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Effects of signal-to-noise ratio on precision of memory for speech

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EFFECTS OF SIGNAL-TO-NOISE RATIO ON PRECISION OF MEMORY FOR SPEECH

By

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Abstract: The effortfulness hypothesis predicts that as background noise, age and hearing loss increase, the accuracy of memory recognition will decrease. Here we presented young and older adult listeners with sentences at three signal-to-noise ratios in multitalker babble \((\infty, +15 \, \text{dB}, +5 \, \text{dB})\) and probed subsequent recognition memory for these sentences as an offline measure of cognitive processing. Our results confirm the effortfulness hypothesis.
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INTRODUCTION

It is estimated that 48 million people in the United States of America have a hearing loss, defined as poorer than a 25 dB HL threshold at 0.5, 1, 2 and 4 kHz, in one or both ears. Approximately 20% of the total population has a hearing loss significant enough to impede spoken communication, with this number increasing to over 50% for individuals between 60 and 79 years of age (Lin, et al., 2011). The consequences of hearing loss go beyond the perception of the world being a quieter place, missing the pre-heat signal on the oven, or thinking that young people just mumble; it can impede human communication and social interaction. To add to the burden of hearing loss, there can be synergistic effects of conversational environment (background noise), speaker characteristics, the characteristics of the message, or other characteristics of the listener.

Masking occurs when an unwanted noise or signal interferes with a target signal, and is frequently classified as being energetic or informational. Energetic masking occurs when the target and competing signals are acoustically similar in frequency (pitch) and intensity (loudness)—the masker prevents the acoustic energy of the target signal from being perceived by the peripheral auditory system (Durlach, et al., 2002). Alternatively, the effects of informational masking are more central or cognitive in nature and the challenge comes largely from the content of the masking signal rather than its acoustic interference. For example, Freyma, Balakrishnan and Helfer (2004), used nonsense sentences and varying signal-to-noise ratios (SNRs) consisting of 3, 4, 6 or 10 multi-talker maskers. The authors concluded that for young adults, 1-talker and 2-talker babble is most effective for informational masking. Furthermore, Rosen, Souza, Ekelund and Majeed (2013), found that with an increase in number of talkers there seemed to be an increase in energetic masking effects and a decrease in informational masking effects. That is,
when the multitalker speech envelope is flattened out and spectral cues are less detectable, as they would be for 10-talker babble, energetic masking is more likely taking place. Therefore, an increase in number of talkers causes an increase on the demand of the peripheral auditory system by creating acoustically similar signals, but relieves the central auditory system of trying to disentangle the target and masker signals. Lastly, Ben-David, Tse and Schneider (2013), found that older adults have an increased disadvantage for listening to speech-in-babble compared to young adults that seems to be related to informational masking. It is likely that energetic and informational masking have different effects on auditory processing, though both are likely to cause some interruption of auditory processing during spoken communication.

One way we encounter masking in our everyday lives is as background noise. Background noise may consist of any unwanted noise that acts as a masker anytime two or more people are trying to communicate. Most individuals, even those with clinically normal hearing, have some difficulty understanding speech in background noise (Cousins, Dar, Wingfield, & Miller, 2014; Gilbert, Chandrasekaran, & Smijanic, 2014). However, for individuals with hearing loss, listening in background noise becomes even more difficult. Many studies have demonstrated that even a mild hearing loss can hinder speech understanding in background noise as compared to normal hearing individuals (Benichov, Cox, Tun, & Wingfield, 2012; Dubno, Dirks, & Morgan, 1984; Gordon-Salant and Fitzgibbons, 1997; Pichora-Fuller, Scheider, & Daneman, 1994; Rabbitt, 1991; Stewart & Wingfield, 2009; Tun, McCoy, & Wingfield, 2009; Wilson, McArdle, Betancourt, Lipton, & Chisolm (2010). For example, Dubno et al. (1984) examined the relationship between mild sensorineural hearing loss (SNHL), age and signal-to-babble ratio thresholds. Participants of this study were younger adults with normal hearing, younger adults with mild SNHL, older adults with normal hearing, and older adults with mild
SNHL. A signal-to-babble ratio threshold was obtained using three different types of speech materials. Effects of hearing loss were found to be significant, with normal hearing participants out-performing the participants with hearing loss (Dubno, et al., 1984). Therefore, individuals with hearing loss required a greater signal-to-babble ratio to understand speech in the presence of background noise compared to listeners with normal hearing.

