, FAS and BNT) will be positively related to memory performance.

Methods

Participants

A total of 64 participants were recruited and participated in this experiment. All of the participants were self-reported as right-handed. None of the participants wore hearing aids in this experiment (see Table 12 for the demographic, hearing-linguistic and cognitive-linguistic characteristics of the groups). No participant from Experiment 1 participated in this experiment.

Table 12

Experiment 2: Mean Participant Characteristics

	Younger Group		Older Group		
Characteristics	*M*	(*SD*)	*M*	(*SD*)	
Demographic Variables					
Age (years)	21.81	(2.51)	65.34	(6.93)	
Education[a]	3.47	(0.80)	3.75	(1.16)	**
Health[b]	3.97	(0.70)	3.84	(0.77)	
Hearing Characteristics					
QuickSIN[c]	0.70	(1.69)	1.64	(1.99)	*
HHIA Survey[d]	4.19	(10.51)	8.25	(13.85)	
RPTA4 (dB)	3.32	(6.21)	23.05	(20.19)	**
LPTA4 (dB)	3.91	(8.14)	23.82	(18.60)	**
Cognitive Characteristics					
FAS (words)[e]	47.94	(10.00)	42.72	(12.28)	
BNT (words)[f]	55.66	(2.21)	55.66	(4.04)	
BackDigit Span[g]	5.30	(1.13)	4.87	(1.18)	
L-Span	27.84	(7.18)	17.75	(9.89)	**

Note. [a] Education - by self reported category 1 = some High School, 2 = High School diploma, 3 = some University/College, 4 = University/College degree, 5 = graduate/professional degree. [b] Health - by self reported category 1 = very poor, 2 = poor, 3 = good, 4 = very good, 5 = excellent. [c] QuickSIN = Quick Speech-in-noise measurement that provides a signal-to-Noise ratio loss expressed as dB SNR loss, higher numbers indicate poorer abilities to understand speech in noise. Normal value = < +3 dB SNR loss (Killion, 2002). [d] HHIA - Hearing Handicap Inventory for Adults is a self-assessment; higher scores indicate greater perception of hearing loss handicap. [e] FAS - verbal fluency executive function task, higher number of words generated is better performance. [f] BNT-Boston Naming Test, naming vocabulary test, higher number of words correctly named is better performance. [g] BackDigit Span - backwards digit span, indicates number of digits reported, higher number is better performance.
$*p < .05$, $**p < .01$

Younger group. Thirty-two younger-adult undergraduate and graduate students from Memorial University of Newfoundland, 18-27 years old, ($M = 22$, $SD = 2.58$), 14 males and 18 females were recruited and participated.

Older group. Thirty-two older community-dwelling adults, 56-84 years old (*M* = 65, *SD* = 6.9) 13 males, and 19 females from the greater St. John's, NL area were recruited and participated.

Recruitment of participants. Younger adults: The younger adult participants were undergraduate or graduate students at Memorial University of Newfoundland. Recruitment was conducted by placing posters around campus, an announcement was posted on the psychology department website, and announcements were made in both undergraduate and graduate classes.

Older adults: Community-dwelling older adults from the greater St. John's area were recruited by announcements and posters at various senior activity/community centers, athletic facilities, and local businesses close to the Memorial University campus. Only healthy adults without known medical events that may have an impact on memory (e.g. cardiovascular event, neurological event or disease) were invited to participate. All participants were ambulatory and physically able to step up into the testing sound booth.

All participants received $10 an hour for their participation. In addition, the older adult participants were provided with an option of free proximal parking on the Memorial University campus.

Ethics. Ethics clearance and approvals were obtained from Memorial University's Interdisciplinary Committee on Ethics in Human Research (ICEHR) in accordance with the Tri-Council Policy Statement on Ethical Conduct involving Humans (TCPS-2). All participants gave their informed consent before participating in accordance with Memorial University's Interdisciplinary Committee on Ethics in Human Research.

Research Design

There was one between-subject variable, age group (younger adults vs. older adults) and two within-subject variables, listening condition (degraded vs. enhanced) and time of memory recall (immediate vs. delayed).

All other aspects of the procedure were identical to Experiment 1, except for the following: In Experiment 2, younger participants were given the option to complete the entire study in two sessions on the same day with a break between session 1 and session 2. All older adults completed the study in two sessions on two separate days.

The Auditory-Verbal Stimuli. The stimuli for this experiment were the same two medical prescription vignettes and training vignette used in Experiment 1. Avid Pro-tools 8.0.5 computer software was used to manipulate the original sound files for the training passage and experimental vignettes to ensure that the recordings were equated for loudness across the stimuli and throughout the passages via root mean squared (RMS) for amplitude. Then Avid Pro-tools 8.0.5 was used to create the two auditory listening conditions.

***The degraded listening condition*.** Using the original sound file the speech was compressed to 65% of the original length, while maintaining normal speech contours so that it sounded naturally fast. A computer algorithm that alters the wave file similar to a sampling technique was used to accomplish this. At a specified rate throughout the sound file, small acoustic bits are deleted equally in the voiced and voiceless segments of the wave file, the remaining sound file is abutted in time, so that the sound file is shorter or 'compressed' relative to its original length. This sample method deletes segments from both words and pauses at a specified rate throughout; the resultant compressed speech retains the temporal patterning of the original speech preserving the pitch and speech prosody (Foulke, 1971).

The enhanced listening condition. Using the original sound file the speech was expanded to 120% of the original length, while maintaining normal speech contours so that it sounded naturally slow. This was again accomplished with a computer algorithm that alters the wave file similar to the sampling-compressing technique. At a specified rate throughout the sound file, small acoustic bits are reiteratively resampled equally in the voiced and voiceless segments of the wave file, the entire sound file is then abutted in time, so that the sound file is longer or 'expanded' relative to its original length. In this way the duration of the speech elements such as vowel duration and silent intervals are lengthened equally throughout; the resultant expanded speech retains again the temporal patterning of the original speech and preserves the pitch and speech prosody (Foulke, 1971).

Speech recordings altered in this way maintain the normal pitch and temporal patterns of the original recordings albeit perceptually faster or slower, however the resultant recordings sound naturally faster or slower (Peelle & Wingfield, 2005). Figure 5 depicts the waveforms of the sentence ‘wash your hands’ from the vignette ‘medipatch’ in its original format, conversational speech technique (196 spm), with clear speech technique (152 spm), at 120% time-expanded (165 spm), and at 65% time-compressed (304 spm)

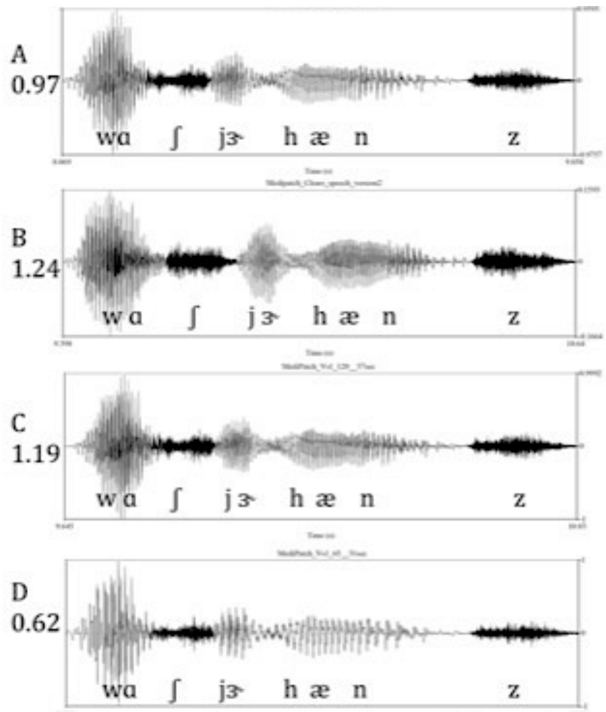

Figure 5. The Praat waveforms: 4 listening conditions. The waveforms depict the phrase "*wash your hands*" from the medipatch vignette. The four listening conditions, from the top: A) in its original format, conversational speech technique (196 spm); B) spoken with clear speech technique (152 spm); C) 120% time-expanded (165 spm); and D) 65% time-compressed (304 spm). Experiment 1 used A and B as the two listening condition. Experiment 2 and 3 used C and D as the two listening conditions. The number below each figure letter (A-D) represents duration of the segments in seconds.

Procedures

Preliminary measures. The same measures that were used in Experiment 1 were used in this experiment.

Vision Screening. All participants demonstrated adequate corrected vision to continue in the experiment. $M_{\text{Far vision}}$ = 25.44, *SD* = 26.51, $M_{\text{Near vision}}$ = 15.66, *SD* = 11.83. ANOVA results confirmed that the two groups differed significantly in far vision abilities F (1, 63) = 4.50, p = .04. The younger group had better far vision $M_{\text{far vision young}}$ = 18.59, *SD* = 10.85 than the older group $M_{\text{far vision older}}$ = 32.28, *SD* = 34.84. The two groups did not significantly differ for near vision. $F\ (1, 63) = 2.72$, $SD = .10$, ($M_{\text{near vision young}} = 13.25$, $SD = 7.55$, $M_{\text{near vision older}} = 18.06$, $SD = 14.67$).

Mini-Mental Status Examination (MMSE). All participants scored well within normal for age and education on the MMSE (Crum, et al., 1993). The scores for Experiment 2, $M_{\text{entire group}} = 29.52$, $SD = .78$, ranged from a minimum score of 27 to a maximum score of 30. Therefore no participant was excluded from this study due to identified pre-existing dementia or cognitive impairment.

Audiometric. No participant was excluded from this study based on audiometric or otoscopic examination. All participants' PB max-MCL was below 90 dBA (the limits of the loudspeakers in the sound booth).

All the procedures from Experiment 2 were the same ones used in Experiment 1 except as described below.

Presentation of the auditory conditions. Participants again were comfortably seated and positioned 1 meter distance and 0 degree azimuth to the speaker within the sound booth.

The degraded listening condition. The time-compressed vignette was presented binaurally at the intensity level identified as the individual's PBmax MCL. The degraded speech vignette (compressed) and competing speech babble noise with a + 5 dB SNR were routed to the speaker at 0 degree azimuth for all participants for that listening condition.

The enhanced listening condition. The time-expanded vignette was presented at the intensity level identified as the individual's PBmax MCL. The enhanced speech vignette (expanded) was presented binaurally via disposable 3A E.A.R.tone™ insert earphones in quiet.

Criteria for learning the vignettes. The participants were instructed that they would have multiple trials to learn the vignettes. The goal was to capture as much of the critical information (37 units) that they could glean, and repeat all that they had heard and remembered after each trial of listening. The participant had met the criteria for completion of learning the vignette when either all of the 37 critical units had been reported; or after 3-consecutive trials in which no increase in critical units had been reported. This criteria for learning was established to equate the two groups for accuracy of learning the vignettes, since the older adults may need more trials of learning to adapt to the degraded listening condition relative to the younger adult group (Peelle & Wingfield, 2005). Only two younger adults (in 4 and 5 trials) and one older adult (in 4 trials) in this experiment reached the max of 37 critical units for the degraded listening condition and only three younger adults (one in 2-trials and two in 4-trials) in the enhanced listening condition. The range of trials to learn the passages was 2-9 trials for the younger adults and 3-10 trials for the older adults. In Experiment 2, the younger and older groups differed significantly for the number of trials to reach criteria, $F(1, 63) = 4.18$, $p = .05$ in the degraded listening, $M_{\text{younger degraded}} = 5.19$ (1.58); $M_{\text{older degraded}} = 6.00$ (1.60); but not in the enhanced listening, $M_{\text{younger enhanced}} = 4.41$ (1.07); $M_{\text{older enhanced}} = 4.78$ (1.16).

Comparing groups on Hearing and Cognitive measures. A series of ANOVAs were used to determine if the two groups differed in hearing-listening or cognitive-linguistic abilities. There were significant differences between the younger and older groups in hearing for the left ear - LPTA4, $F(1, 63) = 30.79$, $p < .001$; and the right ear - RPTA4, $F(1, 63) = 27.90$, $p < .001$ and the listening-in-noise ability - QuickSIN scores, $F(1, 63) = 4.15$, $p = .046$. The older adult group showed the expected poorer hearing in both the left and right ear, and poorer listening-in-noise abilities. There were no significant differences between the groups for perception of hearing handicap - HHIA scores, $F(1, 63) = 1.75$, $p = .19$; or for musicianship scores $F(1, 63) = 0.78$, $p = .38$.

In order to determine if there was a significant difference in hearing between the right and left ears, a paired sample t-test was conducted separately for each group. There were no significant differences between the right ear RPTA4 and left ear LPTA4 for the younger group participants, $t(31) = -0.492$, $p = .63$; or the older group participants, $t(31) = -0.548$, $p = .59$. (see Table 12 for RPTA4 and LPTA4 means and standard deviations; see Figure 1 for audiometric profile data).

A series of ANOVAs were used to determine if the two groups differed in cognitive linguistic abilities such as working memory measured by L-span, executive function as measured by FAS, short-term memory as measured by Backwards Digit span, and lexical access as measured by BNT. Results indicated that there were no significant difference between the younger and older groups in FAS scores, $F(1, 63) = 3.48$, $p = .07$; BNT scores, $F(1, 63) = 0.00$, $p = 1.00$; or backward digit span scores, $F(1, 58) = 2.08$, $p = .16$. However results indicated that there were significant differences between the younger and older participant groups for L-span scores, $F(1, 63) = 21.86$, $p < .001$. The younger adult group demonstrated better working memory capacity reflected by higher

L-span score compared to the older group (see Table 12 for means and standard deviations). Although the younger and older participants did not differ on backward digit span scores, there were 5 missing values (2 in the younger and 3 in the older) due to the computer scoring error as previously described in Experiment 1. Since the missing values most likely reflected poorer backward digit span scores, one fewer poor score in the older group may have artificially inflated the mean in the older participant group.

Self-reported health and education were also examined to determine if the groups differed on these variables. There were no significant differences in the distribution of self-rated health between the younger and older groups, health, χ^2 (2, N = 64) = 1.33, p = .51. However, there were differences in the distribution of self-reported education, χ^2 (4, N = 64) = 16.03, p = .003. The older participants were more educated than the younger participants (see Table 12 for means and standard deviations on demographic, hearing-listening and cognitive-linguistic characteristics, see Figure 1 for audiometric profiles).

Results

Accuracy and consistency of scoring of participant responses

To determine the consistency and accuracy of the coding of the participant sound files for the reported critical units, one paid research assistant, blinded to the listening condition, coded all the participant sound files and then re-coded 20% of the total of the participant files randomly selected from each experiment. A total of 12 participant sound files from Experiment 2, (6 younger and 6 older adults) were recoded. In addition, to ensure that the coding had been done consistently and did not become increasingly strict or lax, of the 12 participants selected, four participant sound files were selected from the beginning, middle and end of the previously coded files. An intra-rater reliability analysis was performed to assess the degree that the coding and recoding of the sound files responses for each participant was consistently captured for the critical units reported. Generally speaking, an ICC value between .75-1.00 is considered excellent (Hallgren, 2012).

Intra-rater reliability. Intra-rater reliabilities for coding of blinded scoring were assessed using intra-class correlation coefficient with a two-way mixed effects model and absolute agreement type (Shrout & Fleiss, 1979). The intraclass correlation coefficient (ICC) for single measures for the reported-recalled critical units for each trial was .99.

Inter-rater reliability. An inter-rater reliability analysis for coding of blinded scoring was performed to assess the degree that the coding and recoding of the sound files responses for each participant could be easily and consistently captured by a second rater. To determine the consistency of the coding of the participants sound files for the reported critical units, a second paid research assistant blinded to the listening condition, coded 10% of the total of the participant files, six participants. None of the re-coded sound files used for the intra-rater reliability was used for this analysis. The intraclass correlation coefficient (ICC) for single measures for the reported-recalled critical units for each trial was .97.

The ICC values reported here are between .97-.99, therefore the intra-rater and inter-rater reliability analysis demonstrates excellent consistency in coding (Cicchetti, 1994). The high ICC for both the intra-rater and inter-rater reliabilities suggests that minimal amount of measurement error is introduced by the coding of the participants' sound files. The original scores for the participants were therefore considered appropriate for use in the hypothesis tests for this study.

Order of the Experiment effects.

There were 8 different orders in which the participants completed the experiment (i.e., EmA/DpB; EmB/DpA; EpB/DmA; EpA/DmB; DmA/EpB; DmB/EpA; DpB/EmA; DpA/EmB as explained previously). Participants were randomly assigned to one of the counterbalanced orders. To determine whether the order of the experiment affected the participant's learning efficiency, immediate, and delayed memory performance, a series of mixed design ANOVAs were conducted.

Learning efficiency performance was analyzed with a 2 (listening condition: degraded vs. enhanced) x 2 (listen order: degraded first vs. enhanced first) x 2 (passage order: medipatch first vs. puffer first) x 2 (interference/filler task set order: Set A first vs. Set B first) mixed factors ANOVA, with listening condition as a within-subjects factor, and the three order variables as between-subjects factors. This was conducted for each of the dependent variables separately (i.e., learning efficiency, immediate memory and delayed memory). (see Table 13 for all F and p values).

Table 13

Experiment 2: Order Effects and Interactions

Variables and Interactions	*F* (1, 56)	*p*
Learn Efficiency		
Listening Condition	28.52	***<.001**
Listening Condition * Listening Order	6.92	***.01**
Listening Condition * Passage Order	0.82	.37
Listening Condition * Interference Order	0.41	.52
Listening Condition * Passage Order * Listen Order	2.60	.11
Listening Condition * Passage Order * Interference Order	0.09	.76
Listening Condition * Listen Order * Interference Order	4.00	.05
Listening Condition * Passage Order * Listen Order * Inter Order	0.19	.66
Immediate Memory		
Listening Condition	11.55	***.001**
Listening Condition * Listen Order	0.02	.90
Listening Condition * Passage Order	1.24	.27
Listening Condition * Interference Order	0.96	.33
Listening Condition * Listen Order * Passage Order	0.35	.56
Listening Condition * Listen Order * Interference Order	.004	.95
Listening Condition * Listen Order * Passage Order	0.15	.70
Listening Condition *Listen Order*Passage Order* Inter Order	0.15	.70
Delayed Memory		
Listening Condition	13.82	***<.001**
Listening Condition * Listen Order	0.96	.33
Listening Condition * Passage Order	0.86	.36
Listening Condition * Interference Order	1.18	.29
Listening Condition * Listen Order * Passage Order	0.01	.96
Listening Condition * Listen Order * Interference Order	2.40	.13
Listening Condition * Passage Order * Interference Order	0.13	.72
Listening Condition *Listen Order*Passage Order*Interference Order	0.01	1.00

Note. * ***p*** value bolded denotes significance

Order of experiment effects - learning efficiency. Learning efficiency was operationally defined and calculated as the number of critical units learned-per-trial, calculated for each participant by summing the total amount of the critical units reported at each of the trials, divided by the number of trials to reach criteria for that listening condition. Criteria were established a priori as either 100% reporting of the 37 critical units; or if the participant demonstrated no increase in reporting of the critical units over 3 consecutive trials. In this way there was a single value for the learning efficiency during the degraded listening, and a single value for the learning efficiency during the enhanced condition. More efficient learning would be reflected as a higher value, in which more of the units were learned over fewer trials.

There were no significant effects of order or interactions for passage (e.g., medipatch vs. puffer) or task set (e.g., Set A vs. Set B) on Learning efficiency (see Table 13 for *F* and *p* values).

However, there was a significant 2-way interaction between listening condition order (e.g. degraded-enhanced vs. enhanced-degraded) and listening condition on learning efficiency, $F(1, 56) = 6.92$, $p = .01$. The learning was more efficient during the second listening condition compared to the first listening condition in both the degraded listening condition, $M_{\text{degraded listening 1st}} = 22.42$, $SD = 5.50$, $M_{\text{degraded listening 2nd}} = 23.55$, $SD = 5.9$; and the enhanced listening condition, $M_{\text{enhanced listening 1st}} = 25.06$, $SD = 4.41$, $M_{\text{enhanced listening 2nd}} = 26.85$, $SD = 4.10$. As a result of the significant interaction between order of listening condition and learning efficiency, listening order was entered as a covariate for further hypothesis testing for the differences of learning efficiency between the younger and older groups in the degraded and enhanced listening conditions.

Order of experiment effects - immediate memory performance. Immediate memory performance was operationally defined and calculated as the sum of the critical units immediately reported for any of the trials of listening-recall prior to the filler tasks for each listening condition (i.e., the total sum of 'new' critical units reported were tallied for all the trials of learning until the criteria was met). The summed total of each 'new' critical unit reported during all of the trials resulted in the immediate memory performance for that listening condition. The maximum possible for recall was 37 critical units for each passage.

Results indicated that there was no significant effect of order or interactions of order on immediate memory performance (see Table 13 for *F* and *p* values).

Order of experiment effects - delayed memory performance. Delayed memory performance was operationally defined and calculated as the total number of the critical units reported after completion of the interference tasks (20 minutes). The maximum possible for recall was 37 critical units for each passage. Results showed there was no significant effect of order or interactions of order on delayed memory performance (see Table 13 for *F* and *p* values).

Degraded and Enhanced Listening affect learning and memory performance by group

According to the effortfulness hypothesis, more resources will be expended for learning and recall during the difficult-degraded listening relative to the enhanced easy listening. The prediction is that the more effortful or difficult the listening condition the less efficient learning and a fewer number of critical units recalled.

Learning efficiency. In order to evaluate how the degraded and enhanced listening condition affected learning efficiency and whether the listening condition differentially affected learning efficiency for the younger and older groups, a mixed design repeated measures ANOVA was used. Listening-order was entered as a covariant.

The learning efficiency scores were analyzed with a 2 (age: younger, older) X 2 (listening condition: degraded, enhanced) mixed design ANOVA in which listening condition was entered as the repeated measure within-subject variable and age group was a between-subject variable. There was a significant main effect of listening condition, $F(1, 61) = 17.83$, $p < .001$. Degraded listening (time-compressed + noise) resulted in less efficient learning $M_{degraded} = 22.99$, $SD = 5.69$ than in the enhanced listening (time-expanded), $M_{enhanced} = 25.96$, $SD = 4.32$, with the listening enhancement improving learning efficiency on average by nearly 2 more critical units per trial. There was a significant main effect of age group, $F(1, 61) = 26.75$, $p < .001$. The younger adult group demonstrated overall more efficient learning $M_{younger} = 26.92$, $SD = 3.43$ than the older adult group, $M_{older} = 22.03$, $SD = 5.16$. The younger group's learning efficiency was nearly 5 more critical units learned on average per trial compared to the older group's learning efficiency.

In addition, there was a significant Learning efficiency X Age group interaction, $F(1, 61) = 4.30$, $p = .04$. Compared to the older adult group, the younger adults were more similar in their learning efficiency for the degraded $M_{younger} = 26.01$, $SD = 3.66$, and enhanced listening condition $M_{younger} = 27.83$, $SD = 3.21$, a difference of 1.82 units. The older adult group demonstrated a larger difference of 4.11 units for learning efficiency between the degraded $M_{older} = 19.97$, $SD = 5.80$ and enhanced listening condition $M_{older} = 24.08$, $SD = 4.52$.

Both younger and older adults were more efficient in learning, in that they recalled more units per trial when they learned during the enhanced listening condition.

The older adult group's learning efficiency was more affected by the differences in listening condition, in that they either benefitted more so from the enhancements and/or were more negatively affected by the degraded condition.

Immediate memory. In order to evaluate how the degraded and enhanced listening condition affected immediate memory and whether the listening condition differentially affected immediate memory performance for the younger and older groups, a mixed design repeated measures ANOVA was conducted.

The immediate memory scores were analyzed with a 2 (age: young, older) X 2 (listening condition: degraded, enhanced) mixed ANOVA in which listening condition was entered as the repeated measure within-subject variable and age was a between-subject variable. There was a significant main effect of listening condition, F (1, 62) = 13.60, $p < .001$. Degraded listening resulted in fewer recalled critical units M_{degraded} = 31.23, SD = 4.77 relative to more critical units reported in the enhanced listening M_{enhanced} = 32.86, SD = 3.09, demonstrating that listening enhancements improved immediate recall on average by 1.63 critical units. There was a significant main effect of age group, F (1, 62) = 22.57, $p < .001$. The younger group demonstrated overall better immediate memory performance M_{younger} = 33.88, SD = 2.38 than the older group, M_{older} = 30.22, SD = 4.32. The younger group immediately recalled 3.66 more critical units compared to the older group's immediate recall.

In addition, there was a significant listening condition by age group interaction, F (1, 62) = 7.26, p =.009. Younger adults were more similar in their immediate recall for the degraded M_{young} = 33.66, SD = 2.65, and enhanced listening condition M_{young} = 34.09, *SD* = 2.10, a small difference of only 0.44 units recalled. The older adult demonstrated a larger difference of 2.82 units reported for immediate recall between the degraded M_{older} = 28.81, *SD* = 5.21 and enhanced listening condition M_{older} =31.63, *SD* = 3.43 (see Figure 6).

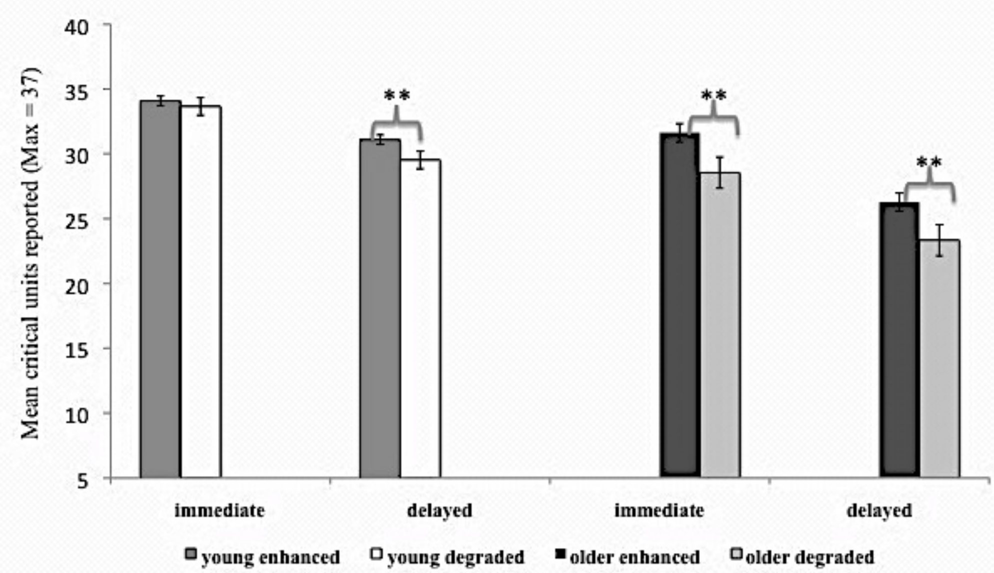

Figure 6. Experiment 2: Immediate and delayed memory performance in enhanced (120% time-expanded in quiet) and degraded (65% time-compressed in noise) listening conditions for younger and older adult groups. Error bars are standard error of the mean. ** p <.01.

Immediate recall by trials 1-5: older listening as if they are younger and younger listening as if they are older. In order to evaluate how immediate recall performance was affected for the condition in which the younger group listened as if they were older and the older group listened as if they were younger, a new variable was coded for each of the immediate recall learning trials 1 to 5.

The younger adults' immediate recall score for trial 1 in the degraded condition, and the older adults' immediate recall score for trial 1 in the enhanced condition was re-coded into a separate variable as ‘degraded-enhanced-trial 1’. Similarly trials 2-5 were recoded in this manner.

These 5 re-coded variables were entered into a one-way ANOVA to compare the means of the immediate recall memory performance between the younger and older group per trial. There were no significant differences in immediate memory performance between the younger and older groups for any of the 5 trials (see Table 14 for means, standard deviations and F and p values). These results demonstrate that when the younger adults listen as if they were older (in the degraded listening condition) and when older adults listen as if they were younger (in the enhanced listening condition) their immediate recall on the first trials 1-5 did not differ (see Figure 7).

Table 14

Experiment 2: Immediate memory by trial (1-5) for Younger Adults in degraded listening and Older Adults in enhanced listening

	Younger[a]		Older[b]		ANOVA	
Degraded-Enhanced	*M*	(*SD*)	*M*	(*SD*)	*F*	*p*
Immediate Memory:						
Trial 1	15.93	(6.87)	14.43	(5.30)	0.96	.33
Trial 2	23.53	(6.10)	20.75	(6.24)	3.25	.08
Trial 3	26.50	(5.70)	24.78	(6.06)	1.37	.25
Trial 4	28.03	(5.48)	26.41	(5.85)	1.32	.26
Trial 5	28.93	(4.50)	26.52	(5.45)	3.55	.06

Note. *M* = mean, (*SD*) = standard deviation. [a] Young adult group performance in degraded listening condition - the number of critical units reported when listening during the 65% time-compressed with +5 dB speech babble Noise. [b] Older adult group performance in enhanced listening condition - the number of critical units reported when listening during the 120% time-expanded in quiet.

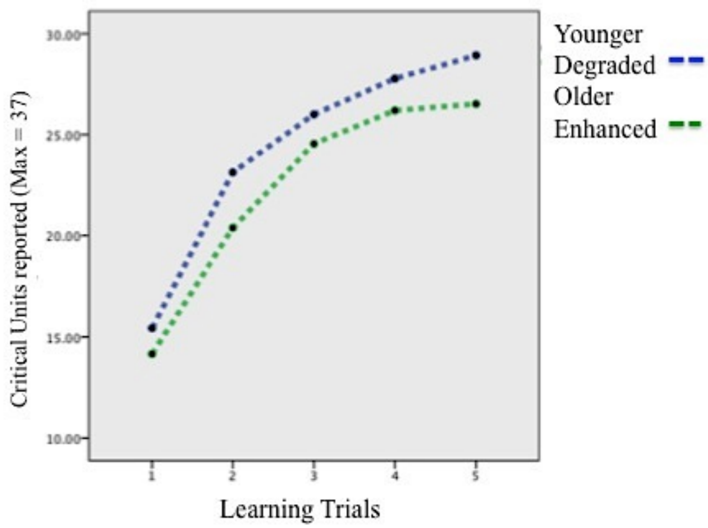

Figure 7. Experiment 2: Mean scores for the immediate recall for trials 1-5. The younger participants listening as if older (i.e., degraded: 65% time-compression with +5 dB SNR speech babble noise) and older participants listening as if younger (enhanced: 120% time-expanded in quiet).

Delayed memory. In order to evaluate how the degraded and enhanced listening conditions affected delayed memory and whether the listening condition differentially affected delayed memory performance for the younger and older groups, a mixed design repeated measures ANOVA was used.

The delayed memory scores were analyzed with a 2 (age: young, older) X 2 (listening condition: degraded, enhanced) mixed design ANOVA in which listening condition was entered as the repeated measure within-subject variable and age was a between-subject variable. There was a significant main effect of listening condition, F (1, 62) = 14.23, $p < .001$. Degraded listening resulted in fewer recalled critical units M_{degraded} = 26.44, SD = .6.35, relative to higher number of critical units recalled in the enhanced listening M_{enhanced} = 28.69, SD = 5.01, demonstrating that listening enhancements improved delayed recall on average by 2.25 critical units. There was a significant main effect of age F (1, 62) = 24.63, $p < .001$. Older adults recalled fewer critical units overall M_{older} = 24.81, SD = 5.97, relative to the younger adults, $M_{younger}$ = 30.31, SD = 3.79, for delayed recall on average by 5.50 less critical units reported.

There was no significant listening condition by age group interaction, F (1, 62) = 1.33, p = .25. These findings indicate that the older adults were not differentially affected in delayed memory between the two listening conditions. When older and younger listen in difficult degraded listening conditions, they are similarly affected, so that they recall fewer critical units relative to their delayed recall in the enhanced listening condition.

These findings demonstrate that the younger adult group continued to perform significantly better for delayed recall in both listening conditions when compared to the older group. The enhancements for the older adults' listening did not bring the groups' delayed memory performance together sufficiently, in that the scores continue to remain different.

Although these scores remained significantly different, the groups' means for delayed recall were consistent with the expected pattern for recall performance in respect to the listening difficulty or effort expended. In other words, the younger adults with normal hearing in the enhanced listening condition demonstrated the highest recall performance whereas the older adults with ARHL while listening in the degraded listening showed the worse recall performance as follows: $M_{young\ enhanced}$ = 31.09, SD = 3.60, $M_{young\ degraded}$ = 29.53, SD = 3.98, $M_{older\ enhanced}$ = 26.28, SD = 5.13, $M_{older\ degraded}$ = 23.34, SD = 6.81.

These two middle values $M_{\text{young degraded}} = 29.53$, $SD = 3.98$, $M_{\text{older enhanced}} = 26.28$, $SD = 5.13$ demonstrate the delayed memory performance when the older adults are listening as if they are younger, and the younger adults are listening as if they are older. These values continue to remain significantly different, $t(62) = 2.83$, $p = .006$.

These results show that the younger participants continued to perform significantly better than the older participants with the older adults demonstrating a larger variability in their performance, noted by larger standard deviations.

Table 15

Experiment 2:Younger and Older groups for Learning Efficiency, Immediate and Delayed Memory Performance in Degraded and Enhanced listening conditions.

	Younger		Older		Total	
Dependent variable	*M*	(*SD*)	*M*	(*SD*)	*M*	(*SD*)
Learning Efficiency						
Degraded[a]	26.01	(3.66)	19.97	(5.80)	22.99	(5.69)
Enhanced[b]	27.83	(3.21)	24.08	(4.52)	25.96	(4.32)
Immediate Memory						
Degraded[a]	33.66	(2.65)	28.81	(5.21)	31.23	(4.77)
Enhanced[b]	34.10	(2.10)	31.63	(3.43)	32.86	(3.09)
Delayed Memory						
Degraded[a]	29.53	(3.98)	23.34	(6.81)	26.44	(6.35)
Enhanced[b]	31.09	(3.60)	26.28	(5.13)	28.69	(5.01)

Note. *M* = mean, (*SD*) = standard deviation. [a] degraded listening: 65% time-compressed speech in noise (speech babble at + 5 dB SNR,) presented via loud speaker, reported in number of critical units. [b] enhanced listening: 120% time-expanded speech in quiet presented via insertion earphones reported in number of critical units.

Figure 6 depicts the pattern for the immediate and delayed memory performance by group and listening condition. The younger and the older groups demonstrated better immediate and delayed recall in the enhanced listening compared to degraded listening (see Table 15 for means and standard deviations for the three dependent variables for both groups).

Delayed memory performance and the relationship with Hearing-Listening and Cognitive-Linguistic abilities

Correlational analyses were conducted to further explore the relationships between the individual's hearing-listening abilities and cognitive-linguistic characteristics and delayed memory performance in the degraded and enhanced condition. Those variables that reflected the hearing-listening ability as it relates to ARHL included in this analysis were LPTA4 and RPTA4, QuickSIN scores, HHIA and musicianship score. The variables that reflected the cognitive-linguistic characteristics that may be associated with memory performance included in this analysis were as follows: auditory working memory capacity as measured by L-span, executive function measured by verbal fluency task (FAS), lexical access ability as measured by the word retrieval-picture naming task (BNT), and auditory short term memory measured by the backward digit span. The memory measures that were included in these correlation analyses were the delayed memory performance in the degraded (time-compressed in noise) and in the enhanced (time-expanded in quiet) listening condition. These relationships were examined separately for the older and the younger adult groups (see correlation Tables 16, 17, 18).

Table 16

Correlation analysis between delayed memory performance and hearing and cognitive abilities - Experiment 2 Both Groups

	Del.Mem.Deg	Del.Mem.Enh	LPTA4	RPTA4	HHIA	QuickSIN	Musician	L_Span	Digits_Back	FAS
Del.Mem.Enh	.67**									
LPTA4	-.63**	-.56**								
RPTA4	-.56**	-.44**	.91**							
HHIA	-.13	-.09	-.34**	.41**						
QuickSIN	-.37**	-.39**	.39**	.44**	.25*					
Musician	.30*	.17	-.10	-.03	.32**	-.09				
L_Span	.66**	.56**	-.55**	-.48**	-.09	-.37**	.24			
Digits_Back	.47**	.50**	-.38**	-.28*	-.12	-.32*	.21	.54**		
FAS	.33**	.24	-.42**	-.40**	-.11	-.34**	.08	.35**	.45**	
BNT	.33**	.39**	-.12	-.09	-.02	-.20	.20	.18	.40**	.16

Note. Del.Mem.Deg = Delayed Memory Degraded, Del.Mem.Enh = Delayed Memory Enhanced, HHIA = Hearing Handicapped Inventory for Adults (HHIA), Digit Back = Backward Digit Span.
*$p < .05$, **$p < .01$

Hearing-listening characteristics. The results of the correlation analysis for the relationship between delayed memory performance and each of the individual variables that may contribute to listening effort are described below.

LPTA4 and RPTA4: left and right ARHL and delayed memory performance. There were significant negative correlations for the LPTA4 for the older group in the degraded, r = -.54, p = .001, and enhanced, r = -.46 p = .008 listening condition, and for the RPTA4 in the degraded, r = -.48 p = .006 but not in the enhanced, r = -.31 p = .09 listening condition. Right and left ear ARHL was negatively associated with delayed memory performance in the degraded listening condition. Left ear ARHL was negatively associated with delayed memory performance in the enhanced condition.

There were no significant correlations for the LPTA4 or RPTA4 for the younger group in the degraded or the enhanced condition (see Table 17 for r, and p values). All the significant values reported above would be considered between a medium to large effect size (Cohen, 1992). These results were in the expected negative direction and suggest that ARHL as measured by LPTA4 and RPTA4 is negatively correlated with delayed memory performance for older adults. The lack of significant findings for a relationship of ARHL and delayed memory performance in the younger group was the expected finding, since the younger adults did not demonstrate ARHL (see Table 12 for hearing characteristics by group; see Figure 1 for audiometric profiles of the groups).

In addition to the significant negative relationship of ARHL (LPTA4 and RPTA4) and delayed memory performance for the older adults, there was a greater magnitude of the effect size for the correlation between ARHL and delayed memory performance in the left ear relative to the right ear in the degraded listening condition. There was also a greater magnitude of the effect size for the correlation between left ear ARHL and delayed memory in the degraded listening relative to the enhanced listening condition. The magnitude of the effect size for the relationship for the right ear ARHL and delayed memory performance in the enhanced listening was the smallest, and was not significant.

These results suggest that when the listening condition was enhanced, the negative correlation between ARHL and delayed recall decreased. In addition, these findings suggest that the negative correlation between ARHL and delayed memory performance was greater in magnitude in the left ear compared to the right ear.

These findings are consistent with other electrophysiological and behavioral studies that examine dichotic listening in both younger and older adults. An inter-aural asymmetry between auditory perception and/or processing, known more commonly as either the right ear advantage REA or a left ear disadvantage LED, has been previously identified in the literature and found in all age groups (Jerger & Lew, 2004; Jerger & Martin, 2004). This REA appears to be one of a temporal nature. Electrophysiological responses as measured by auditory event-related potentials (AERP), demonstrate approximately a 46 ms advantage of the right ear, which is the latency of response between the left ear in relationship to the right ear. Perhaps this finding of a REA or LED suggests that temporal resolution of the target is further enhanced by the REA, effectively a 46 ms head start over the left ear for linguistic processing (Jerger & Martin, 2005; Jerger & Reagor, 2012; Mehta, Jerger, Jerger, & Martin, 2009). However since this experiment was not designed to test REA or LED any explanations of the above statistical finding would be purely speculative.

HHIA: self-perception of hearing handicap and delayed memory performance. The Hearing Handicap Inventory for Adults (HHIA) may capture aspects of hearing beyond poor auditory acuity, such as listening effort, cognitive abilities and self-efficacy for hearing handicap (CHABA, 1988).

First, a correlation analysis was used to determine if the perception of hearing handicap measured by the HHIA, significantly correlated with QuickSIN and LPTA4 and RPTA4 for the younger and older participants in this study. There were no significant correlations for the HHIA scores and LPTA4, RPTA4 and QuickSIN scores in the younger group (see Table 17 for *r*, and *p* values). This was expected as the younger adults did not demonstrate hearing loss. However, for the older adult participants the results indicated that HHIA scores significantly correlated with LPTA4, $r = .46$, $p = .008$; with

RPTA4, $r = .53$, $p = .002$ and with QuickSIN, $r = .47$, $p = .007$; (see Table 18 for *r* and *p* value).