Conversely, other studies have not found a significant correlation between hearing loss and speech recognition in noise (Fogerty, Kewley-Port, Humes, 2012; Piquado, Benichov, Brownell, & Wingfield, 2012; Yoon, Allen, Gooler, 2012). However, it should be noted that there are many variables to consider when examining such a correlation, including the rate of speech and the intensity of the stimuli. In one study (Piquado, et al. 2012), young adults with hearing loss and young adults without hearing loss were asked to listen to 10 narratives of approximately 166 words in length. The authors concluded that even when speech is audible, individuals with hearing loss recall significantly less information (main ideas and details) compared to normal hearing individuals after hearing a narrative passage presented at a normal conversational speed. However, when individuals were able to hear the passage at a self-paced rate, the effect of hearing loss on performance disappeared (Piquado, et al., 2012). The Piquado, et al. (2012) study nicely demonstrates how the cognitive drain of hearing loss can be lessened by the use of compensation strategies. In a study by Yoon, et al. (2012), the authors examined the relationship between audiometric hearing loss configurations and consonant-vowel (CV) recognition in noise. Participants were individuals with mild to moderately-severe SNHL and stimuli were CV syllables embedded in speech-weighted noise at varying SNRs. The authors did not find a clear relationship between audiometric configuration and percentage correct on CV recognition scores. However, the results did point to the importance of 2000 Hz thresholds in
The determination of sensation level for presentation of speech stimuli (Yoon, et al., 2012). The presence of hearing loss (in contrast to normal hearing) has an effect on speech recognition performance. However, with groups of listeners with hearing loss, the materials and tasks used to assess speech recognition vary, and thus the degree of hearing loss does not necessarily correlate with speech recognition performance.

Unfortunately, a hearing loss is not the only force working against an individual attempting to understand speech in the midst of background noise: the cognitive changes associated with normal aging can also impact performance (Ben-David, et al., 2012; Fogerty, et al., 2012; Pichora-Fuller, et al., 1994; Rabbitt, 1991; Stewart & Wingfield, 2009; Tun, et al., 2009; Veneman, Gordon-Salant, Matthews, & Dubno, 2013; Wilson, et al., 2010). For example, Veneman, et al. (2013) investigated age effects of listening in noise and found that older adults need a greater SNR compared to young adults to obtain the same level of accuracy on speech comprehension tasks. Participants in this study were older and younger adults with good hearing who were asked to listen to sentences in noise. It is well documented that age and hearing loss play significant roles for speech recognition in noise.

Another possible factor affecting speech recognition in noise is that additional cognitive processing may be required to process a degraded acoustic signal. This possibility was first proposed by Rabbitt (1968). In his first experiment, Rabbitt used recorded lists of eight digits, spoken by a male talker, presented at a 0 dB SNR and in a no noise (or “clear”) condition. Participants were asked to repeat back the digits in the order they were heard. In this first experiment, Rabbitt found that the lists were more likely to be recalled when they were heard in the clear condition (no noise condition), than when they were heard in the presence of background noise. For his second experiment, Rabbitt asked participants to listen to and try to
remember eight digits, but to only repeat back four of the eight digits, either the first half or the second half. Each half list of eight digits was presented in noise or in no noise conditions creating four possible list types: noise/noise, noise/clear, clear/noise or clear/clear. Lists were scored based on the sections of four digits being recalled in the correct order. Based on this experiment, Rabbitt discovered that no matter the condition of the first half-lists, recall was better when the second half-lists were presented in the clear condition as compared to the noise condition. Energetic masking effects cannot explain this phenomenon. Rabbitt’s results are consistent with the hypothesis that extra cognitive load is required for speech rehearsal, or encoding, when the second group of words are presented in noise. In other words, resources that would otherwise be drawn upon for encoding speech into memory are also being drawn upon for recognition of speech in the presence of noise. This hypothesis was later termed the “effortfulness hypothesis”. Rabbitt (1991) further tested this hypothesis using short stories with the methodologies described above. He found that participants were significantly better at recalling the story and portions of the story in which there was no background noise present. Therefore, even with greater contextual cues, participants struggled to remember story details in the presence of background noise. Rabbitt concluded that even with good intelligibility (the ability to correctly hear speech), background noise created an added pull on cognitive resources that could otherwise be utilized for processing and encoding speech information for later use (Rabbitt, 1968, 1991).