Table 17

Correlation analysis between delayed memory performance and hearing and cognitive abilities - Experiment 2 Younger Group

	Del.Mem.Deg	Del.Mem.Enh	LPTA4	RPTA4	HHIA	QuickSIN	Musician	L_Span	Digits_Back	FAS
Del.Mem.Enh	.43*									
LPTA4	-.31	-.21								
RPTA4	-.01	.002	.59**							
HHIA	.26	.27	-.13	-.12						
QuickSIN	-.12	-.32	-.18	-.05	-.15					
Musician	.22	.17	-.27	-.19	.29	-.08				
L_Span	.33	.38*	-.32	-.10	.09	-.28	.15			
Digits_Back	-.04	.26	-.18	.04	.09	-.27	.31	.35		
FAS	-.21	.05	-.25	-.18	.06	-.13	-.03	.16	.41*	
BNT	-.23	.01	.09	-.29	.03	-.27	.30	-.32	.09	.23

Note. Del.Mem.Deg = Delayed Memory Degraded, Del.Mem.Enh = Delayed Memory Enhanced, HHIA = Hearing Handicapped Inventory for Adults (HHIA), Digit Back = Backward Digit Span.
**p* < .05, ***p* < .01

To determine if perception of hearing handicap (HHIA) scores were associated with delayed memory performance a correlation analysis was used. As expected there were no significant correlations for the HHIA scores for the younger group in the degraded, $r = .26$, $p = .16$, or for the enhanced, $r = .27$, $p = .14$ listening condition. However, there were no significant correlations for the HHIA scores for the older group in the degraded, $r = -.19$, $p = .29$, or for the enhanced, $r = -.17$, $p = .37$ listening condition. The perception of hearing handicap (HHIA) did not correlate with delayed memory performance for degraded or enhanced listening in the older adult group despite the fact that the perception of hearing handicap (HHIA) measure correlated with the other hearing measures (LPTA, RPTA and QuickSIN) in the expected ways in this group of older adults. Although the correlations for the older adults did not reach significance, the weak correlation was in the expected negative direction and the magnitude further decreased in the enhanced listening relative to the degraded listening.

QuickSIN: listening-in-noise ability and delayed memory performance. There was a significant negative correlation for the QuickSIN scores for the older group in the degraded, *r* = -.39, *p* = .03, but not in the enhanced, *r* = -.31 *p* = .08 listening condition.

There were no significant correlations for the QuickSIN scores and delayed recall performance in the younger group in the degraded or the enhanced condition (see Tables 16 and 17 for *r*, and *p* values).

The older adult group's correlations reported above (.39 and .31), demonstrate a medium effect size for the relationship between listening-in-noise ability (measured by QuickSIN) and delayed recall performance (Cohen, 1992). Again, the magnitude of the effect size became smaller (and non-significant) when the listening condition was more favorable, that is in the enhanced condition relative to the degraded condition.

Musicianship scores: temporal processing ability and delayed memory performance. When the entire group was analyzed there was a significant positive correlation for musicianship scores and memory performance in the degraded listening, *r* = .30, *p* = .02, but not in the enhanced listening, *r* = .17 *p* = .17 condition. When the younger and older groups were examined separately for musicianship and delayed memory performance the results showed that there were no significant correlations for delayed memory performance in both the older group in the degraded, *r* = .33, *p* = .07, and enhanced, $r = .12$ $p = .52$ listening condition, or for the younger group in the degraded, $r = .22$ $p = .24$ and the enhanced, $r = .17$ $p = .36$ listening condition.

Although the correlations did not reach significance in the smaller sample size when the groups were examined separately, the significant correlation reported for the entire group in the degraded listening would be considered a medium effect size (Cohen, 1992). These results suggest that musicianship scores, and possibly this cohort's better temporal-spectral processing ability, has a medium positive relationship with delayed memory performance particularly in the more difficult or degraded listening condition. This finding is consistent with the literature that has examined the relationship between musicianship, temporal processing, auditory attention and auditory memory abilities (Kraus & Chandrasekeran, 2010; Zendel & Alain, 2012; Zendel & Alain, 2013; Zendel & Alain, 2014). The relationship between musicianship, temporal-spectral processing, and memory performance will be examined further in Experiment 3.

It was still possible that using MCL in dB HL and not an absolute sensation level for the presentation of the stimuli, may have influenced the results of the delayed memory performance, even though there were no differences in sensation levels (db SL) between the Younger and Older groups. In regards to the older individuals with greater ARHL, MCLs reflecting lower sensation levels may be indicating an intolerance to the greater signal intensity (i.e., the sound is uncomfortably loud) and consequently the stimuli had to be presented at a quieter level than was optimal for one listening condition but perhaps not both listening conditions. If this were the case then the expectation would be that the sensation level should significantly correlate with the delayed memory performance. To further examine this possibility a correlation analyses between the sensation levels in dB SL and delayed memory performance in the degraded and enhanced listening condition were conducted for the entire sample. There were no significant correlations between sensation level presentation of the stimuli and delayed memory performance in either the conversational or clear speech listening for the participants in this experiment (see Table 11 for *r* and *p* values).

Cognitive-linguistic abilities. The results of the correlational analysis for the relationship between delayed memory performance and each of the individual variables that may contribute to listening effort are described below**.**

L-span: working memory ability and delayed memory performance. There were significant positive correlations for the L-span scores and delayed memory performance for the older adult group in the degraded, $r = .64$, $p < .001$, and in the enhanced, $r = .43$, $p = .02$ listening condition.

There were significant positive correlations for the L-span scores and delayed memory performance for the younger group for the enhanced, $r = .38$, $p = .03$ but not for the degraded, $r = .33$, $p = .07$ listening condition.

All the significant values would be considered between a medium to large effect (Cohen, 1992). The magnitude of that effect decreases when the listening condition is more favorable for the older adult. However, the opposite occurs for the younger adult group, the magnitude of the effect size increases when the listening condition is more favorable. This finding is consistent with a dissociation of younger and older adults for the relationship of working memory and delayed memory performance by listening condition.

In the younger group, there were no other significant correlations of cognitive-linguistic scores (e.g. BNT, FAS, and Digits Backwards) and delayed memory performance in either listening condition (see Table 17 for *r* and *p* values).

Backward digit span: short-term memory ability and delayed memory performance. There were significant positive correlations for the backward digit span scores and delayed memory performance for the older group in the degraded, $r = .74$, $p < .001$, and for the enhanced, $r = .63$, $p < .001$ listening condition. There were no significant correlations for the backward digit span scores and delayed memory performance for the younger group for either listening condition (see Tables 17 and 18 for *r* and *p* values).

All the above values would be considered a large effect size (Cohen, 1992). The magnitude of that effect became smaller when the listening condition was more favorable for the older adult.

FAS: executive function ability and delayed memory performance. There was a significant positive correlation for the FAS scores for the older group in the degraded, $r = .49$, $p = .005$, but not for the enhanced, $r = .20$, $p = .27$ listening condition. There were no significant correlations for the FAS scores for the younger group for either listening condition (see Tables 17 and 18 for *r* and *p* values).

Thus there was a medium-large effect size for the relationship between executive function and delayed memory performance (Cohen, 1992). The magnitude of that effect became smaller (and non-significant) when the listening condition was more favorable for the older adult.

Boston Naming Test (BNT): lexical ability (naming/verbal fluency) and delayed memory performance. There were significant positive correlations for the BNT scores and delayed memory performance for the older group in the degraded, $r = .58$, p = .001, and the enhanced, $r = .62$, p < .001 listening condition. There were no significant correlations for the BNT scores and delayed memory performance for the younger group for either listening condition (see Table 17 for *r* and *p* values).

The above values would be considered a large effect size (Cohen, 1992). The magnitude of that effect became larger when the listening condition was more favorable (i.e., enhanced condition) for the older adult.

Summary of results. The relative degrading (time-compressed in noise presented in the sound field) or relative enhancing (time-expanded in quiet presented through insertion earphones) of the listening condition affected learning and memory performance in both the younger and older adult groups. It should be noted that there was no listening condition, which could be inferred as the absolute baseline of learning and memory performance for participants in this experiment (i.e., a listening condition which suggests neither degrading or enhancing, such as the passages produced with a more typical conversational speech rate with the audibility set at MCL in sound field listening with and/or without competing background noise). However, without a baseline performance as comparison, it is hard to determine whether the two listening conditions created an absolute degradation effect, an absolute enhancement effect or both. For this reason, in this study, describing enhancing or degrading effects are relative to each other. The degraded listening condition resulted in poorer learning and memory (*a degradation effect*) and enhanced listening improved learning and memory (*an enhancement effect)* in both the younger and older groups. The older adult group demonstrated less efficient learning, and recalled fewer critical units for immediate and delayed memory as compared to the younger adult group. When compared to the younger adults, the older adult group either benefitted more so from the enhanced listening condition or were more negatively affected by the degraded listening condition or both, in that they demonstrated a greater difference in memory performance for the two listening conditions.

Hearing-listening and cognitive-linguistic characteristics were correlated with delayed memory performance for the older adult group. Specifically in relationship to hearing characteristics for the older adult group, ARHL measured by LPTA4 and RPTA4 was negatively associated with delayed memory performance in the degraded listening condition. Enhancements to the listening condition decreased the magnitude of this negative association of ARHL and delayed memory performance for both the left and right ear with a greater magnitude of the negative association of age-related hearing loss and delayed memory performance in the left ear (LPTA4) relative to the right (RPTA4).

Better listening-in-noise (QuickSIN), and musicianship scores (perhaps temporal processing abilities) correlated positively with delayed memory performance. There were no significant correlations between the Hearing Handicap Inventory for adults (HHIA) and memory performance in either listening condition for the older adult group (see Table 18 for *r* and *p* values).

Table 18

Correlation analysis between delayed memory performance and hearing and cognitive abilities - Experiment 2 Older Group

	Del.Mem.Deg	Del.Mem.Enh	LPTA4	RPTA4	HHIA	QuickSIN	Musician	L_Span	Digits_Back	FAS
Del.Mem.Enh	.63**									
LPTA4	-.54**	-.46**								
RPTA4	-.48**	-.31	.92**							
HHIA	-.19	-.17	.46**	.53**						
QuickSIN	-.39*	-.32	.52**	.53**	.47**					
Musician	.33	.12	.05	.11	.39*	-.05				
L_Span	.64**	.43*	-.40*	-.33	-.06	-.29	.27			
Digits_Back	.74**	.63**	-.43*	-.32	-.24	-.29	.10	.66*		
FAS	.49**	.20	-.42*	-.41*	-.16	-.41*	.12	.35	.44*	
BNT	.58**	.62**	-.21	-.08	-.05	-.19	.16	.41*	.58**	.14

Note. Del.Mem.Deg = Delayed Memory Degraded, Del.Mem.Enh = Delayed Memory Enhanced, HHIA = Hearing Handicapped Inventory for Adults (HHIA), Digit Back = Backward Digit Span.
$^*p < .05$, $^{**}p < .01$

There were no significant correlations of hearing-listening characteristics (e.g., LPTA 4, RPTA4, QuickSIN, HHIA) and delayed memory performance in either listening condition for the younger adult group (see Table 17 for *r* and *p* values). These were the expected findings since the younger adult group did not demonstrate significant hearing loss, self-perceived hearing handicap, or listening-in-noise difficulties (see Table 12 for hearing characteristics means and SD).

In relation to cognitive-linguistic characteristics, there were significant positive relationships with delayed memory performance in the older adult group in the degraded listening condition. The magnitude of the effect size was medium to large for the relationship of delayed memory performance and working memory, short-term memory, executive function, and lexical abilities in the degraded listening condition.

The magnitude of the effect size of cognitive-linguistic characteristics and delayed memory performance decreased in the enhanced listening condition compared to the degraded listening condition. These findings suggest that for the older adults, when listening was degraded and hence more effortful, the memory performance was more positively associated with strengths in working memory, short-term memory, executive function, and lexical abilities.

Discussion

Learning-Practice Effects: Order of listening condition and learning and memory performance

The significant interaction between the order of the presentation of the listening condition (i.e., degraded-enhanced vs. enhanced-degraded) and listening condition on the learning efficiency measure is consistent with the expected *learning-practice effect*.

In this study, as was the case in Experiment 1, the order in which the participant experienced the listening condition interacted with the *degradation effect* and the *enhancement effect* by effectively decreasing the relative degradation effect and increasing the relative enhancement effect.

For example, when the degraded listening condition (compressed in noise) was experienced as the second listening condition, the learning effect reduced the degradation effect, as those participants had the benefit of learning how to do the task first in the enhanced listening condition (expanded in quiet), perhaps were less anxious, and perhaps were able to generate and employ a strategy for learning and remembering. When the enhanced listening condition was experienced as the 2nd listening condition, the learning effect further increased the enhancement effect, as those participants had the extra benefit of the learning effect as well as the enhanced listening.

The observed learning effect was expected due to the nature of the within-subject learn-relearn experimental design. Despite the learning effect and the interaction of listening condition, there remained a significant main effect of listening condition on learning efficiency. The learning efficiency for the enhanced listening condition was more efficient, than the degraded listening condition. Participants were randomly assigned and the order of the experiment was counterbalanced to control for this expected and observed learning effect.

There are at least two ways to consider this finding of learning effect and its interaction with the listening condition on learning efficiency in this experiment. First, what may this interaction mean in terms of the effect that the learning effect had on the participants' performance in this study? Second, how may the interaction of the listening condition and learning effects influence the older adult's memory performance in the real-world listening environment?

In this study, the listening condition (degraded vs. enhanced) and the order of the listening condition (first task versus second task of listening-learning) interacted in such a way that this results in a differential affect on learning/practice effects. That is that the difference between the enhanced listening condition second – enhanced listening condition first was significantly greater than the difference between degraded listening condition second – degraded listening condition first). Perhaps, while listening in adverse conditions (i.e., degraded listening), with multiple external or internal sources of degradation to the stimuli (Mattys et al., 2012), the distorted stimuli then decreased the stability for auditory processing (i.e., mapping sub-lexical acoustic information to lexical features). A highly variable target stimulus could have negatively affected the perceptual learning of the speakers' pattern, in that it created a relatively *novel listening-learning experience*. This then resulted in a smaller practice/learning effect for the degraded listening condition relative to the enhanced listening condition. (i.e., a smaller difference between degraded 1st task and degraded 2nd than the difference between enhanced 1st task and enhanced 2nd task).

Similarly, perhaps the enhancements to the auditory message decreased both the external and internal sources of degradation that further distort the target stimulus. The auditory processing then was able to efficiently operate, mapping sub-lexical acoustic information to lexical features. It is possible that more stable auditory perception and processing of the target effectively reduced the variability, resulted in the listening situation being more familiar and similar to other previous *listening-learning experiences*. Therefore the learning effect can operate effectively and resulted in better performance on subsequent trials of the task.

Even with no practice with the experimental task, the learning efficiency performance was better in the enhanced compared to the degraded listening condition, thus demonstrating a pure listening condition effect. In addition, there was an interaction of listening condition with practice/learning effects such that the size of the difference between the degraded and enhanced listening conditions was larger when the enhanced condition was experienced as the second listening condition.

Perhaps, this latter comparison is mimicking the difference in the older adults' learning experiences compared to the younger adults' learning experiences. This comparison revealed a much more striking difference for learning efficiency, a difference of 4.42 more critical units learned-per-trial during the *experienced-enhanced* listening compared to the *novel-degraded* listening condition. This interaction of listening condition and learning effect (4.42 more critical units learned-per-trial) compared to no learning effect or pure listening condition effect (2.63 more critical units learned-per-trial in the enhanced compared to the degraded) reveals a striking 43% improvement in learning efficiency.

Variability in listening abilities: Limitations for equating listening ability and memory performance for the Older versus Younger adults

In the present study, the older adults performed significantly better in learning efficiency, immediate recall and delayed recall in the enhanced listening condition compared to their performance in the degraded listening condition.

However, the older adults' performance was still poorer than the younger adults. Even when the younger adults listened in the degraded condition (i.e., listening more similarly to an older adult) their delayed memory performance remained significantly better than the older adults in the enhanced condition (i.e., listening more similarly to a younger adult).

Although the enhanced listening condition mitigates some aspects of ARHL for the older adults, it would not have corrected for all of the variables that may affect listening ease. The following addresses how the inability to fully equate the groups for the individual differences in listening ability may have affected the results, and the interpretation of the results in light of these limitations.

Signal-to-Noise ratio levels - Same is not equal. All participants experienced the noise in the degraded listening condition with the same + 5 dB SNR (the signal 5 dB above the competing speech babble). The rationale for this + 5 dB SNR level was to create a listening condition that was ecologically valid. A + 5 dB SNR level would be considered a more typical difficult-listening scenario, one which both older and younger adults may encounter in real-world listening environments.

However, as previously mentioned this would not have equated the participants within the group for their individual listening-in-noise ability. The lack of individualization of the message-to-competition presentation levels may have contributed to the younger adult group in the degraded listening condition (mimic of older hearing) still performing significantly better than the older adult group in the enhanced condition (mimic of younger hearing).

It is possible that the listening-in-noise level (as measured by QuickSIN) was not significantly related to the performance of the recall task for the younger adults, because the listening task was not sufficiently difficult in other ways. In other words, perhaps the noise interferes less (is less distracting) with listening to the target, if the targeted speech message is sufficiently discriminable. This would have been the case for the younger adult group with better acuity, more stable and dynamic temporal-spectral processing, and the absence of distortions to the stimuli due to auditory phenomenon that co-exist with ARHL such as from recruitment and tinnitus.

Similarly, in Experiment 1, the temporal degrading and noise were examined separately between two groups of older adults matched for age and hearing loss, separating the confound of both temporal degrading/distortions and noise. The results of Experiment 1 were consistent with the findings in this experiment. When the target is easily segmented into its components for listening, as in the 'clear' speech listening condition for the older adults in Experiment 1 and for the younger adults with 'young temporal-spectral processing' in Experiment 2, the presence of the distractor (speech babble noise) has less effect on listening effort. Perhaps the participants' listening-in-noise abilities for this task difficulty level were closer to ceiling levels. Therefore the listening-in-noise ability (QuickSIN score) was not significantly related to their performance for the learning and memory tasks.

To summarize, when the speech target message is sufficiently discriminable, in that the auditory stream segregation is more automatically and effortlessly performed, then that same level of competing speech babble noise in relationship to the message (e.g. + 5 dB SNR) has less of an impact on learning and memory performance. This was the case in young normal hearing adults with more precise auditory spectral and temporal processing and with older adults with ARHL listening to a speech message temporally enhanced in ways that decreased the effort in listening (i.e., Experiment 1, clear speech listening condition in the Noise group). These findings suggest that the distractor effect is mitigated in the high perceptual load condition that is enhanced and conversely the distractor effect is increased in the high perceptual load that is degraded (Lavie, 2005; Lavie & DeFockert, 2003).

Time-compression and Time-expansion rates - relatively degrading or enhancing. All participants experienced the degraded listening at the same 65% time-compressed rate. The rationale for this was to provide a challenging temporal-processing listening condition that would be ecologically valid, but at the same time to avoid ceiling effects for the younger adult (too easy) and floor effects for the older adult (too difficult).

Similarly, all participants experienced the enhanced listening at the same 120% time-expanded rates. As previously described, this expansion rate was based on the literature in which older and younger adults perform with higher recall accuracy rates (Tun, 1998).

The lack of individualization of the time-compressed speech rates could have contributed to the younger adult group in the degraded listening condition (simulated older hearing) still performing significantly better than the older adult group in the enhanced condition (simulated younger hearing) for at least two reasons: 1) The temporal processing ability may interact with the auditory acuity deficit and other distorting aspects of hearing loss that would differentially affect those older adults with more significant age-related hearing loss and the associated distortions from recruitment and tinnitus; 2) The threshold of tolerance to temporal compression may be a relative one. At the point at which the rate is at a favorable enough one for the speech signal to be automatically and efficiently segregated, discriminated and comprehended, any further temporal enhancements would not further enhance recall performance. For example, if one has sufficient temporal processing ability and is therefore able to perceive the duration of voicing (*pea* versus *bee*) or a gap between two words (*quarter back*) increasing the duration of the voicing or increasing the gap would have a null effect for auditory segmentation for comprehension. The automatic temporal processing of the message frees up the resources to perceptually learn the pattern (or adapt to the rate). Consistent with the effortfulness hypothesis, further enhancement beyond those that are necessary to efficiently decode, would not free up more resources, as those resources would have already been available for encoding for later recall.

Interaction of ARHL and degraded listening. There is support for an interaction between the auditory acuity deficit and the degraded temporal processing in both this experiment and in Experiment 1. There was a significant negative relationship of ARHL (as measured by LPTA4 and RPTA4) and delayed memory performance in both the degraded and the enhanced listening for the older adults in this experiment. The magnitude of that effect became smaller in the enhanced listening condition.

Similarly, in Experiment 1, despite a non-significant correlation between ARHL and delayed memory performance for the relatively degraded listening (conversational speech) the nature of that relationship was in the expected negative direction and the relative magnitude of this relationship changes similarly as it did in Experiment 2. Together these findings suggest that the impact of ARHL on memory performance is more significant when the stimuli are more degraded. Perhaps additional distortions from the individual's ARHL further increased listening effort and resulted in poorer delayed memory performance.