Numerous other studies are consistent with the effortfulness hypothesis; these studies used a variety of methods and came to the same conclusion. For instance, many different types of degradations have been used to test the effortfulness hypothesis including in the presence of broad-band noise (Ljung, Israelsson, & Hygge, 2013; Surprenant, 1999; Zekveld, Rudner,
Johnsrude, & Rönnberg, 2013), the presence of speech-shaped noise (Fogerty, et al., 2012; Horowitz, 2015; Janse & Jesse, 2014), the presence of multitalker babble (Benichov, et al., 2012; Cousins, et al., 2014; Janse & Jesse, 2014; Pichora-Fuller, et al., 1994; Zekveld, et al., 2013), and vocoding (Horowitz, 2015). Furthermore, different structural levels of speech have been used to assess the effortfullness hypothesis, including phonemes (Janse & Jesse, 2014; Surprenant, 1999), target words in word lists or whole word lists (Cousins, et al., 2014; Ljung, et al., 2013; McCoy et al., 2005; Piquado, Cousins, Wingfield, & Miller, 2010; Rabbitt, 1968; Rabbitt 1991; Stewart & Wingfield, 2009; Tun, et al., 2009), final word of sentences (Benichov, et al., 2012; Gordon-Salant & Fitzgibbons, 1997; Pichora-Fuller, 1994; Piquado, et al., 2010), sentences (Gilbert, et al., 2014; Gordon-Salant & Fitzgibbons, 1997; Stewart & Wingfield, 2009; Van Engen, Chandrasekaran, & Smiljanic, 2012; Zekveld, et al., 2013), and narratives or short stories (Horowitz, 2015; Piquado, et al., 2012; Rabbitt, 1968). In addition, some studies used free recall to assess this hypothesis (Horowitz, 2015; Ljung, et al., 2013; McCoy, et al., 2005; Pichora-Fuller, 1994; Rabbitt, 1968; Rabbitt 1991; Stewart & Wingfield, 2009; Surprenant, 1999; Tun, et al., 2009; Zekveld, et al., 2013), while others used recognition memory tasks (Benichov, et al., 2012; Gilbert, et al., 2014; Gordon-Salant & Fitzgibbons, 1997; Janse & Jesse, 2014; Van Engen, et al., 2012; Zekveld, et al., 2013). Thus, there is a great deal of evidence suggesting that understanding degraded speech requires additional cognitive resources beyond those required for understanding undegraded (‘clear’) speech.

Evidence for the effortfulness hypothesis has not been universal, however. For example, Horowitz (2015) investigated the effortfulness hypothesis using short stories with young adults who had normal hearing. Participants were assessed using the Reading Span, Pseudoword Listening Span, and recall of short stories. There were a total of 10 degradation conditions for the
stories: speech was vocoded (32, 16, 8 channels), speech was low-pass filtered (cutoff frequencies of 3000, 2200 and 1500 Hz), and speech was presented with speech-shaped noise presented at SNRs of +10 dB, +5 dB, and 0 dB, as well as a clear condition. A sentence intelligibility check was completed under all conditions. Results from this study showed no significant effect of speech degradation on recall. Also, no correlation was found between recall accuracy and cognitive assessments (Reading Span and Puedoword Listening Span). However, a positive correlation between, right ear PTA and mean speech recall in the clear condition, and right ear PTA and degraded speech recall, was found. This study does not offer clear support for the effortfulness hypothesis (Horowitz, 2015). However, the results of this study should be taken with reservation, as the number of participants was small (N = 12). Alternatively, it could be that the added linguistic context provided by the stories help listeners overcome the challenge of listening to degraded speech. That is, free recall of stories may not be a particularly sensitive measure of the effortfulness hypothesis.

One way to experimentally manipulate cognitive load is by reducing linguistic complexity, allowing for greater ease of listening. In one study investigating talker variables (Van Engen, et al. 2012), consequences of intra-talker variability on encoding of speech in memory was examined. The authors’ first experiment utilized a challenging listening environment (speech-in-noise) to assess the degree to which a clear speaking style (speaking as if the listener was having difficulty understanding) aided speech intelligibility. The authors’ second experiment examined the effect of conversational speaking (speaking as if the listener was having no difficulty understanding) and clear speaking styles on recognition memory accuracy. These experiments used semantically normal and anomalous sentences (sentences in which the meaning does not make sense) to explore the effect of linguistic processing variables on
recognition memory. Results demonstrated that a clear speaking style by the talker allowed for
greater speech recognition and memory for sentences by the listener in adverse listening
conditions (Gilbert, et al., 2014; Van Engen, et al., 2012). In summary, when the speaker slowed
down his/her speaking rate and used better pronunciation, thus giving fuller acoustic cues, even
young participants were able to better remember sentences.

Another means of reducing the cognitive load includes enhancing linguistic cues such as
contextual or semantic cues. Many studies have examined the effects of contextual cues and
found that with increased contextual cues came an improvement in speech recognition or recall
(Benichov, et al., 2012; Gordon-Salant & Fitzgibbons, 1997; Janse & Jesse, 2014; McCoy, et al.,
Older adults appear to apply these contextual cues better than young adults and hence decrease
the speech comprehension gap often found between old and young adults (Pichora-Fuller, et al.,
1994; Rogers, et al., 2012). For example, Pichora-Fuller, et al. (1994) studied young and older
participants with normal or near-normal hearing and older adults with SNHL. The authors used
SPIN (Speech Perception in Noise) sentences with 8-talker babble, where the sentences had
either predictable or unpredictable final-words. A difference was found between young and older
adults in ability to use context, but not between older participants with and without hearing loss.
Older participants were better able to use contextual cues to their advantage. The second portion
of the Pichora-Fuller, et al. (1994) experiment included delayed recall of the sentence’s final
words and a self-report of contextual difficulty. Recall set size varied from 1-8 sentences and
they were presented in quiet, +8, +5 or 0 dB SNR. In addition, a visual-only working memory
span was completed. Increased set size revealed an increase in age and contextual effects. There
was no difference in working memory span scores between older and younger adults; a
correlation between visual-only and auditory-only working memory assessments for both the young and older adults was found (Pichora-Fuller, et al., 1994). Finally, one study (Stewart and Wingfield, 2009) found that with increasing syntactic complexity within sentences came a decrease in recall accuracy which was further aggravated by increasing hearing loss and age (Stewart & Wingfield, 2009). Syntactic complexity and contextual cues appear to play a significant role in cognitive resource allocation, which agrees with the effortfulness hypothesis.

It has been determined that beyond simple intelligibility, the increased challenge of listening in an adverse environment requires additional cognitive processing. Furthermore, working memory capacity seems to play a very large role in one’s ability to understand speech in background noise (Ljung, et al., 2013; Pichora-Fuller, 2003; Rönnberg, et al., 2013; Shannon, Nusbausm, & Nusbausm, 2014; Zekveld, et al., 2013). For example, Pichora-Fuller (2003), explains that working memory can become overloaded by processing demands and/or time limitations. She notes that with increasing age, long-term memories are well preserved while processing within working memory declines. The use of contextual information of sentences may assist individuals during speech comprehension and lighten the burden on working memory. Finally, those with higher working memory capacity are better able to handle difficult processing situations (Pichora-Fuller, 2003).

Another cognitive aspect of speech processing that appears to matter is intelligence (IQ). In one of his experiments Rabbitt (1991), recruited older participants whose hearing loss ranged from slight to moderate in degree, and whose raw AH 4 IQ scores ranged from 21-98. The task of the experiment was shadowing or repeating word lists. The following correlations were found: (negative) age and ability to compensate for hearing loss, age and IQ scores (negative), hearing loss and shadowing errors (positive), and higher IQ scores and ability to compensate for hearing
loss (positive). In this study, IQ scores seem to counteract the effects of hearing loss and age in recall of words. In addition, IQ scores had greater correlations with processing rate (higher IQ, faster processing), than with age. Individuals with higher IQ scores are better able to compensate for any hearing loss, and if they retain high IQ scores with age they can compensate for any age differences in auditory processing (Rabbitt, 1991). Therefore, individuals with high working memory capacity and high IQ can more easily combat the effects of adverse listening conditions, especially if hearing loss and increased age are also factors.

In addition to the many relevant behavioral studies are functional neuroimaging studies, which provide insight into neural activity during speech recognition that may not be observable in simple behavioral measures. Using fMRI, several researchers were also able to see unique neural activation related to speech intelligibility. For example, Golestani, Hervais-Adelman, Obleser and Scott (2013) saw increased, intelligibility-associated, activation in Broca’s area, left anterior insula/frontal operculum medially, left posterior superior temporal sulcus, left IF, left posterior STS/MTG and other areas related to task difficulty and attention (Golestani, et al., 2013). Davis, Ford, Kherif and Johnsrude (2011) saw increased neural activity correlated with speech intelligibility, specifically in the bilateral medial-temporal region, the left putamen, left inferior temporal and fusiform gyri, Hechl’s gyrus and planum temporale, anterior and posterior portions of the MTG and IFG and medial-temporal regions, left frontal cortex, bilateral temporal cortex, hippocampus, and subcortical structures (Davis, et al., 2011). Finally, with increased difficulty in listening environment or decreased SNR, Davis, et al., (2011) found increased neural activity in several regions of both temporal and frontal cortex. Hence, when individuals are subjected to adverse listening conditions there tends to be greater neural activity further from the auditory cortex, as compared to non-adverse listening conditions. This implies that
individuals require adjacent brain regions, including the frontal lobe, to sort through adverse
listening conditions or situations; the auditory cortex alone no longer suffices. That is, there is
increased neural activity and/or novel activation of secondary/tertiary auditory regions and
frontal lobe regions when a degraded speech signal is presented. Behaviorally, it is known that
these processes are taking place, but with fMRI researchers are able to identify and confirm
neurological activity brain regions thought to be responsible for these behavioral activities.