Perceptual learning - adapting to the stimuli. In regard to the second point, older adults have a less dynamic and less stable temporal processing mechanism relative to the younger adult group (Anderson et al., 2011; Anderson et al., 2012; Anderson et al., 2013). The younger adult group, with dynamic yet stable temporal processing would have been able to adapt to the time-compressed faster rate in the degraded listening condition, and maintain the benefit in the time-expanded enhanced listening condition more so relative to the older adult group. If the younger and older adult groups had been equated for starting accuracy levels for time-compressed speech intelligibility (i.e., individualize the time-compression rate), then perhaps the two groups' learning and memory performance would have been become more similar and perhaps not significantly different (Peelle & Wingfield, 2003).

Since musicianship has been found to be correlated with more dynamic and stable spectral and temporal auditory processing (Parbery-Clark et al., 2012a; Parbery-Clark et al., 2012b), the prediction was that musicianship scores would be positively associated with delayed memory performance in this experiment.

When the correlation analysis was conducted on the entire group in this experiment, higher musicianship scores correlated significantly with better recall performance in the degraded listening condition revealing a medium effect size (Cohen, 1992). The higher musicianship scores were correlated with better memory performance, perhaps due to the more dynamic yet stable auditory spectral and temporal processing abilities associated with musical training (Parbery-Clark et al., 2012b).

Thus these findings suggest that when the stimuli are degraded, as was done in the experimental manipulations, the individuals with better temporal processing (younger adults or those with higher musicianship scores) are less affected by the temporal degrading of the stimuli.

Experiment 3 was designed to further investigate whether there is an interaction of acuity deficit, (LPTA4 and RPTA4), with age related spectral-temporal processing changes. By using older musicians, a cohort of older adults that have more dynamic yet stable spectral-temporal processing abilities, and comparing their memory performance to older non-musicians matched for age and hearing loss, one can examine the role that more preserved auditory spectral-temporal processing ability plays in listening effort for older adults with ARHL and how this affects memory performance.

Experiment 3

Rationale

The purpose of this experiment was to investigate two related questions: 1) whether instrumental-musicians' training and experience, which has been shown to preserve the consistency of the auditory neural response to speech sounds, promotes effortless listening for more complex and ecologically valid stimuli (Kraus & Chandrasekaran, 2010; Zendel & Alain, 2012; Zendel & Alain, 2013; Zendel & Alain, 2014); and 2) whether a cohort of older adult musicians with hearing loss have enhanced listening abilities and consequentially better learning and memory performance relative to an older non-musician group matched for age and hearing loss. Ultimately the goal is to investigate whether the interaction of age-related acuity deficit (RPTA4 and LPTA4), and age-related spectral-temporal processing declines contributes to the effort for listening.

If the effort in listening arises from age-related declines in temporal-spectral processing, then preserved temporal-spectral processing should decrease listening effort. In this way, the suggestion is that 'super' or 'expert' listeners with more consistent neural encoding of speech, will experience less effort in decoding the message. A finding in which the older musician group with hearing loss performs more similarly to the younger adult group without hearing loss, would suggest that it is the older musicians' better temporal-spectral processing abilities, despite their age and auditory acuity deficit, that acts as a further enhancement to the listening. It is reasonable to suggest then that a cohort that would conceivably have decreased listening effort as a result of this more preserved spectral and temporal processing, would expend fewer cognitive resources for decoding of the message and therefore more resources would be available for the secondary task, encoding for later recall and therefore better learning and memory performance.

The temporal-spectral and acoustic manipulations of the stimuli. The same stimuli and the same manipulations to the stimuli from Experiment 2 were used.

Hypothesis and Predictions

According to the effortfulness hypothesis (Rabbitt, 1968; 1990), the degrading of the acoustic stimuli as a result of ARHL increases listening effort. Decoding the message in these effortful listening conditions then consumes the resources that would otherwise be allocated for elaborate encoding of the information for later recall. Those individuals who either experience less effort in listening, such as younger adults without hearing loss or 'trained' listeners such as musicians, and/or those who have more cognitive-linguistic resources available to be shared with the two competing processes (comprehension and recall) will perform better than those who experience more effort in listening such as older non-musicians with ARHL. A group of 'expert listeners' – older adult musicians, with preserved dynamic and stable temporal-spectral processing abilities – would, at least theoretically so, expend less effort in listening. Older adult musicians should be able to perceptually learn or adapt to the time-compressed rate more easily, and maintain the benefit of the time-expanded rate; this should result in less effortful listening. If effort in listening arises from inconsistency or unstable spectral and temporal processing ability, then the group with the age-related decline in temporal processing *and* auditory acuity deficits (older non-musicians) should experience the greatest amount of effort and demonstrate less efficient learning, and poorer immediate and delayed memory performance for both the degraded and enhanced listening conditions.

If the hypotheses for this study are confirmed then results of Experiment 3 should show a main effect of listening condition. The groups will demonstrate more efficient learning and better immediate and delayed memory performance (i.e., a larger number of critical units reported) in the enhanced (time-expanded speech in quiet) relative to the degraded listening (time-compressed speech in noise) condition.

If the age-related decline in temporal-spectral processing ability interacts with the age-related auditory acuity deficits (LPTA4 and RPTA4), further interfering with the processing of the target, then the expectation is that there would be a significant interaction of the listening condition and group. The groups will be differentially affected by the two listening conditions. The younger non-musician group without hearing loss and potentially with a more dynamic and stable temporal processing mechanism will demonstrate the best performance in learning efficiency, immediate and delayed memory in the degraded and enhanced listening. The older musician group with hearing loss but more preserved temporal processing will perform more similarly to the younger non-musician adult group in learning efficiency, immediate and delayed memory more so in the enhanced and less so in the degraded listening condition. Additionally, the older musician group will demonstrate more efficient learning and greater critical units reported for immediate and delayed recall compared to the older non-musicians.

Compared to the older non-musician group, if the older musician groups' preserved temporal-spectral processing acts as a further listening enhancement they should be less affected by the degrading of the stimuli (time-compressed in noise) and at the same time able to benefit more so from the enhancements (time-expanded in quiet). In this way the difference between the older musicians' learning and memory performance in the degraded and the enhanced listening should be the largest. The younger non-musician (without ARHL) will have the least difference in learning and memory performance between degrading of the stimuli and the enhancements since they will be less affected by the degrading and benefit less so from the enhancements, since the target is already sufficiently discriminable. The older non-musician group will be the most significantly affected by the degraded stimuli and benefit from the enhancement but less so than the older musicians, therefore the difference between the two listening conditions will be significant but less so than the older musicians. If age-related acuity deficits (PTA4) contribute to listening effort then the older non-musicians and older musicians matched for acuity deficits (PTA4) will perform more similarly to each other, particularly in the degraded listening condition (time-compressed with noise). This prediction is based on the findings that even mild age-related acuity deficits negatively affects speech understanding in adverse listening conditions (fast and noisy), with less of an effect in more optimal listening conditions (e.g. enhanced in quiet) (Mattys et al., 2012).

If the results are consistent with these predictions this will support the effortful listening hypothesis. When listening effort arises from a less dynamic and less stable temporal-spectral processing ability, more effort in decoding the speech comes at the cost of fewer resources available for encoding into memory.

Methods

Participants

A total of 61 adults participated in this study, divided into three groups: older musicians, younger non-musicians, and older non-musicians.

Older musicians. A new group of older adult musicians were recruited for this experiment, 21 older community dwelling adult musicians, 55-84 years, (M = 66.14, SD = 7.6; 9 males, 12 females) with musicianship scores M = 9.49, SD = .93. Handedness: All participants were right handed except for 1 left handed older musician. Only one older musician participant wore bilateral hearing aids. The participant wore the hearing aids for the entire study except in the enhanced listening in which he wore the 3A E.A.R.tone™ insertion earphones that all the participants used in these experiments for the enhanced listening condition.

Musicians were operationally defined as those individuals who considered themselves to be musicians, had initiated formal musical training by 10 years of age or younger, and had a minimum of 12 years musical experience. In addition, they had been actively engaged in music, currently performing, teaching and/or practicing on average 6 times a week for 1 hour or greater daily. These established criteria were based on other studies that have investigated musical training and its impact on hearing and listening performance (Skoe & Kraus, 2012; White-Schwoch, Carr, Anderson, Strait, & Kraus, 2013). The older adult musician participants recruited for this study obtained a musicianship score, $M_{\text{musician group}}$ = 9.48, SD .93, range 8-10, on the musicianship scale created for and used in this study.

Forty non-musician participants were identified from Experiment 2 and selected as a comparison group. The selection criteria used for the participants from Experiment 2 was the 20 participants with the lowest values obtained on the musicianship interval scale (i.e., self-report of formal instrumental musical training), which reflected very minimal to no exposure to music, a range of 0-2. The rationale to compare the older musician group to younger and older *non-musicians* is based on the findings that even moderate exposure of formal instrumental music training earlier in life has been associated with more efficient auditory function even decades after training had been discontinued (White-Schwoch, et al., 2013).

Younger non-musicians. The younger non-musicians (selected from Experiment 2) were 20 Memorial University of Newfoundland undergraduate and graduate students, 19-26 years old, (M = 21.85, SD = 2.28, 8 males and 12 females) with musicianship scores M = 1.3, SD = 1.13; All the younger non-musician participants were right handed. No younger participant wore hearing aids in this group.

Older non-musicians. The older non-musicians (selected from Experiment 2) were 20 older community-dwelling adults, 56-84 years old (M = 66.15, SD = 7.9, 10 males, 10 females) with musicianship scores M = .4, SD = .75. All older non-musician group participants were right handed. No participant wore hearing aids in this group.

Recruitment of participants

Older Musicians: Community-dwelling older adult musicians, from the greater St. John's area, were recruited. Announcements were made to musical groups (e.g., Newfoundland Symphony Orchestra, Philharmonic Choir of Newfoundland, and the

Memorial University Music Hall) and posters and flyers were distributed to various venues of musical productions. Only healthy adults without known medical events that may have an impact on memory (e.g. cardiovascular event, neurological event or disease) were invited to participate. All participants were ambulatory and physically able to step up into the testing sound booth.

The younger and older non-musician participants were recruited as described in Experiment 2.

All participants received $10 an hour for their participation. In addition, the older adult participants were provided with an option of free proximal parking on the Memorial University campus.

Ethics. Ethics clearance and approvals were obtained from Memorial University’s Interdisciplinary Committee on Ethics in Human Research (ICEHR) in accordance with the Tri-Council Policy Statement on Ethical Conduct involving Humans (TCPS-2). All participants gave their informed consent before participating in accordance with Memorial University’s Interdisciplinary Committee on Ethics in Human Research.

Research Design

There was one between-subject variable, ‘listening expertise’ groups (younger non-musician adults vs. older musician adults vs. older non-musicians) and two within-subject variables, listening condition (degraded vs. enhanced) and time of memory recall (immediate vs. delayed). All other aspects of the research design were identical to Experiment 2.

Procedures

This experiment was a replication of Experiment 2 with a new group of older adult musicians.

Preliminary measures. The same measures that were used in Experiment 1 were used in this experiment.

Vision Screening. All participants demonstrated adequate corrected vision to continue in the experiment. $M_{\text{All far vision}}$ = 24.66, *SD* = 24.80, $M_{\text{All near vision}}$ = 19.03, *SD* = 10.33. ANOVA results confirmed that the groups did not significantly differ in far vision abilities F (2, 60) = 2.61, p = .08. Far vision: $M_{\text{far vision younger}}$ = 15.85, *SD* = 2.98; $M_{\text{far vision older nonmusic}}$ = 33.30, *SD* = 40.79, $M_{\text{far vision older music}}$ = 24.81, *SD* = 10.15. The three groups did significantly differ for near vision, F (2, 60) = 8.07, p = .001. The younger non-musician group had better corrected near vision $M_{\text{near vision young}}$ = 13.05, *SD* = 6.5, compared to the older musician group $M_{\text{near vision older music}}$ = 24.71, *SD* = 10.87, but there were no significant differences between the younger non-musician group and the older non-musician group, $M_{\text{near vision older nonmusic}}$ = 19.05, *SD* = 9.85, p = .14. Also, there were no significant differences for corrected near vision between the older musician and older non-musician groups, p = .17.

Mini-Mental Status Examination (MMSE). All participants scored well within normal for age and education on the MMSE (Crum, et al., 1993). The scores for Experiment 3, $M_{\text{entire group}}$ = 29.51, *SD* = .79, ranged from a minimum score of 27 to a maximum score of 30 (see Table 19 for means and standard deviations). Therefore no participant was excluded from this study due to identified pre-existing dementia or cognitive impairment.

Audiometric. No participant was excluded from this study based on audiometric or otoscopic examination. All participants' PB max-MCL were below 90 dBA (the limits of the loudspeakers in the sound booth).

Comparing groups on Hearing and Cognitive measures. A series of ANOVAs were used to determine if the three groups differed in age, ARHL as measured by LPTA4 and RPTA4, listening-in-noise ability as measured by QuickSIN scores and self-perception of hearing handicap as measured by HHIA scores. Results indicated that there was a significant difference in age, F (2, 60) = 312.51, p < 001. Post Hoc tests with a Bonferroni correction for multiple comparisons revealed that there was the expected difference in age between the younger non-musician adult participants and the two older participant groups (musician and non-musician groups), p < .001, but there was no significant difference between the older non-musician and the older musician groups, p = 1.00 (see Table 19 for means and standard deviations).

Similarly, the MCL in dB HL that the stimuli were presented were significantly different among the groups in Experiment 3, F = 19.48, p < .001, this difference was between the younger and the two older participant groups (musicians and non musicians), there was no significant difference in MCL in dB HL between the older musician and older non-musician, p = 1.00 (Table 4 for means and standard deviations).

There was a significant difference among the groups for ARHL in the left ear (LPTA4), F (2, 60) = 4.04, p = .02 and the right ear (RPTA4), F (2, 60) = 6.19, p = .004. Post Hoc tests with a Bonferroni correction for multiple comparisons revealed that these differences in ARHL were the expected difference between the younger and the two older participant groups, there were no significant differences in hearing for the LPTA4 or RPTA4 between the older musician and the older non musician groups, $p = 1.00$. In order to determine if there was a significant difference in hearing between the right and left ears, a paired samples t-test was conducted separately for each group. Paired samples t-tests indicated that there were no significant differences between the right and left PTA4 for the older musician participants, $t\ (20) = -0.16$, $p = .87$; or the older non-musician participant group, $t\ (19) = 0.636$, $p = .53$. There was a significant difference between the right and left PTA4 in the younger non-musician participants, $t\ (19) = 2.24$, $p = .04$, in which the younger participants had better hearing in the right ear. (see Table 19 for RPTA4 and LPTA4 means and standard deviations; see Figure 1 for audiometric profile data.)

There were no significant differences in listening-in-noise ability as measured by QuickSIN, $F\ (2, 60) = 1.69$, $p = .19$, or self-perception of hearing handicap as measured by HHIA, $F\ (2, 60) = 1.36$, $p = .26$ (see Table 19 for means and standard deviations).

Table 19

Mean Participant Characteristics for Experiment 3

	Younger		Older Musician		Older Non-Musician		
Characteristics	*M*	(*SD*)	*M*	(*SD*)	*M*	(*SD*)	
Demographic Variables							
Age (years)	21.85	(2.28)	66.14	(7.61)	66.15	(7.92)	**
Education[a]	3.00	(1.30)	4.43	(0.75)	2.95	(0.95)	**
Health[b]	4.20	(0.70)	4.33	(0.73)	3.75	(0.72)	
Hearing Characteristics							
QuickSIN[c]	0.68	(1.75)	1.76	(2.00)	1.45	(2.06)	
HHIA Survey[d]	2.00	(2.60)	6.00	(11.83)	7.50	(14.46)	
RPTA4 (dB)	5.63	(9.57)	18.46	(13.80)	16.69	(13.83)	**
LPTA4 (dB)	8.06	(10.66)	18.17	(14.75)	17.49	(12.02)	*
Cognitive Characteristics							
FAS (words)[e]	48.10	(9.70)	55.95	(8.37)	44.90	(10.60)	**
BNT (words)[f]	55.40	(2.42)	56.90	(3.35)	54.90	(4.66)	
BackDigit Span[g]	5.05	(1.26)	5.17	(1.35)	4.59	(1.18)	
L-Span	27.45	(6.76)	23.67	(11.14)	14.85	(9.07)	**

Note. [a] Education - by self reported category 1 = some High School, 2 = High School diploma, 3 = some University/College, 4 = University/College degree, 5 = graduate/professional degree. [b] Health - by self reported category 1 = very poor, 2 = poor, 3 = good, 4 = very good, 5 = excellent. [c] QuickSIN = Quick Speech-in-noise measurement that provides a signal-to-Noise ratio loss expressed as dB SNR loss, higher numbers indicate poorer abilities to understand speech in noise. Normal value = < +3 dB SNR loss (Killion, 2002). [d] HHIA - Hearing Handicap Inventory for Adults is a self-assessment; higher scores indicate greater perception of hearing loss handicap. [e] FAS - verbal fluency executive function task, higher number of words generated is better performance. [f] BNT-Boston Naming Test, naming vocabulary test, higher number of words correctly named is better performance. [g] BackDigit Span - backwards digit span, indicates number of digits reported, higher number is better performance.
$*p < .05$, $**p < .01$

A one-way ANOVA was used to determine if the three groups differed in musicianship score. There was a significant difference among the groups $F(2, 60) =$

573.35, $p < .01$. The older musician group had the expected significantly higher musicianship scores $M_{\text{older music}} = 9.48$, $SD = .93$, than either the older non-musician group, $M_{\text{older non-music}} = .40$, SD .75, ($p < .001$) or the younger non-musician group, $M_{\text{younger non-music}} = 1.30$, $SD = 1.13$, ($p < .01$).

Self reported health and education were also examined to determine if the groups differed on these variables. There were no significant differences between the young non-musicians, the older non-musicians and the older musicians groups on Health, χ^2 (4, N = 61) = 7.47, $p = .11$. However, the groups differed in the distribution of maximum level of Education, χ^2 (4, N = 61) = 27.38, $p = .001$. The older musician group was more educated than the younger and older non-musician group.

These results confirmed that the two older participant groups, musicians and non-musicians were matched for age and hearing-listening abilities. The younger participants were indeed significantly younger and had normal hearing compared to the older participant groups with similar ARHL. The results confirmed that the groups significantly differed on instrumental-musical training and experience. The older musician group indicated by self-report on the demographic questionnaire a greater extent of musicianship relative to the younger and older non-musician groups.

A series of ANOVAs and follow up Post Hoc tests with a Bonferroni correction for multiple comparisons were used to determine if the three groups differed in cognitive linguistic abilities such as, working memory measured by L-span, executive function as measured by FAS, short-term memory as measured by backwards digit span, and lexical access as measured by BNT. Results indicated that there were no significant differences between groups for backward digit span, F (2, 55) = 1.09, p = .34; or for BNT, F (2, 60) = 1.75, p = .18 (see Table 19 for means and standard deviations).

However, there were significant differences between the groups for L-span scores, F (2, 60) = 9.88, p < .001. The younger non-musician group demonstrated better working memory capacity reflected by higher L-span score compared to the older non-musician group (p < .001), but not the older musician group (p = .58); also the older musician adult group demonstrated better working memory capacity reflected by higher L-span score compared to the older non-musician group (p = .01).

There were significant differences between the groups for FAS scores, F (2, 60) = 7.26, p = .002. The older musician adult group demonstrated better executive function/verbal fluency reflected by higher FAS score compared to the older non-musician group (p = .001) and the younger non-musician group (p = .03); the older non-musician adult group did not significantly differ in FAS scores compared to the younger non-musician group (p = .89) (see Table 19 for means and standard deviations).

These results confirmed that the groups were well matched on short-term memory (backward digits span) and lexical access (BNT). However, the groups demonstrated the expected finding that the younger non-musicians and the older musicians have better auditory-working memory (higher L-span values) compared to the older-non-musician group. In addition, the older musicians demonstrated significantly better executive function (FAS) when compared to the two non-musician groups, whose FAS scores did not differ from each other (older and younger). These findings of superior auditory-working memory (L-span), executive control (FAS) in addition to other cognitive-linguistic abilities (auditory attention) of musicians compared to non-musician groups are consistent with previous research (Kraus & Chandrasekaran, 2010; Strait & Kraus, 2014 Zendel & Alain, 2012; Zendel & Alain, 2013; Zendel & Alain, 2014).

Results

Accuracy and consistency of scoring of participant responses

To determine the consistency and accuracy of the coding of the participant sound files for the reported critical units, one research assistant, blinded to the listening condition, coded all the participant sound files and then re-coded 20% of the total of the participant files randomly selected. A total of four participant sound files from Experiment 3 from the older musician group were selected for this intra-rater analysis. Previous intra and inter-rater reliabilities had already been completed for the younger and older non-musician groups included, as mentioned above in Experiment 2. In addition, to ensure that the coding had been done consistently and did not become increasingly strict or lax, of the four participants selected, two participant sound files were selected from the beginning, and two were selected from the end of the previously coded files. An intra-rater reliability analysis was performed to assess the degree that the coding and recoding of the sound files responses for each participant was consistently captured for the critical units reported. Generally speaking, an ICC value between .75-1.00 is considered excellent (Hallgren, 2012).

Intra-rater reliability. Intra-rater reliabilities for coding of blinded scoring were assessed using intra-class correlation coefficient with a two-way mixed effects model and absolute agreement type (Shrout & Fleiss, 1979). The intraclass correlation coefficient (ICC) for single measures for the reported-recalled critical units for each trial was .99.

Inter-rater reliability. An inter-rater reliability analysis for coding of blinded scoring was performed to assess the degree that the coding and recoding of the sound files responses for each participant could be easily and consistently captured by a second rater. To determine the consistency of the coding of the participants sound files for the reported critical units, a second research assistant blinded to the listening condition, coded 10% of the total of the participant files from Experiment 3, two participants. None of the re-coded sound files used for the intra-rater reliability was used for this analysis. The intraclass correlation coefficient (ICC) for single measures for the reported-recalled critical units for each trial was .97.

The ICC values reported here are between .97 and .99, therefore the intra-rater and inter-rater reliability analysis demonstrates excellent consistency in coding (Cicchetti, 1994). The high ICC values for both the intra-rater and inter-rater reliabilities suggests that minimal amount of measurement error is introduced by the coding of the participants sound files. The original scores for the participants were therefore considered appropriate for use in the hypothesis tests for this study.

Order of the Experiment effects

There were 8 different orders in which the participants completed the experiment (i.e., EmA/DpB; EmB/DpA; EpB/DmA; EpA/DmB; DmA/EpB; DmB/EpA; DpB/EmA; DpA/EmB as explained previously). Participants were randomly assigned to one of the counterbalanced orders. To determine whether the order of the experiment affected the participant's learning efficiency, immediate, and delayed memory performance, a series of mixed design ANOVAs were conducted.

Learning efficiency performance was analyzed with a 2 (listening condition: degraded vs. enhanced) x 2 (listen order: degraded first vs. enhanced first) x 2 (passage order: medipatch first vs. puffer first) x 2 (interference/filler task set order: Set A first vs. Set B first) mixed factors ANOVA, with listening condition as a within-subjects factor, and the three order variables as between-subjects factors. This was conducted for each of the dependent variables separately (i.e., learning efficiency, immediate memory and delayed memory). By conducting the analysis in this way all two, three and four-way interactions could be determined (see Table 20 for all F and p values).

Table 20

Experiment 3: Younger non-musicians and Older musicians and Older non-musician adults Order of Experiment effects on dependent variables

Variables and Interactions	*F* (1, 53)	*p*
Learn Efficiency		
Listening Condition	13.77	***<.001**
Listening Condition * Listening Order	10.66	***.002**
Listening Condition * Passage Order	2.02	.16
Listening Condition * Interference Order	0.28	.60
Listening Condition * Passage Order * Listen Order	0.10	.76
Listening Condition * Passage Order * Interference Order	0.00	.96
Listening Condition * Listen Order * Interference Order	0.46	.50
Listening Condition * Passage Order * Listen Order * Interference Order	0.50	.48
Immediate Memory		
Listening Condition	12.47	***.001**
Listening Condition * Listen Order	2.24	.14
Listening Condition * Passage Order	0.00	.96
Listening Condition * Interference Order	0.07	.80
Listening Condition * Listen Order * Passage Order	0.04	.84
Listening Condition * Listen Order * Interference Order	0.18	.68
Listening Condition * Interference Order * Passage Order	0.15	.70
Listening Condition * Listen Order * Passage Order * Interference Order	0.05	.82
Delayed Memory		
Listening Condition	25.01	***<.001**
Listening Condition * Listen Order	7.20	***.01**
Listening Condition * Passage Order	0.11	.75
Listening Condition * Interference Order	0.76	.39
Listening Condition * Listen Order * Passage Order	2.26	.14
Listening Condition * Listen Order * Interference Order	0.92	.34
Listening Condition * Passage Order * Interference Order	0.04	.84
Listening Condition * Listen Order * Passage Order * Interference Order	1.20	.28

Note. * ***p*** value bolded denotes significance

Order of experiment effects - learning efficiency. Learning efficiency was operationally defined and calculated as the number of critical units learned-per-trial, calculated for each participant by summing the total amount of the critical units reported at each of the trials, divided by the number of trials to reach criteria for that listening condition. Criteria were established a priori as either 100% reporting of the 37 critical units or if the participant demonstrated no increase in reporting of the critical units over 3 consecutive trials. In this way there was a single value for the learning efficiency during the degraded listening, and a single value for the learning efficiency during the enhanced condition. More efficient learning would be reflected as a higher value, in which more of the units were learned over fewer trials. Only one younger non-musician (in 4 trials) reached the max of 37 critical units for the degraded listening condition, all other participants reached criteria by demonstrating no new learning over 3-consecutive trials. The range of trials to learn the passages was 3-8 trials for the younger adults, 4-10 trials for the older non-musician adults and 3-8 trials for the older musician adults. In Experiment 3, the groups did not differ significantly for the number of trials to reach criteria, $F(2, 60) = 2.66$, $p = .08$ in the degraded and in the enhanced listening condition, $F(2, 60) = 2.14$, $p = .13$. $M_{\text{younger degraded}} = 5.25$ (1.56); $M_{\text{older non musician degraded}} = 6.25$ (1.37) $M_{\text{older musician degraded}} = 5.43$ (1.47); $M_{\text{younger enhanced}} = 4.50$ (1.05); $M_{\text{older non musician enhanced}} = 5.10$ (1.25) $M_{\text{older musician enhanced}} = 4.33$ (1.39).

There was no significant effect of order or interactions for passage (e.g. medipatch vs. puffer) or interference task set (e.g. Set A vs. Set B) on Learning efficiency (see Table 20 for all *F* and *p* values).

However, there was a significant 2-way interaction between listening condition order (e.g. degraded-enhanced vs. enhanced-degraded) and listening condition on learning efficiency, $F(1, 53) = 10.66$, $p = .002$. The learning was more efficient during the second listening condition compared to the first listening condition in both the degraded listening, $M_{\text{degraded 1st}} = 20.20$, $SD = 5.65$; $M_{\text{degraded 2nd}} = 22.82$, $SD = 5.21$; and the enhanced listening, $M_{\text{enhanced 1st}} = 23.47$, $SD = 4.47$; $M_{\text{enhanced 2nd}} = 25.08$, $SD = 4.08$.

As a result of the significant interaction between order of listening condition and listening condition on learning efficiency, listening order was entered as a covariate for further hypothesis testing for the differences of learning efficiency between the groups in the degraded and enhanced listening conditions.

Order of experiment effects - immediate memory performance. Immediate memory performance was operationally defined and calculated as the sum of the critical units immediately reported for any of the trials of listening-recall prior to the filler tasks for each listening condition (i.e., the total sum of 'new' critical units reported were tallied for all the trials of learning until the criteria was met). The summed total of each 'new' critical unit reported during all of the trials resulted in the immediate memory performance for that listening condition. The maximum possible for recall was 37 critical units for each passage. Results indicated that there was no significant effect of order or interactions of order on immediate memory performance (see Table 20 for all F and p values).

Order of experiment effects - delayed memory performance. Delayed memory performance was operationally defined and calculated as the total number of the critical units reported after completion of the interference tasks (20 minutes). The maximum possible for recall was 37 critical units for each passage. There were no significant effects of order of passage, order of interference task, or interactions of order on delayed memory performance. (see Table 20 for all F and p values).

However, there was a significant 2-way interaction between listening condition order (e.g. degraded-enhanced vs. enhanced-degraded) and delayed memory performance, $F(1, 53) = 7.19$, $p = .01$. The group's delayed recall was better (i.e., higher number of critical units reported) during the second listening condition compared to the first listening condition in both the degraded listening, $M_{\text{degraded 1st}} = 23.97$, $SD = 6.07$; $M_{\text{degraded 2nd}} = 25.30$, $SD = 5.27$; and the enhanced listening, $M_{\text{enhanced 1st}} = 27.03$, $SD = 4.92$; $M_{\text{enhanced 2nd}} = 28.71$, $SD = 5.31$.

As a result of the significant interaction between order of listening condition and delayed memory performance, listening order was entered as a covariate for further hypothesis testing for the differences of delayed memory between the younger and older-non-musician and older musician groups in the degraded and enhanced listening conditions.

Degraded and Enhanced Listening affects learning and memory performance by group

According to the effortfulness hypothesis more resources will be expended for learning and recall during the difficult-degraded listening relative to the enhanced easy listening. The prediction was that the more effortful or difficult the listening condition would result in less efficient learning and a fewer number of critical units recalled.

If the results demonstrate that fewer critical units were learned or recalled per trial in the degraded listening relative to the enhanced listening this supports the effortfulness hypothesis. Listening effort expended for discrimination and decoding of the message results in fewer resources available to encode for recall which has a negative impact on learning efficiency, immediate and delayed memory performance.

Learning efficiency. In order to evaluate how the degraded and enhanced listening condition affected learning efficiency and whether the listening condition differentially affected the learning efficiency of the three groups (older musicians, younger non-musicians and older non-musicians), a mixed design ANOVA was used.

The learning efficiency scores were analyzed with a 3 (group: older musicians, younger non-musicians, older non-musicians) X 2 (listening condition: degraded, enhanced) mixed design ANOVA in which listening condition was entered as the repeated measure within-subject variable and group was a between-subject variable. There was a significant main effect of listening condition, F (1, 57) = 23.82, $p < .001$. Degraded listening resulted in less efficient learning with fewer critical units per trial learned $M_{degraded} = 21.48$, $SD = 5.56$, relative to the higher number of critical units per trial learned in the enhanced listening $M_{enhanced} = 24.29$, $SD = 4.32$, demonstrating that listening enhancements improved learning efficiency on average by 2.81 critical units. There was a significant main effect of group, F (2, 57) = 9.19, $p < .001$. The younger adults' learning efficiency was significantly better than the older non-musicians' ($p < .001$) but not the older musicians' learning efficiency ($p = .12$). The older musicians' learning efficiency was not significantly different from the older non-musicians' learning efficiency ($p = .09$). (See Table 21 for means and standard deviations).

In addition, there was a significant listening condition by group interaction, F (2, 57) = 6.62, $p = .003$. Younger adults were very similar in their learning efficiency for the degraded $M_{\text{young non music}} = 25.39$, $SD = 3.96$, and enhanced listening condition $M_{\text{young non music}} = 25.25$, $SD = 3.08$, a difference of only 0.14 units. Planned follow up paired sample t-test confirm this finding as a non-significant difference for listening condition, $t\,(19) = .128$, $p = .90$.

However, there were significant differences in the learning efficiency between the degraded and enhanced listening condition for both the older non-musicians, $t\,(19) = -4.35$, $p < .001$, and older musician groups, $t\,(20) = -3.38$, $p = .001$. Older non-musicians demonstrated a larger difference in learning efficiency for the degraded $M_{\text{older non-music}} = 18.62$, $SD = 4.17$, and enhanced listening condition $M_{\text{older non-music}} = 22.21$, $SD = 4.04$, an increase in learning efficiency of 3.59 units. The older musicians demonstrated the largest difference in learning efficiency for the degraded $M_{\text{older musicians}} = 20.48$, $SD = 6.06$, and enhanced listening condition $M_{\text{older musicians}} = 25.36$, $SD = 5.0$, an increase in learning efficiency of 4.88 units.

These finding demonstrate that the older musician group benefitted more so from the enhanced listening condition relative to both the older non-musician and the younger non-musicians. In addition, relative to the older non-musicians, the older musicians' learning efficiency was less negatively affected by the degraded listening condition.

Immediate memory. In order to evaluate how the degraded and enhanced listening condition affected immediate memory and whether the listening condition differentially affected the immediate memory performance of the three groups (older musicians, younger non-musicians and older non-musicians), a mixed design ANOVA was used.

The immediate memory scores were analyzed with a 3 (group: older musicians, younger non-musicians, older non-musicians) X 2 (listening condition: degraded, enhanced) mixed design ANOVA in which listening condition was entered as the repeated measure within-subject variable and group was a between-subject variable. There was a significant main effect of listening condition, F (1, 58) = 16.23, $p < .001$. Degraded listening resulted in fewer recalled critical units $M_{degraded}$ = 30.38, SD = 4.85 relative to the higher number of critical units recalled in the enhanced listening $M_{enhanced}$ = 32.28, SD = 3.27, demonstrating that listening enhancements improved immediate recall on average by 1.88 critical units. There was a significant main effect of group, F (2, 58) = 8.76, $p < .001$. The younger adults' immediate memory was significantly better than the older non-musicians' ($p < .001$) but not the older musicians' immediate memory ($p = .06$). The older musicians' immediate memory was not significantly different from the older non-musicians' immediate memory ($p = .22$). (See Table 21 for means and standard deviations by group).

Table 21

Experiment 3: Memory and Learning Efficiency by Listening Condition for Younger Non-Musicians, Older Non-Musicians and Older Musicians

	Young Non-Musicians		Older Non-Musicians		Older Musicians		Total	
Dependent Variable	*M*	(*SD*)	*M*	(*SD*)	*M*	(*SD*)	*M*	(*SD*)
Delayed Memory								
Degraded[a]	28.60	4.01	22.05	5.48	23.90	5.30	24.84	5.62
Enhanced[b]	30.70	3.80	24.70	5.33	28.24	4.54	27.89	5.15
Immediate Memory								
Degraded[a]	33.60	2.91	28.10	4.92	29.48	4.79	30.38	4.85
Expanded[b]	33.55	2.01	30.45	3.58	32.81	3.28	32.28	3.27
Learning Efficiency								
Degraded[a]	25.39	3.96	18.62	4.17	20.48	6.06	21.48	5.56
Enhanced[b]	25.25	3.08	22.21	4.04	25.36	5.01	24.29	4.32

Note. M = Means and *SD* (standard deviations in parenthesis) [a] degraded listening condition: 65% time-compressed speech in noise (speech babble at + 5 dB SNR), presented via loud speakers, in number of critical units reported. [b] enhanced listening condition: 120% time-expanded speech in quiet presented via insertion earphones in number of critical units reported.

In addition, there was a significant listening condition by group interaction, F (2, 58) = 4.65, p = .01. Younger adults were very similar in their immediate recall for the degraded $M_{\text{young nonmusic}}$ = 33.6, SD = 2.91, and enhanced listening condition $M_{\text{young nonmusic}}$ = 33.55, SD = 2.01, a difference of only 0.05 units recalled. A planned follow up paired samples t-test confirmed this finding as a non-significant difference for listening condition, t (19) = 0.08, p = .94.

However, there was a significant difference in immediate recall for the two listening conditions, in both the older non-musicians, t (19) = -2.77, p = .01, and older musician groups, t (20) = -3.65, p = .002. The older musicians demonstrated the largest difference of 3.33 units for immediate recall between the degraded $M_{\text{older-Musicians}}$ = 29.48, SD = 4.79 and enhanced listening condition $M_{\text{older-Musicians}}$ = 32.81, SD = 3.28. The older non-musicians demonstrated a significant, but smaller difference of 2.35 units recalled between the degraded $M_{\text{older-nonmusic}} = 28.1$, $SD = 4.92$ and enhanced listening condition $M_{\text{older-nonmusic}} = 30.45$, $SD = 3.58$. These finding demonstrate that the older musician group benefitted more so from the enhanced listening condition relative to both the older non-musician and the younger non-musicians (Figure 8). In addition, relative to the older non-musicians, the older musicians' immediate recall performance was less negatively affected by the degraded listening condition.

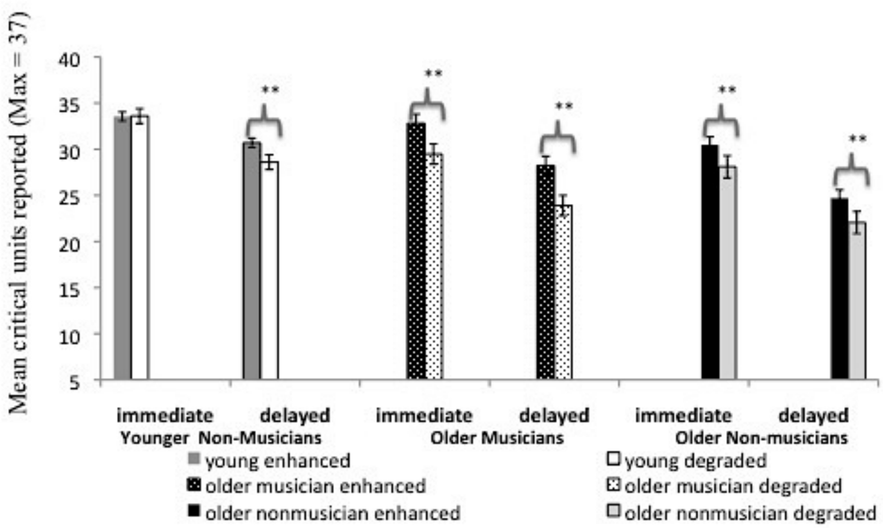

Figure 8. Experiment 3: Immediate and delayed memory performance in enhanced (120% time-expanded in quiet) and degraded (65% time-compressed in noise) listening conditions for younger non-musicians and older musician and older non-musician adult groups. Error bars are standard error of the mean.
** $p <. 01$.

Delayed memory. In order to evaluate how the degraded and enhanced listening condition affected delayed memory performance and whether the listening condition differentially affected delayed memory performance for the younger non-musicians and the older musician and older non-musician groups, a mixed design repeated measures ANOVA was used.

The delayed memory scores were analyzed with a 3 (group: young non-musicians, older musician, older non-musicians) X 2 (listening condition: degraded, enhanced) mixed designed ANOVA in which listening condition was entered as the repeated measure within-subject variable and group was a between-subject variable.

There was a significant main effect of listening condition, $F(1, 57) = 19.12$, $p < .001$. Degraded listening resulted in fewer recalled critical units $M_{\text{degraded}} = 24.84$, $SD = 5.62$, relative to more critical units recalled in the enhanced listening $M_{\text{enhanced}} = 27.89$, $SD = 5.15$, demonstrating that listening enhancements improved delayed recall on average by 3.05 critical units. There was a significant main effect of group, $F(2, 57) = 11.65$, $p < .001$. The younger non-musicians overall recalled 6.32 more critical units than older non-musicians ($p = < .001$) and recalled 3.60 more critical units than older musicians ($p = .007$). Also, the older musicians recalled 2.73 more critical units than older non-musicians ($p = .04$).

There was no significant listening condition by group interaction, $F(2, 57) = 1.32$, $p = .28$. When the groups (younger non-musicians, older non-musicians, and older musicians) listen in a difficult degraded listening condition, they are similarly affected, so that they recall fewer critical units relative to their recall in the enhanced listening condition. Despite no significant interaction by group, there were numerical trends consistent with the predictions regarding how these groups performed for the two listening conditions. Younger non-musician adults were the most similar in their delayed recall for the degraded $M_{\text{young}} = 28.6$, $SD = 4.05$, and enhanced listening condition $M_{\text{young}} = 30.7$, $SD = 3.8$, a difference of 2.1 units. The older non-musician still demonstrated a larger numerical difference of 2.65 units for delayed recall between the degraded $M_{\text{older-nonmusic}}$ = 22.05, *SD* = 5.48 and enhanced listening condition $M_{\text{older-nonmusic}}$ = 24.7, *SD* = 5.33. However, the older musicians demonstrated the largest difference of 4.33 critical units recalled, between their delayed memory performance in the degraded listening condition, $M_{\text{older-musician}}$ = 23.9, *SD* = 5.3, and in the enhanced listening condition $M_{\text{older-musician}}$ = 28.24, *SD* = 4.54. As depicted in Figure 8, these findings suggest that the older musicians in the degraded listening condition were similarly negatively affected by the degraded listening condition (when compared to the older non-musicians) but benefitted the most from the enhancements to the listening condition for delayed memory performance.

Comparison of groups. The comparison of the three groups' performance in the immediate and delayed memory event for the two listening conditions was done to examine the following. If older adults 'listen' more similarly to younger adults does this decrease the effort for decoding of the message for these ecologically valid stimuli, free up those resources for encoding for later recall and result in immediate and delayed memory more similar to the younger adults' memory performance?

The predictions based on the effortfulness hypothesis were that the younger group with no hearing loss and better temporal processing should have the highest recall scores in both the degraded and enhanced listening conditions. The older adult musician group should demonstrate the next highest memory performance scores. The expectation was that older musicians, even those with ARHL, have better temporal processing ability more similar to the younger adults, which acts as a further enhancement to the listening and decrease the effort, freeing up resources for encoding for later recall. The younger adult group and the older musicians should demonstrate memory performances that are more similar to each other. The older musicians should perform significantly better by reporting more critical units when compared to the older non-musicians. Lastly, the older non-musician group would have the poorest memory performance, as they would have both age-related acuity deficits and age-related temporal processing decline. The older non-musicians would demonstrate significantly fewer critical units reported during the memory performance in both listening conditions when compared to the older musician and the younger non-musician groups. Figure 8 depicts the immediate and delayed memory performance in the degraded and the enhanced listening condition by group and shows this expected trend.

Immediate memory performance. In order to determine if the visual trend observed in Figure 8 was a significant finding, a pair of ANOVAs using a Bonferroni correction for multiple comparisons were used to compare the groups for immediate recall by listening condition.

In the degraded listening condition there was a significant difference among the groups, $F\ (2, 60) = 8.82$, $p <.001$. The younger group demonstrated better immediate recall, $M_{\text{younger nonmusic}} = 33.6$, $SD = 2.91$, compared to the older non-musician group, $M_{\text{older-nonmusic}} = 28.1$, $SD = 4.92$, p < .001, and the older musician group, $M_{\text{older musician}} = 29.48$, $SD = 4.79$ $p =.01$. There was no difference between the older musicians and older non-musicians in the degraded listening condition, $p = .94$.

In the degraded listening condition, the younger non-musician group demonstrated the highest number of critical units recalled in the immediate memory performance compared to both older adult groups, musicianship did not significantly improve the memory performance when the listening was degraded for older adults.

In the enhanced listening there was a significant difference among the groups, F (2, 60) = 5.70, p = .006. The younger non-musician group demonstrated better immediate recall $M_{\text{younger nonmusic}}$ = 33.55, SD = 2.01, compared to the older non-musician group, $M_{\text{older-nonmusic}}$ = 30.45, SD = 3.58, p = .006, but not compared to the older musician group, $M_{\text{older-musician}}$ = 32.81, SD = 3.28, p = 1.0. In addition, there was a significant difference between the older musician, $M_{\text{older musician}}$ = 32.81, SD = 3.28, and the older non-musician, $M_{\text{older-non-musician}}$ = 30.45, SD = 3.58, p = .04 in the enhanced listening.

In the enhanced listening condition, the younger group's and the older musician group's mean immediate recall performances were not significantly different from each other, and these two groups showed the highest number of critical units recalled for the immediate memory performance. Also, the older musicians' mean immediate memory performance was better than the older non-musicians' in the enhanced listening condition.

These findings suggest that musicianship provides an additional enhancement to listening. While listening in the enhanced condition, the older musician group, despite having age-related hearing loss, demonstrated better immediate memory performance than the older non-musician group. In addition, the older musician group's immediate memory performance in the enhanced listening was not significantly different from the younger non-musician group.

Delayed memory performance. In order to determine if the visual trend observed in Figure 8 was a significant finding, a pair of ANOVAs and a Bonferroni correction for multiple comparisons were used to compare the groups for delayed recall by listening condition.

In the degraded listening condition there was a significant difference among the groups, $F\ (2, 60) = 9.22$, $p < .001$. The younger group demonstrated significantly better delayed recall, $M_{younger} = 28.6$, $SD = 4.01$, compared to the older non-musician group, $M_{older\text{-}nonmusic} = 22.05$, $SD = 5.48$, $p < .001$, and the older musician group, $M_{older\ musician} = 23.90$, SD = 5.3, $p = .01$. There was no significant difference between the older musicians and older non-musicians in the degraded listening condition, $p = .71$. In the degraded listening condition, the younger group demonstrated the highest number of critical units recalled in delayed memory performance compared to both older adult groups, musicianship did not significantly improve the delayed memory performance when the listening was degraded for older adults.

In the enhanced listening there was a significant difference among the groups, $F\ (2, 60) = 8.61$, $p = .001$. The younger non-musician group demonstrated significantly better delayed recall $M_{younger} = 30.7$, $SD = 3.80$, compared to the older non-musician group, $M_{older\text{-}nonmusic} = 24.7$, SD = 5.33, $p < .001$, but not compared to the older musician group, $M_{older\text{-}musician} = 28.24$, SD = 4.54, $p = .28$. In addition, the older musician group demonstrated a higher number of critical units recalled, compared to the older non-musician, $p = .05$ in the enhanced listening. In the enhanced listening condition, the younger non-musician group and the older musician group were not significantly different from each other, (p = .28), and these two groups demonstrated the highest number of critical units recalled for delayed memory performance. Also, the older musicians' delayed memory performance was significantly higher in number of critical units recalled when compared to the older non-musicians' in the enhanced listening condition (p = .05).

Figure 8 reveals another interesting trend. The older musicians' delayed memory performance in the *degraded* listening appeared to match the older non-musicians' memory performance in the *enhanced* listening condition. A post hoc independent t-test was used to determine if this visual trend was a significant finding. Indeed, results indicated that when older musicians listened in the degraded listening condition their delayed memory performance was not significantly different from the older non-musicians when they listened in the enhanced listening condition, t (39) = 0.479, p = .64. This finding suggests that perhaps the temporal enhancement (time-expanded speech) in this experimental manipulation was similar to the temporal enhancement that older musicians experience due to their relatively more preserved temporal-spectral processing abilities. In this way, perhaps the older musicians' more stable and dynamic auditory processing abilities allowed them to perceive the degraded listening (time-compressed speech) as relatively less fast or less degraded (i.e., closer to a normal rate) than older non-musicians.

Delayed memory performance and the relationship with Hearing-Listening and Cognitive-Linguistic abilities

Correlation analyses were conducted to further explore the relationships between the individuals' hearing-listening and cognitive-linguistic characteristics and their delayed memory performance. The variables that reflected the hearing-listening ability as it relates to ARHL included in this analysis were LPTA4 and RPTA4, QuickSIN scores, and HHIA. The musicianship scores were used to define the three groups as young non-musician, older musician, and older non-musician, therefore musicianship scores were not entered into the correlation analyses.

The variables that reflected the cognitive-linguistic characteristics that may be associated with the memory performance included in this analysis were L-span, FAS, BNT, and backward digit span.

The memory measures that were included in these correlation analyses were the delayed memory performance in the degraded (time-compressed in noise) and in the enhanced (time-expanded in quiet) listening condition. These relationships were examined separately among the three groups, younger non-musicians and older musicians and older non-musicians.

Hearing-listening abilities.

LPTA4 and RPTA4: Left and Right ARHL and delayed memory performance. There were no significant correlations for the LPTA4 or RPTA4 for the younger non-musicians, older musician or older non-musician groups in the degraded or the enhanced condition. (see Tables 22-25 for *r*, and *p* values).

Table 22

Correlation analysis between delayed memory performance and hearing and cognitive abilities - Experiment 3 Entire sample

	Del.Mem.Deg	Del.Mem.Enh	LPTA4	RPTA4	HHIA	QuickSIN	L_Span	Digits_Back	FAS
Del.Mem.Enh	.58**								
LPTA4	-.04	.03							
RPTA4	-.02	-.04	.88**						
HHIA	-.42**	-.22	-.12	-.17					
QuickSIN	-.41**	-.24	-.14	-.12	.56**				
L_Span	.41**	.31*	.003	-.03	-.35**	-.25*			
Digits_Back	.25	.20	.16	.12	-.18	-.21	.46**		
FAS	.19	.18	-.05	-.05	-.05	-.16	.09	.10	
BNT	.39**	.42**	.15	.25	-.20	-.35**	.07	.12	.36**

Note. Del.Mem.Deg = Delayed Memory Degraded, Del.Mem.Enh = Delayed Memory Enhanced, HHIA = Hearing Handicapped Inventory for Adults (HHIA), Digit Back = Backward Digit Span.
**p* < .05, ***p* < .01

The lack of significant findings for a relationship of ARHL, as measured by LPTA4 and RPTA4, and delayed memory performance in both older musician and non-musician group was an unexpected finding, it was however expected regarding the younger adults since as a group they did not demonstrate ARHL (see Table 19 for hearing characteristics by group).

HHIA: Self-perception of hearing handicap and delayed memory performance. The Hearing Handicap Inventory for Adults (HHIA) may capture aspects of hearing beyond poor auditory acuity, such as listening effort, cognitive abilities and self-efficacy for hearing handicap (CHABA, 1988).

First, a correlation analysis was used to determine if the perception of hearing handicap measured by the HHIA, significantly correlated with QuickSIN and LPTA4 and RPTA4 for the participants in this study. In the younger non-musician group there were no significant correlations for HHIA and QuickSIN, LPTA4 and RPTA4 (see Table 23 for r and p values). In the older non-musician group there were significant correlations for HHIA and QuickSIN, $r = .53$, $p = .02$; but not with LPTA4, $r = -.26$, $p = .26$; or RPTA4, $r = -.41$, $p = .07$ (see Table 24 for r and p values). In the older musician group there were significant correlations for HHIA and QuickSIN, $r = .83$, $p < .001$; but not with LPTA4, $r = -.24$, $p = .30$; or RPTA4, $r = -.23$, $p = .31$ (see Table 25 for r and p values). These findings suggest that perception of hearing handicap in the older adult groups was correlated with listening-in-noise ability (QuickSIN), but not with auditory acuity (LPTA4 and RPTA4).

To determine if perception of hearing handicap (HHIA) scores were associated with delayed memory performance a correlation analysis was used. In the younger group there were no significant correlations for the HHIA scores for the degraded, $r = -.34$, $p = .14$, or for the enhanced, $r = -.02$, $p = .93$ listening condition. In the older non-musician group there were no significant correlations for the HHIA scores for the degraded, $r =-.25$, $p = .30$, or for the enhanced, $r = -.35$, $p = .13$ listening condition. In the older musician group there was a significant correlation for the perception of hearing handicap (HHIA scores) for the degraded, $r = -.57$, $p = .007$, but not for the enhanced, $r =.01$, $p = .68$ listening condition (see Tables 22-25 for *r* and *p* values).

The significant correlation of HHIA in the degraded listening condition for older musicians reported above would be considered to be a large effect size (Cohen, 1992). The relationship of self-perception of hearing handicap and delayed memory performance was non-significant in the enhanced listening condition for all groups.

Table 23

Correlation analysis between delayed memory performance and hearing and cognitive abilities - Experiment 3 Younger Non-Musician Group

	Del.Mem.Deg	Del.Mem.Enh	LPTA4	RPTA4	HHIA	QuickSIN	L_Span	Digits_Back	FAS
Del.Mem.Enh	.47*								
LPTA4	.15	.17							
RPTA4	.21	.07	.89**						
HHIA	-.34	-.02	.10	.04					
QuickSIN	.05	-.17	-.27	-.37	-.23				
L_Span	.64**	.31	.01	-.004	-.36	.02			
Digits_Back	-.07	.25	.22	.19	.14	-.36	.36		
FAS	-.11	-.001	.06	-.04	.26	-.19	-.15	-.02	
BNT	-.41	-.003	-.17	-.10	.27	-.44	-.32	-.10	.41

Note. Del.Mem.Deg = Delayed Memory Degraded, Del.Mem.Enh = Delayed Memory Enhanced, HHIA = Hearing Handicapped Inventory for Adults (HHIA), Digit Back = Backward Digit Span.
*p < .05, **p < .01

Table 24

Correlation analysis between delayed memory performance and hearing and cognitive abilities - Experiment 3 Older Non-Musician Group

	Del.Mem.Deg	Del.Mem.Enh	LPTA4	RPTA4	HHIA	QuickSIN	L_Span	Digits_Back	FAS
Del.Mem.Enh	.58**								
LPTA4	.26	.18							
RPTA4	.36	.38	.92**						
HHIA	-.25	-.35	-.26	-.41					
QuickSIN	-.53*	-.46*	-.34	-.34	.53*				
L_Span	.14	-.05	.05	.04	-.37	-.49*			
Digits_Back	.06	-.10	.11	.04	-.30	-.17	.54*		
FAS	.45*	.27	-.22	-.23	-.14	-.35	-.06	-.27	
BNT	.65**	.63**	.19	.42	-.14	-.31	-.14	-.28	.19

Note. Del.Mem.Deg = Delayed Memory Degraded, Del.Mem.Enh = Delayed Memory Enhanced, HHIA = Hearing Handicapped Inventory for Adults (HHIA), Digit Back = Backward Digit Span.
*p < .05, **p < .01

Table 25

Correlation analysis between delayed memory performance and hearing and cognitive abilities - Experiment 3 Older Musician Group

	Del.Mem.Deg	Del.Mem.Enh	LPTA4	RPTA4	HHIA	QuickSIN	L_Span	Digits_Back	FAS
Del.Mem.Enh	.36								
LPTA4	.08	.22							
RPTA4	.07	-.12	.83**						
HHIA	-.57**	.10	-.24	-.23					
QuickSIN	-.48*	.07	-.14	-.09	.83**				
L_Span	.19	.13	.28	.27	-.26	-.15			
Digits_Back	.63**	.34	.23	.21	-.06	-.10	.44		
FAS	.25	.06	-.17	-.15	-.03	-.15	.08	.40	
BNT	.68**	.45*	.24	.16	-.41	-.54*	.32	.67**	.41

Note. Del.Mem.Deg = Delayed Memory Degraded, Del.Mem.Enh = Delayed Memory Enhanced, HHIA = Hearing Handicapped Inventory for Adults (HHIA), Digit Back = Backward Digit Span.
**p* < .05, ***p* < .01

QuickSIN: listening-in-noise ability and delayed memory performance. There was a significant negative correlation for the QuickSIN scores with delayed memory for the older non-musician group in the degraded, $r = -.53$, $p = .02$, and in the enhanced, $r = -.46$ $p = .04$ listening condition.

There was a significant negative correlation for the QuickSIN scores for the older musician group in the degraded, $r = -.48$, $p = .03$, but not in the enhanced, $r = .07$ $p = .76$ listening condition.

There were no significant correlations for the QuickSIN scores and delayed recall performance in the younger non-musician group in the degraded or the enhanced condition (see Tables 22-25 for *r*, and *p* values).

The older musician and older non-musician groups' correlations reported above (.43 to .53), demonstrate a medium to large effect size (Cohen, 1992). Again, the magnitude of the effect size became smaller and non-significant when the listening condition was more favorable, that is in the enhanced listening condition.

It was still possible that using MCL in dB HL and not an absolute sensation level for the presentation of the stimuli, may have influenced the results of the delayed memory performance, even though there were no differences in sensation levels (db SL) among the three groups (Younger non-musicians, Older musicians and Older non-musicians). As described previously, poor tolerance to the intensity of the stimuli may differentially affect the delayed memory performance for the two listening conditions. To further examine this possibility a correlation analyses between the sensation levels in dB SL and delayed memory performance in the degraded and enhanced listening condition were conducted for the entire sample. There were no significant correlations between sensation level presentation of the stimuli and delayed memory performance in either the degraded or enhanced listening for the participants in this experiment (see Table 11 for *r* and *p* values).

Cognitive-linguistic characteristics.

L-span: working memory ability and delayed memory performance. There were significant positive correlations for the L-span scores and delayed memory performance for the younger non-musician adult group in the degraded, $r = .64$, $p = .002$, but not in the enhanced, $r = .31$, $p = .19$ listening condition.

There were no significant correlations for the L-span scores and delayed memory performance for the older non-musician or older musician groups in either the enhanced, or the degraded listening condition (see Tables 24 and 25 for *r* and *p* values).

In the younger group, there were no other significant correlations of cognitive-linguistic scores (e.g. BNT, FAS, and Digits Backwards) and delayed memory performance in either listening condition (see Table 23).

Backward Digit Spans: short-term memory ability and delayed memory performance. There were significant positive correlations for the Backward Digit span scores and delayed memory performance for the older musician group in the degraded, $r = .63$, $p = .004$, but not for the enhanced, $r = .34$, $p = .16$ listening condition. There were no significant correlations for the backward digit span scores and delayed memory performance for the younger or older non-musician group for either listening condition (see Tables 23-24 for r and p values).

Thus there is a large effect size for the relationship between short-term memory and delayed memory performance (Cohen, 1992). The magnitude of that effect became smaller when the listening condition was more favorable for the older musician adult.

FAS: executive function ability and delayed memory performance. There was a significant positive correlation for the FAS scores for the older non-musician group in the degraded, r = .45, p = .05, but not for the enhanced, r = .27, p = .25 listening condition. There were no significant correlations for the FAS scores and delayed memory for the younger group or older musician group for either listening condition (see Tables 23-25 for r and p values).

Thus there is a medium-large effect size for the relationship between executive function and delayed memory performance (Cohen, 1992). The magnitude of that effect became smaller when the listening condition was more favorable for the older non-musician group. Younger non-musicians and older musicians delayed memory performance was not significantly related to executive function in either the degraded or enhanced listening condition.

Boston Naming Test (BNT): Naming/verbal fluency ability and delayed memory performance. There were significant positive correlations for the BNT scores and delayed memory performance for the older non-musician group in the degraded, $r = .65$, $p = .002$, and in the enhanced, $r = .63$, $p = .003$ listening condition. There were significant positive correlations for the BNT scores and delayed memory performance for the older musician group in the degraded, $r = .68$, $p = .001$, and in the enhanced, $r = .45$, $p = .04$ listening condition. There were no significant correlations for the BNT scores and delayed memory performance for the younger group for either listening condition (see Tables 22-25 for r and p values).

The above values would be considered a medium to large effect size (Cohen, 1992). The magnitude of the relationship between lexical ability and delayed memory became smaller when the listening condition was more favorable (i.e., enhanced condition relative to the degraded condition) for both the older musician and older non-musician adult groups.

Summary of Results and Discussion - Experiment 3

Listening condition. The degrading (time-compressed with noise) or enhancing (time-expanded in quiet) of the listening condition affected learning and memory performance in the younger non-musician, older musician, and older non-musician adult groups. The degraded listening condition resulted in poorer learning and memory performance for the groups, *a degradation effect*, and enhanced listening improved learning and memory, *an enhancement effect*.

Learning efficiency. The learning efficiency performance of the groups was differentially affected by the two listening conditions (degraded and enhanced). Younger non-musicians performed more similarly in the two listening conditions for learning efficiency. Older non-musicians performed less similar in the two listening conditions for learning efficiency (i.e., greater difference in learning efficiency performance for degraded and enhanced listening compared to the younger non-musician group). This result indicates that they either benefitted more so from the enhancements or were more negatively affected by the degradation of the stimuli. However, the older musicians had the greatest difference in learning efficiency performance between the two listening conditions and appeared to have benefitted the most from the enhancements and were less negatively affected by the degrading when compared to the older non-musician group.

Immediate memory. The immediate memory performance of the groups was differentially affected by the two listening conditions. Similar to learning efficiency the younger non-musician's immediate memory was more similar in the enhanced and the degraded listening. Older non-musicians benefitted more so from the enhancements (larger differences between degraded and enhanced listening), however again the older musicians benefitted the most from the enhancements and were less negatively affected by the degrading when compared to the older non-musician group.

Immediate memory performance in the degraded condition revealed that younger adults performed better than both older adult groups (non musicians and musicians). The older musicians and older non-musician's immediate memory performance did not differ significantly in the degraded listening condition.

However, this was not the case in the enhanced listening condition. The younger group's memory performance was better than the older non-musician group, but younger non-musicians and older musicians did not differ in immediate memory performance. Also older musicians' immediate memory was significantly better compared to the older non-musicians in the enhanced listening condition. These results suggest a musicianship benefit for immediate memory in which older musicians perform more similarly to younger adults and significantly better than an older non-musician group matched for age and hearing loss.

Delayed memory. The delayed memory performance of the groups was not differentially affected by the two listening conditions. All three groups demonstrated a similar pattern of poorer delayed memory performance in the degraded listening compared to the enhanced listening condition. The younger group's delayed memory performance was more similar in the two listening conditions (i.e., differed by only 2.1 units). The older non-musicians had a larger numeric difference between the degraded and enhanced listening condition (2.65 units), and the older musicians had the largest numeric difference between degraded and enhanced listening for delayed memory (4.33 units). Although these values did not result in a statistically significant group by listening condition interaction, there was a numeric trend consistent with the predictions.

Additionally, post hoc comparison of means between the older musician and older non-musician groups demonstrated that the older musicians benefitted more so from the enhancements relative to the older non-musician adults by recalling a significantly higher number of critical units.

In the degraded listening condition the younger adults performed better in their delayed memory performance relative to both older non-musicians and the older musicians. The older non-musicians and the older musicians did not differ for delayed memory performance in the degraded listening condition. Musicianship did not improve delayed memory performance when the listening condition was degraded. The finding that older non-musicians and older musicians did not differ in delayed memory performance in the degraded listening condition suggests that the age-related acuity deficit (RPTA4 and LPTA4) is interacting with the noise and the time-compressed speech stimuli and results in similarly poorer performance.

In the enhanced listening condition the younger non-musicians' delayed memory performance was better than the older non-musicians. Older musicians demonstrated better delayed memory compared to the older non-musicians, and were not significantly different from the younger non-musician group in delayed memory. The finding that the older musicians' delayed memory performance in the *degraded* listening was not significantly different from the older non-musicians' memory performance in the *enhanced* listening condition suggests that the training-experience of instrumental music (i.e., preserved temporal-spectral processing abilities) may act as a further listening enhancement.

These findings suggest that musicianship provides an additional enhancement to listening. While listening in the enhanced condition, the older musician group demonstrated better memory performance than the older non-musician group. In addition, the older musicians' memory performance resembled the younger non-musician group.

Hearing-listening and cognitive-linguistic characteristics. There were no significant relationships between aspects of ARHL (RPTA4, LPTA4, listening-in-noise, and perception of hearing handicap) and delayed memory performance in the younger non-musician group. This was an expected finding as the younger non-musician group did not exhibit ARHL. This was not expected for the older non-musician and older musician group.

Despite finding no relationship between PTA4 and delayed memory performance in the older non-musician and older musician groups, there were negative correlations between listening-in-noise ability (QuickSIN) and delayed memory performance in both the older musicians and older non-musicians. The magnitude of this effect was larger in the degraded listening relative to the enhanced listening condition. Similarly, there were significant negative correlations between self-perception of hearing handicap (HHIA) and delayed memory performance in both the older musicians and older non-musicians, with the magnitude of this effect being greater in the degraded relative to the enhanced listening.

These findings suggest that the right and left ear acuity deficits (i.e., PTA4) are less predictive of listening effort in these three groups. This finding is consistent with the studies that demonstrate that poorer speech recognition scores and reports of effortful listening are not consistently predicted based on the audiometric profiles (acuity deficits) for older adults (CHABA, 1988).

In relation to cognitive-linguistic characteristics, there were positive correlations between executive function and lexical abilities and delayed memory performance in the older adult groups (musicians and non-musicians). The magnitude of the effect size was medium to large.

Delayed memory performance scores were positively correlated with strengths in executive function and lexical abilities, more so when listening was more difficult as in the degraded listening condition.

Taken together these results suggest, for both groups of older adults musicians and non-musicians alike, that when listening is degraded and hence more effortful, memory performance is more positively correlated with strengths in executive function ability and lexical abilities than with acuity. In addition, when two groups of older adults are matched for age and acuity deficits (i.e., LPTA4 and RPTA4), delayed memory performance is not predicted by their auditory acuity deficit (PTA4). However, a greater perception of hearing handicap (HHIA) was negatively related to memory performance, and better listening in noise ability (QuickSIN) was positively related to memory performance in the older adult groups. The magnitude of the effects became smaller in the easier enhanced listening condition (time-expanded speech in quiet).

The findings in which the older musician group performed significantly better than the older non-musician group is suggestive of the following. It may be the older non-musicians' less preserved spectral and temporal processing which further contributes to greater listening effort. In other words, perhaps there is an interaction of the acuity deficit (LPTA4 and RPTA4) with the age-related decline in temporal-spectral processing. The less dynamic and less stable temporal processing of the older non-musician with ARHL contributes to the listening effort by further degrading the stimuli and this results in an increase in the distractor effect (Lavie, 2005). The less dynamic and stable temporal-spectral processing abilities of the older non-musician with ARHL results in a more novel listening environment (i.e., less consistency of the sub-lexical acoustic stimuli) and this in turn decreases the perceptual learning and/or adaptation. The impact of a greater distractor effect and/or a decrease in perceptual learning then requires those cognitive-linguistic resources to discern the meaning of the message; these resources would otherwise be allocated for memory encoding.

Or similarly, the impact of the age-related acuity deficit (LPTA4 and RPTA4) in the older musicians may be partially or completely *mitigated* by their more preserved temporal-spectral processing abilities. In this way, the more preserved dynamic and stable temporal processing ability of the older musician (and younger adult) may promote listening ease and better learning and memory performance in the following ways: the distractor effect is reduced to a larger extent by the higher fidelity target stimuli (Lavie, 2005); the targeted stimuli (i.e., sub-lexical acoustic features) are more stable and consequently less novel, which allows for the learning effect to operate so that the listener is able to more efficiently perceptually learn or adapt to the speaker's pattern. Auditory stream segregation of the message is more efficient in that it is rapid, automatic and implicit. Thus in this way fewer cognitive-linguistic resources are required explicitly to discern the meaning in the message freeing these resources for encoding for later recall.

The findings in Experiment 3 suggest that decreased memory performance is not purely the result of a degraded stimulus (from cochlear hearing loss) delivered to the memory processes for encoding, in which the trace is less useful for memory redintegration, as would be suggested by a strict interpretation of the information degradation hypothesis. Instead, the results from this experiment support the effortfulness hypothesis. When older adults with ARHL listen to degraded stimuli in difficult listening conditions, cognitive-linguistic processes are required for successful deciphering or decoding of the auditory message. These limited capacity cognitive resources (Kahnemann, 1973) are consumed by the primary task (that is, decoding the message for meaning), and therefore come at the cost of those cognitive-linguistic processes required for encoding for later recall.

General Discussion

The purpose of this study was to examine how auditory perception and processing of a relatively degraded message (time-compressed and/or conversational speech in noise presented in sound field) affected learning and memory performance and whether auditory perceptual and processing enhancements (clear speech and time-expanded speech presented through insertion earphones) improved learning and memory performance with ecologically valid stimuli; medical prescription instructions. This was examined in groups of younger normal hearing adults and older adults with varying levels of ARHL. This was done in order to examine how specific aspects of age-related auditory perception and processing changes influence learning and memory performance. Ultimately, the study explored whether ‘effortful listening,’ a hypothesized causal mechanism for the role of ARHL in cognitive (memory) decline, could be remediated through mechanisms that mitigate the impact of effortful listening. In so doing, the results of this study shed light on how sensory perception and processing declines in the older adult affect the implicit experience-dependent perceptual learning processes. This disruption to the perceptual learning processes then has cascading effects on higher-level cognitive-memory processes. Additionally, facilitating listening ease through extensive listening training (i.e., a musicianship benefit) for the older adults, even those with age-related acuity deficits, maintained more of the automatic implicit auditory processing and perceptual learning. The implications of the musicianship benefit in an ecologically valid task suggest that opportunities exist for prevention or even reversal of cognitive-memory declines in an older adult population.

Two related hypotheses were proposed to explain why degrading or enhancing the temporal-spectral perceptual aspects of the message would serve to decrease or increase memory performance: the information-degradation hypothesis (Schneider & Pichora-Fuller, 2000) and the effortfulness hypothesis (Rabbitt, 1968, 1990). These related hypotheses predict similar results in that the degraded listening condition (time-compressed or conversational speech in noise) should result in poorer learning and memory performance relative to the enhanced listening (time-expanded or clear speech in quiet). Also, older adults with ARHL perform more poorly than younger adults with normal hearing. However, the two hypotheses differ in their predictions in regard to the role of perceptual learning/adaptation, and the relationships of cognitive-linguistic abilities with learning and memory performance in the degraded and enhanced listening conditions.

The *information (perceptual) degradation hypothesis* (Schneider & Pichora-Fuller, 2000) suggests that ARHL results in unclear or distorted messages delivered to the cognitive-memory processes. These degraded memory traces are less useful for redintegration for retrieval of the message and therefore learning and memory performance is negatively affected. A strict interpretation of this hypothesis is that there is no interaction between the perceptual systems and the cognitive-memory processes; instead the effects are temporary and do not result in changes to the cognitive-linguistic processes per se. The predictions based on this hypothesis are that the more degraded the stimuli the greater the impact on learning and memory, with poorer overall memory performance in degraded relative to enhanced listening. In this way a greater degree of

ARHL should always more strongly correlate with poorer learning and memory performance independent of the individual's cognitive-linguistic abilities.

However, the *effortfulness hypothesis* (Rabbitt, 1968) suggests that when individuals listen to a degraded signal (due to adverse listening condition or the individual's ARHL), successful speech discrimination comes at the cost of limited-capacity resources (Kahneman, 1973). Under less effortful listening conditions, these limited-capacity resources would normally be used for encoding the information for later recall. Instead, they are re-allocated to cognitive-linguistic processes necessary for understanding speech. ARHL increases listening effort due to increased perceptual, lexical and cognitive loads for decoding the information for communication purposes. This listening effort comes at the cost of those same resources needed for the secondary task, elaborate encoding processes for later recall. The predictions based on the effortfulness hypothesis are that participants will demonstrate poorer learning and memory performance in the degraded listening relative to enhanced listening condition. Younger participants without hearing loss will perform better on learning and memory in the two listening conditions relative to the older adults. The older adults with greater ARHL will be differentially affected (i.e., more extremely) by the degrading and enhancing of the message, that is, more negatively affected by the degraded listening, and benefit more so from the enhanced listening condition. In addition, that ARHL may be compensated for by those with greater capacity or efficiencies in sharing of those cognitive-linguistic resources required for the two tasks (comprehension and recall). This hypothesis predicts then that individual strengths in cognitive-linguistic abilities are positively associated with learning and memory performance with the magnitude of that relationship being greater in the degraded listening relative to the enhanced listening.

Taken together the results of these three experiments were as predicted and best explained by the effortfulness hypothesis. Although an information-degradation hypothesis can account for some of the findings such as the younger and older adults demonstrating poorer learning and memory performance in degraded relative to enhanced listening conditions, it does not explain all the findings. The information-degradation hypothesis does not account for the interaction between the perceptually degraded stimuli and the cognitive-linguistic processes employed to discern the meaning. This interaction was evident in the differential impact of the *learning effect* during the clear versus conversational speech in Experiment 1. Also, in all three experiments, the magnitude of the effect size for the relationship between cognitive-linguistic abilities and learning and memory performance was greater in the degraded relative to the enhanced listening condition. As a within-subject variable, this differential effect indicates that strengths in these cognitive-linguistic abilities are related to better memory performance more so when the listening condition demands these resources in effortful listening, and less so when the listening condition is relatively more effortless.

ARHL and Cognition – Impact and Interactions

Experiment 1 demonstrated that temporally enhancing the message by using a ‘clear speech’ technique resulted in better learning and memory performance in two groups of older adults matched for age and ARHL. It also showed that the clear speech technique compared to conversational style speech reduced the negative impact that the competing noise had on learning and memory. Third, the finding that there was the largest learning effect on 2nd trial performance in the conversational speech after the clear speech listening condition was the first trial of the experiment is suggestive of a greater perceptual learning or adaptation to the speaker's speech and voice pattern. This is suggestive of the role that experience-dependent perceptual learning plays for facilitating or interfering with memory encoding.

Experiment 2 demonstrated that when younger and older groups experienced effortful listening (degraded with time-compression and noise) they learned and remembered less of the information, and when they experienced effortless listening (enhanced with time-expansion in quiet) they learned and remembered more of the information. Also, older adults' immediate memory performance in effortless listening was not significantly different from the younger adults' in the effortful listening condition on the first 5 trials of learning (Figure 7).

However, it is important to note that this was not the case for immediate memory performance on trials 6-10. The second 5 trials of learning for the older adults in the enhanced listening condition (effortless) compared to the younger adults in the degraded listening condition (effortful) revealed two different patterns of learning. The older adults' pattern was consistent with a trend of diminishing immediate memory performance (i.e., reporting fewer critical units over the last three trials of learning) and a downward curve. The younger adults demonstrated a trend of a plateau in learning of the last three trials to criteria (i.e., reporting no additional critical units on the last three trials) so that the curve flattens or asymptotes. However, since the design and methods in this experiment did not require that all participants perform trials 6-10, this visual trend could not be examined with statistical tests (i.e., there were too few younger adults and older adults completing trials 6 - 10 of learning). Although these patterns were not examined explicitly, the differential impact of listening condition between the older group in effortless and younger adults in effortful listening on the second 5 trials of learning is suggestive of proactive interference (PI), memory for earlier trials interfering with memory for later trials (Neath & Surprenant, in press). The role of PI is an important area warranting further investigation. PI may be yet another contributing factor of the effort in listening for the older adult with ARHL.

In Experiment 2, ARHL was negatively related to delayed memory performance with a greater magnitude of that effect when the listening was effortful compared to when it was relatively more effortless. Cognitive-linguistic abilities were positively related to delayed memory performance with greater magnitude of that effect when the listening was effortful compared to when it was effortless. These findings demonstrate that when the individual experiences effortful listening (i.e., degraded with time-compression and irrelevant speech babble or due to distortions arising from the ARHL), those cognitive-linguistic abilities are employed for the comprehension of the message for communication purposes. Those individuals with a greater capacity or efficiencies in employing explicit use of these resources will have residual resources for subsequent memory encoding.

Experiment 3 demonstrated that when an older musician group experienced effortful listening they too learned and remembered less well than when they experienced effortless listening. However, the older musician group's 'trained listening' and presumed enhanced temporal-spectral processing abilities seemed to further enhance their memory performance relative to the older non-musician group, as demonstrated by the following: 1) Older musicians with ARHL were less negatively affected by the degraded listening condition. 2) Older musicians with ARHL benefitted more so from the enhancements. 3) Older musicians with ARHL performed more similarly to the younger adults in the enhanced listening condition, in that their learning and memory performance was not significantly different from the younger non-musician group's immediate and delayed memory performance. 4) In addition, the older musicians' delayed memory performance in the enhanced listening condition was significantly better than the older non-musicians' even though the groups were matched for age and hearing loss (i.e., PTA4 or high-frequency auditory acuity deficit). 5) The older non-musicians' delayed memory performance in the enhanced listening was not significantly different from the older musicians' in the degraded listening condition. These findings suggest that the 'trained-expert listening' of the older musician preserves neural encoding in a way that may be similar to the experimental enhancements (time-expanded speech) used in the effortless listening condition. However, since the temporal processing ability of the older musician participants in this study was not directly assessed, the suggestion that it is an enhanced temporal processing ability of the musician that enhanced memory performance in this study is purely speculative. Musicianship may have provided a temporal, a spectral, or a temporal-spectral benefit.

Finally, the result that the older musicians' delayed memory performance in the degraded listening condition was not significantly different from the older non-musicians' is suggestive of an interaction between the ARHL with the temporally degraded stimuli (time-compressed) and the noise (irrelevant speech babble). This last finding of an interaction indicates a confounding effect of the degraded listening condition on memory performance. It appears that these degrading factors reached a threshold in which an instability or inefficiency to employ compensatory processes to offset the impact of ARHL resulted. This indeed may be the scenario the older adult experiences in listening in the real-world environment. The result of the older musicians' immediate and delayed memory performance not being significantly different from the younger adults' in the enhanced listening condition suggests causal inference of ARHL as an underlying mechanism contributing to memory decline.

Mistuning subcortical processes – loss of perceptual learning. Kraus and colleagues have consistently demonstrated that in populations with ongoing specialized auditory-verbal training (bilinguals and musicians) the neural specialization continues to maintain the higher fidelity of the auditory message delivered to the perceptual-learning processes (Krizman et al., 2012; Krizman, Skoe, Marian, & Kraus, 2014; Strait, 2013; Strait & Kraus, 2014). That is to say that the fidelity of the auditory message more highly correlates with the cABR neural signal and is highly correlated with those neural signals seen in younger adults.

This enhanced auditory message then allows the more automatic and implicit perceptual-learning processes to operate so that the individual is able to attend to the salient acoustic features and map sound to meaning (i.e., phonemes), segment those sound units into meaningful parts (e.g., "quarter back"), and identify the speaker from the soundscape. This enhanced listening environment therefore decreases the perceptual, lexical and cognitive load on discerning the message for meaning for communication purposes (Mattys et al., 2009; Mattys & Wiget, 2011; Mattys et al., 2012). Those cognitive-linguistic processes that are required for the secondary task, elaborate encoding to facilitate retrieval/recall are then more efficient and stable and then are not consumed by the primary task (comprehension).

However in non-bilingual, or non-musician older adult populations there is a decrease of the fidelity of the neural signal in that it correlates less well with the auditory stimuli with age. Perhaps it is the loss of the continuous neural specialization, the tuning of the neural pathways, due to an incipient sensori-neural hearing loss of the middle-aged adults, that serves to degrade the fidelity of the acoustic signal delivered to the sub-cortical perceptual processes for learning (information-degradation hypothesis).

The older adult with age-related hearing loss then starts auditory processing with a disadvantage; a lesser or poorly tuned subcortical auditory neural system. This disadvantaged 'poorly tuned' peripheral auditory processing mechanism is then processing the incoming auditory-verbal message that is additionally degraded by a combination of the individual's sensori-neural hearing loss (i.e., PTA4) and the noisy environment. This describes the listening condition of the older adults with ARHL during the degraded listening condition (time-compressed and noise) in Experiment 2 and 3.

This degradation overtaxes the auditory processing, decreasing the automaticity of perceptual processing, perhaps to the point in which it is intractable and results in failed comprehension. However, in the cases of successful understanding, the effort required for deciphering or decoding that message comes at the cost of those explicit cognitive-linguistic processes. The older adult recruits higher cognitive (e.g., attention, memory, inhibition, fund of knowledge) and linguistic processes (e.g., phonologic, syntactic, semantic transitional probabilities) to fill in to decode the auditory stream at the cost of the secondary task, those same cognitive processes needed for encoding the information into memory.

Neural specialization from the bilingual's and musician's learning experience helps to ameliorate this disadvantage through improved subcortical auditory representations of sound (Kraus, 2012). These neural enhancements potentially facilitate a more automatic and efficient processing of sound, by mitigating the distractor effect, phase-locking on to the speaker, and thereby reducing the effort in deciphering and decoding of the auditory-verbal message, freeing up those resources for encoding for later recall.

Perhaps, it is this same auditory neural plasticity from experience-dependent learning, similar to the bilingual and the musical training, which is operating for older adults with ARHL (Zendel & Alain, 2012). However, instead of enhancing the representation of sound through the experience-dependent perceptual learning that 'tunes' the subcortical processes, it further degrades the sound representation, in other words 'mistuning' the subcortical auditory processing mechanism.

The individual's mistuned subcortical auditory processing mechanism is then required to process incoming auditory stimuli that are further degraded by the individual's acuity deficit (PTA4) and the noisy-reverberating listening environment. This would be similar to the confounding effects (Experiment 2 and 3) in the present study in which the older adult listened in the degraded listening condition with speech babble competition. The older adults (musicians and non-musicians) with ARHL subjected to the temporally-spectrally degraded stimuli with noise, demonstrated learning and memory performance that was significantly poorer compared to the younger adults in the same degraded listening conditions. However, making the listening relatively more *effortless* (time-expanded in quiet) mitigated some aspects of the older adults' ARHL and resulted in significantly better memory performance compared to the *effortful* listening condition.

The negative relationship of the individuals' ARHL and delayed memory performance decreased in magnitude during the effortless listening condition compared to the effortful listening condition. Likewise, the positive relationship of the individuals' cognitive-linguistic abilities and delayed memory performance decreased in magnitude during the effortless listening condition compared to the effortful listening condition. These differential relationships of both ARHL and cognitive-linguistic abilities with delayed memory performances are suggestive of the role of compensatory mechanisms (Wild et al., 2012). Indeed this may be what accounts for the greater variability in memory performance with increasing age (Salthouse, 2010). For the older adult with

ARHL, methods to either prevent or decrease this variability in listening ability will increase the stability and efficiency of those higher-level cognitive processes - memory.

For example, as Jenstad and Souza (2007) suggested, amplification systems could be configured specifically for the individual with age-related hearing loss (ARHL), so that the level of the distortion from the signal processing is set at a level so that it does not interact with fast conversational speech and a noisy-reverberating listening environment. In addition, a style of speech communication (clear speech and/or time-expanded speech) could be identified that optimizes the intelligibility benefit (speech that is more easily understood), specifically for the older adults with ARHL. Lastly, it is possible that older adults with ARHL could be trained in ways that 'exercise' those perceptual and/or cognitive processes that would serve to preserve their listening abilities (Kraus, 2012; Zendel & Alain, 2014). An eclectic approach would be to combine these three interventions to maximize listening ease for the older adult with ARHL. Ultimately, creating *effortless* listening for the older adult with ARHL could result in more stable and efficient cognitive ability (i.e., memory) and result in more functional independence.

Relevance of the problem

The population statistics that are cited in the introduction to this study point to a number of reasons why research exploring the relationship between sensory capabilities and cognitive performance is critical. First, older adults in North America are increasingly choosing, or are being forced by circumstances, to work beyond what had become the normal retirement age. The United States Census Bureau (2010) reports that in 2006 approximately 15% of those who traditionally are retired (65+ years) were still in the workforce and that the ratio of working-age people to retirement-age people will go from about 5-to-1 to 3-to-1in the next two decades (US Census Bureau, 2010). According to Statistics Canada (2011), the census data reveals that for the first time older adults, 55-64 years old, make up more of the work force than those who are just entering the work force, 15-24 years old. The evidence is clear that a greater number of older adults are remaining in the work force for a longer period of time. Therefore, the older adult has a continued high need for listening and remembering in order to remain functionally independent and actively engaged.

However, when it comes to diminishing hearing and cognitive abilities, the evidence is not clear regarding the consequences that these have on the older adult's functional performance on complex tasks. Specifically, what is the consequence of the interaction of ARHL and cognitive abilities for communication and the effect that this may have on memory performance for instructional activities of daily living (IADLs)? By using more ecologically valid stimuli with an experimental manipulation that can be readily applied to the real world listening environment, specific types of listening enhancements (clear speech or temporally-enhanced speech) can be assessed for treatment efficacy. By demonstrating direct links between effortful listening and memory performance, it is possible to then explore the specific mechanisms that improve the older adult's memory performance both externally and internally. One example of an external mechanism to improve the older adult's memory performance is through environmental improvements such as delivery of important information in enhanced listening conditions (e.g., sound treated rooms to reduce noise and reverberation). Another example is to train health-care professionals (such as pharmacists, physicians, nurses and allied health professionals) and other professionals who regularly interact with older adults (e.g., financial planners), to use slow 'clear speech', particularly if the listener demonstrates hearing or cognitive impairments or is at risk for same. Yet another example is to educate the middle age and older adult on the consequence of effortful listening on memory performance in order to promote self-efficacy for earlier management of a hearing impairment. Perhaps this will prevent the 'mistuning' of the auditory system. Further to this, enhancements can be made internally through access to sensory aids such as hearing aids, which are programmed in such ways as to minimize the distorting aspects of signal processing, and other personal listening devices (e.g., FM systems) that maximize a favorable signal to noise ratio. Additionally, listening practice or exercises that are similar to the progressive training of musicians that 'tunes' the individual's ability to process speech in adverse listening conditions can be explored (Orduña, Liu, Church, Eddins, & Mercado, 2012). Then one can determine the effectiveness for improvements in memory performance for other types of complex messaging that relates to employment (e.g., complex instructions for computer/internet, use of machinery/equipment, driving directions). Collectively these interventions, in turn will increase an individual's ability to remain an active member of the workforce as he or she grows older whether due to financial necessity or personal fulfillment.

Second, the direct costs of taking care of the older adult increases exponentially if he or she is no longer able to manage independently. The functional independent abilities to perform activities of daily living (ADLs) such as bathing, toileting, dressing and feeding oneself; as well as instructional activities of daily living (IADLs) such as paying bills, preparing meals, making appointments and taking medications, require sufficiently intact perceptual and cognitive abilities. In terms of health care cost and societal impact, those individuals with ARHL and mild cognitive impairment may be at a higher risk for earlier loss of independence with IADLs. Interventions that may delay the onset or mitigate the consequence of poorer auditory memory such as a loss of functional independence for IADLs (i.e., medication self-management, financial self-management, independent living) consequently can significantly reduce the financial and societal costs (Hurd, Martorell, Delavande, Mullen, & Langa, 2013). Beyond the improved functional independent performance of a task, it is important to determine the underlying causal mechanisms that may contribute to the declining cognitive function of the older adult. Understanding how these specific age-related changes in auditory perception and processing affects cognitive abilities, and determining the causal mechanism that may be operating, will inform both the researcher and the practitioner on potential prevention and intervention.

Specific to this study, in the case of the older adult with hearing loss, interventions that target these specific auditory perceptual processes that may contribute to a decrease in memory performance, may translate to an older adult population that maintains cognitive abilities, remains functionally independent longer, enjoys overall better health, and continues to be socially engaged as a contributing member to the community.

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Appendix A

Medical Prescription Vignettes: Medipatch, Puffer and Training item

The fictional medical prescription vignettes and the practice item used in all three experiments.

Bolded items represent the critical units to recall. The bolded numbers in parentheses at the end of each sentence represent the numbers of units to recall per phrase.

Medipatch : *This patch has a strong medication for pain and is delivered through the skin. Follow these instructions carefully.*

1. **Wash** your **hands** **_______(2)**
2. **Hold** the **patch** so that the **plastic backing/ faces you ______(4)**
3. **Peel** off **one side** of the **plastic backing __________(3)**
4. **Apply** the **sticky side to** your **body _________(3)**
5. **Hold** onto the remaining piece of **plastic backing** and **pull** the patch **across** your **skin ___(5)**
6. To **remove** the used/old **patch** /**press** in **center** and **peel** from **edges** away from skin. __**(6)**
7. **Flush** the protective plastic **backing** and the used/**old patches ___(3)**
8. **Medicine** may **remain on** an old **patch** and can be **dangerous** to **children and pets ___(6)**
9. **Wash** your hands well **after** applying or removing a patch ___**(2)**
10. **Store** your **medipatches** /**out of reach** ___(**3**) *Total units:_____/ 37*

Puffer/inhaler: This inhaler is your rescue puffer to help you breathe easier, the capsules are used inside the puffer. Follow these instructions carefully.

1. **Remove** the **blue cap** on your **rescue inhaler ___(3)**
2. **Hold** the inhaler at the **base** and **turn mouthpiece** in the **direction** of the **arrow ___(5)**
3. **Place** /**one capsule** in the **compartment** in the **base** of the inhaler **___(4)**
4. **Twist** the mouthpiece to the **closed position ___(2)**
5. **Hold** the inhaler **upright /squeezing /two /blue buttons** inwards to **pierce** the **capsule ___(7)**
6. **Breathe /out** fully, ___(2)
7. **Insert** the **mouthpiece into** your **mouth** and **inhale quickly** and **deeply ___(6)**
8. **Hold** your **breath for** a count of **ten ___(3)**
9. **Breathe out** /**gently** through your **mouth and nose**. **___(3)**
10. **Replace** the **cap ___(2)** ***Total units:*** *___/37*

Training/ Practice: What to do for aching joints. Follow these instructions carefully.

1. When you notice swelling or aching in your joints, a cold compress is helpful.
2. Wrap a bag of frozen peas in a dishtowel and place it on the joint.

Appendix B

Creation and Recording of the Auditory-verbal stimuli

Recording of the stimuli. The same male speaker of American English recorded the stimuli in a single recording session, using Avid Pro-tools 8.0.5 software. The recordings took place in a sound studio. The digitized uncompressed sound files were sent to a sound engineer at a 48kHz/24 bit sampling rate. The microphone used during the recording was an Audio-Technica 4033 condenser microphone with a pop filter. The speaker was a professionally trained, 24-year-old male with a bass-baritone voice (average F0 = 125Hz). The instructions to the speaker were to use a normal conversational rate and natural intonation pattern as he would for optimal clarity and intelligibility.

Speaking rates of the stimuli. The average speaking rate for the two experimental passages was 192.5 syllables per minute (spm), 189 spm for puffer and 196 spm for medipatch. According to Goldman-Eisier (1968), the normal rate of speech is between 138-258 spm, with rate varying depending on the speaker's geographic location, content of the message and emotional state. See the chart below for the rates of each passage in each listening condition.

Condition	Medipatch	Puffer-Inhaler
Original/conversational	196 syllables per min	189 syllables per min
Compressed/fast	304 syllables per min	296 syllables per min
Expanded/slow	165 syllables per min	159 syllables per min
Clear/slow	152 syllables per min	139 syllables per min

Training/practice vignette. A practice vignette was created so that the participants could understand the nature of the task with specific feedback provided during the training task. In addition, the training/practice item provided an opportunity to perform the task prior to the experimental condition to confirm that the intensity level determined during the audiometric testing as PB max-MCL was comfortably loud but not too loud. Participants could also become familiar with the speaker's voice and speech rate for the targeted message prior to the two experimental listening conditions.

The content of the training item was the exact same two-sentence vignette (see Appendix A). However, the training conditions matched the experimental listening condition. For example, the practice vignette was experienced as it was to be in the experimental listening condition. Therefore, in Experiment 1 for the *Quiet* group, the practice vignette was either conversational speech presented through the loudspeaker or 'clear speech' technique presented through the insertion earphones. In Experiment 1 for the *Noise* group, the practice vignette was either conversational speech in noise presented through the loudspeaker or 'clear speech' in noise presented through the insertion earphones. In Experiments 2 & 3, the practice vignette was either degraded, 65% time-compressed with speech babble noise presented through the speaker; or enhanced, 120% time-expanded in quiet presented through insert earphones. Immediately following the training item, the participants were reminded to perform the experimental task as they had been instructed and had just performed during the practice vignette.

Avid Pro-tools 8.0.5 computer software was used to manipulate the original sound files for the training passage and experimental vignettes to ensure that the recordings were equated for loudness across the stimuli and throughout the passages via root mean squared (RMS) for amplitude. Then Avid Pro-tools 8.0.5 was used to create the two auditory listening conditions.

Speech babble noise was used as the competition. The competition used in Experiment 1 for the Noise group and in Experiment 2 and 3 in the degraded listening condition was speech babble noise obtained from a public domain website, (http://spib.rice.edu/spib/data/signals/Noise/babble.html) at Rice University.

The Institute for Perception-TNO, The Netherlands Speech Research Unit, RSRE, United Kingdom produced the recording of the speech babble used in this study. The voice babble was acquired in a public canteen, and recorded with a condenser microphone. The source is approximately 100 people speaking in a room with a radius over two meters. The sample length was 235 seconds. Individual voices are slightly audible.

Playing the stimuli for the experiment and recording the participants' responses

GarageBand '11 version 6.0.5 (428.5) was the software program used to play the vignettes for the training and experimental listening conditions. The digitized sound files were loaded to separate tracks so that they could be individually attenuated to the appropriate intensity levels.

Four templates for the two listening conditions with the two different vignettes were created: medipatch degraded (conversational speech or compressed) and medipatch enhanced (clear speech or expanded); puffer-inhaler degraded (conversational speech or compressed) and puffer inhaler enhanced (clear speech or expanded). The appropriate experimental template was selected and then ‘saved as’ with the participants’ assigned number. The auditory stimuli were routed from a MacBook Pro computer via Apogee One, a studio quality USB music interface and microphone, to the auxiliary channels of the GSI-61 (e.g., channel 1 for the compressed or conversational speech vignette and channel 2 for the speech babble).

The participants’ responses to repeat the vignette after each listening trial, were recorded by an Apex 850 dynamic professional microphone positioned 6” from the middle of the chin. The recordings were routed via the Apogee One to the MacBook Pro computer. Each of the participants’ trials were recorded on separate tracks on line in GarageBand ‘11 and saved for later off-line scoring.

Appendix C

Demographic Questionnaire

EXP# _____Participant #_________________

What is your birth date (YYYY/MM/DD)_______________________________

What is your sex? (circle one) Male Female

What is the highest level of education you have obtained?

(circle one)

Some High School High school Some College/University

College/University Graduate Some Graduate School

Graduate School/Professional degree other___________________________

What is your occupation (or, if you are retired former occupation)?________________

Please list any medications you are currently taking:

___________________________ __________________________________

__________________________________ _____________________________

Please rate your overall physical health (circle one)

Excellent Very Good Good Poor Very Poor

Do you consider yourself to be an instrumental or vocal musician? (circle one)

YES NO

How many years have you been active in playing/singing music? _____________

How old were you when you started in music education? _____________

On average how often do you practice your music per week? ______________per week

On average how many hours do you practice per day? ___________per day.

How many languages do you speak?___________

Which languages do you speak?

____

Handedness (circle): RIGHT LEFT AMBIDEXTROUS

Appendix D

QuickSIN: Instructions and practice and sentences items.

Instructions for this Quick Speech in Noise test (QuickSIN)

The following instructions were read to the participant prior to completing the QuickSIN test. These are the standard instructions provided in the test manual.

"Imagine that you are at a party. There will be a woman talking and several other talkers in the background. The woman's voice is easy to hear at first, because her voice is louder than the others. Repeat each sentence the woman says. The background talkers will gradually become louder, making it difficult to understand the woman's voice, but please guess and repeat as much of each sentence as possible.

First let's do one for practice. Speak clearly into the microphone during this test so I can record your responses." (p. 6)

Practice sentences (Track 21) list A

The lake sparkled in the red hot sun.

Tend the sheep while the dog wanders.

Take two shares as a fair profit.

North winds bring colds and fevers.

A sash of gold silk will trim her dress.

Fake stones shine but cost little.

Test list 1 (Track 3)

A white silk jacket goes with any shoes.

The child crawled into the dense grass.

Footprints showed the path he took up the beach.

A vent near the edge brought in fresh air

It is a band of steel three inches wide.

The weight of the package was seen on the high scale.

Test list 2 (Track 4)

Tear a thin sheet from the yellow pad.

A cruise in warm waters in a sleek yacht is fun.

A streak of color ran down the left edge.

It was done before the boy could see it.

Crouch before you jump or miss the mark.

The square peg will settle in the round hole.

Appendix E

Instructions to participants for executive function (FAS) TASK

I am going to tell you a letter and I need you to try to think of as many different words that start with that letter as you can. Do this as quickly as you can, you will have one minute.

For example, if I said the letter "B" You might say boy, ball, bear, best, begin etc. Do not use proper names like "Betty". Do not repeat words that you previously said. Do not use different forms of the same words like "begin, beginning beginnings…"

Do you have any questions? Are you ready?

Tell me as many words that start with the letter: (start timer 1 min. per letter)

F A S

Appendix F

Instruction to complete experiments: Script read to participants

The following script was printed in 16 point Cambria font, in black letters on white paper. It was read to the participant as they read along:

Thank you for participating in this experiment.

I will explain completely at the end of the experiment why we had you listen to the type of speech samples that you heard. I will also answer any questions you have about the experiment.

For now I will explain how you will do this part of the experiment and you will have an opportunity to try a practice one.

You will hear medical prescription instructions. These instructions may sound similar to the ones you may have used in the past but these are made up.

You need to listen very carefully and try to remember each instruction, the best you can, so that you could recite back as exactly as possible in the correct order. It is not critical that you memorize the exact wording, as long as you report the gist of the instructions correctly with the critical details that are needed for these medical instructions.

For example:

If the instructions said, "place in your hand", and you said, "put in your hand" it would be considered correct.

However, if the instructions said, "Shake the bottle and pour out two tablespoons" and you said, "Take the bottle and pour out a spoonful" it would be considered incorrect.

Since “shake” is important for medication and “two tablespoons” is also important for the correct dosage needed.

Before you start the experiment we will do a practice item so that you can hear the level of loudness and the quality of the speech. The beginning part of these instructions says. “What to do for aching joints. Follow these instructions carefully.” Your job is to start paying very careful attention after the phrase: “Follow these instructions carefully…”. You will be asked to report back in order the instructions you heard.

Example: Training:

Let’s try one as practice. There are just two sentences. Listen carefully to the male voice even though there are other conversations going on in the background. The male voice will say “What to do for aching joints-follow these instructions carefully…” and then he will say the two instructions that you will report back to me. Listen really carefully and report back what he says after ‘follow these instructions carefully’. “What to do for aching joints - Follow these instructions carefully…

1)

2)

The actual experiment recording will go completely through the (10) sentences without stopping. Then you will be asked to report as best you can all of what you heard and remembered immediately after each time you listen to the recording. You will have many opportunities to hear and learn these instructions. Right after each time you listen, you will report again all of what you remember in order. Some of these samples are harder to hear and understand and some are easier to hear and understand. Are you ready?

Fast speech with background conversation

This speech sample has been made to sound like fast speech. Also there are background conversations happening at the same time. Ignore the background babble-conversations and pay attention to the male voice that says, “Follow these instructions carefully. Report back the 10 instructions that he says.

Slower speech in quiet

This speech sample has been made to sound like slowed down speech. It is said in quiet. Pay attention to the male voice that says, “Follow these instructions carefully.” Report back the 10 instructions that he says.

Clearer Speech in quiet/(Noise)

This speech sample has been spoken in a way to make the most important parts of the medical instructions sound clearer. It is said in quiet. Pay attention to the male voice that says (ignore the background speakers)… “Follow these instructions carefully”…report back the 10 instructions that he says.

Appendix G

Critical units and acceptable gist synonym responses for Puffer and Medipatch

The words or phrases in italics following the critical units were the a priori acceptable gist synonyms (or gist phrases). The participant was scored as having correctly recalled the critical unit if either the verbatim response was given or one of the acceptable synonyms (phrases) was reported.

Puffer-Inhaler vignette.

1. Remove: *Take off*
2. Blue cap: *cap, top, lid*
3. Rescue inhaler: *inhaler, puffer, on your device*
4. Hold: *Take*
5. Base: *Bottom*
6. Turn mouthpiece: *twist mouthpiece, position mouthpiece*
7. Direction: *towards*
8. Arrow:
9. Place: *put, insert, put in*
10. One capsule: *a single*, *a capsule*
11. Compartment: *holder*
12. Base of the inhaler: *inside*
13. Twist: *turn it*
14. Closed position: *closed, shut position, so it's closed*
15. Hold: *Take*, *position it*

16. Upright:

17. Squeezing: *pressing in, push, push in on, pinching in*

18. Two: *both, both sides*

19. Blue buttons: *buttons, knobs,*

20. Pierce: *bust, break, open, release*

21. Breathe/out: *exhale, blow out all your air completely*

22. Insert: *put it in, take it into, hold it in*

23. Mouthpiece: *end of puffer/inhaler for your mouth*

24. Mouth: *between your lips*

25. Inhale: *breathe in*

26. Quickly: *rapidly, fast (breath in), sharply*

27. Deeply: *strongly*

28. Hold:

29. Breath for: *breath*

30. Count of Ten: *ten seconds*

31. Breathe out: *exhale, blow out your air, release your air out*

32. Gently: *slowly, easily*

33. Mouth and nose: *mouth*

34. Replace: *put it back on, put it on*

35. Cap: *top*

Medipatch vignette.

1. Wash: *Clean, scrub*

2. Hands:
3. Hold: *take*
4. Patch: *pad*
5. Plastic backing: *plastic bit, backing, protective backing, protective covering, plastic cover*
6. Faces you: *towards you, towards your body, towards your skin, facing the body/skin, in the direction of-body, skin, you*
7. Peel: *take off, remove, pull*
8. One side: *one part, part of, half, a single side of*
9. Apply: *put on, put, place*
10. Sticky side to: *sticky side (part, bit, half, piece) to (on)*
11. Body: *skin, part that needs the patch, back, arm, leg*
12. Hold: *take*
13. Plastic backing: *plastic bit remaining, the piece of the back, part of the plastic cover/protective plastic*
14. Pull: *peel*
15. Across: *sliding it over top your skin/body, moving overtop your body/skin*
16. Skin: *body*
17. Remove: *take off*
18. Patch(es): *used or old ones, it, them (only after clearly identifying patch)*
19. Press: *push, touch, apply pressure to*
20. Peel: *remove, pull back, pull off, pull*

21. Edges: *sides, corners, the edge*
22. Flush: *put down the toilet*
23. Backing: *protective plastic, plastic part, tabs, them, it*
24. Old patches: *used, patches, patch, both of them, them, it*
25. Medicine: *medical substances, ingredients*
26. Remain on: *still be on, still on that*
27. Patch: *used or old ones, it, them*
28. Dangerous: *harmful, hazardous*
29. Children: *kids, little ones*
30. Pets: *animals, dogs*
31. Wash: *clean*
32. After: *again, following removing*
33. Store: *put up, secure, place, put away, return, keep*
34. Medipatches: *patches, them, these medicinal pads, it (when very clear identified as patch)*
35. Out of reach: *up high, away from children and pets, in a safe place, secured from, safe place*