In addition to examining speech intelligibility, researchers have used fMRI to study
semantic ambiguity (Rodd, Davis, & Johnsrude, 2005), semantic cues during speech-in-noise
listening tasks (Davis, et al., 2011; Golestani, et al., 2013), and syntactic complexity (Peelle,
Troiani, Wingfield, & Grossman, 2010). For instance, with poor semantic cues (high ambiguity),
increased activation was found in the left hemisphere with frontal lobe involvement, specifically,
in the left and right inferior frontal gyrus, left posterior inferior temporal cortex, lateral frontal
cortex, and middle frontal gyrus (Rodd, et al., 2005). While Davis, et al. (2011) found increased
activation for semantic and syntactic processing in the superior temporal gyrus (MTG and STG)
and frontal regions (LIFG), greater activation was also seen in the left hemisphere. The authors
concluded that semantic integration is most likely associated with anterior temporal and frontal
regions, rather than posterior SRG/MTG, although these regions probably play a role in
integration. Finally, Peelle, et al. (2010) demonstrated that with increased syntactic difficulty, all
young adults showed greater activation of the left IFG/anterior insula, while older adults have
greater activation of the left MFG and right SFG, bilateral precentral gyrus and right temporal
pole. These authors also found that with increased speech rate, older adults had greater neural
activation in the frontal lobe, which may correspond to additional processing for this difficulty.
Older adult’s difficulty of speech comprehending in adverse listening environments may be due to reduced neural connectivity and activation of specialized regions for processing (Peelle, et al., 2010). Behaviorally, it is know that semantic information improves listening in adverse environments. With imaging techniques the approximate brain location where improvement occurs might identified. Overall, there is agreement that additional areas of the brain are recruited outside the normal processing pathways when a listener is in adverse environments and/or when the linguistic context becomes difficult. Neuroimaging studies are beginning to show what we already know behaviorally: different cognitive processes share resources, which supports the effortfulness hypothesis.

In the current project we will investigate how the accuracy of memory for spoken sentences is affected by background noise. This study will use sentences of high and low ambiguity so that participants may be challenged by semantic cues. Sentences will be utilized because they closely approximate everyday stimuli, they have greater contextual information to be utilized for speech comprehension, and they are easy to score. In addition, many studies have looked at the cost of listening in adverse environments using words, but very few have examined the cost using sentences. We will use 8-talker babble as we are attempting energetic masking, rather than informational making which would require additional, higher level processing. Hearing acuity will be taken into account for all participants, allowing us to examine whether individual differences in audibility relate to cognitive costs during listening.

We predict that as background noise, age and hearing loss increase, the accuracy of memory recognition will decrease. This finding would be consistent with a shared-resource framework in which limited capacity cognitive processes are required for both auditory processing and memory encoding. This study will add to our knowledge about listening in
adverse environments and the effects this has on memory. In addition, the current project may eventually lead to the development of a screening tool for working memory and auditory processing difficulty.

METHODS

Participants

This study had an intersubject design. We examined two groups of participants: 12 young adults with normal hearing (12 female) and 11 older adults (9 female) with a continuum of hearing acuity. The participants’ mean ages were 24 years (SD = 1.3 years; range = 22-26 years) for the young adults and 69 years (SD = 4.2 years; range = 65-77 years) for the older adults. All participants were native speakers of English. Exclusion criteria for this study were a diagnosed central neurological condition or a conductive hearing loss. Participants were recruited via: the databases AudBase and Volunteers for Health; the Psychology Department’s older adults subject pool; community posters; or word of mouth. Participants provided written informed consent and were paid for study participation. This study was approved by the Washington University School of Medicine Institutional Review Board.

Questionnaires and Assessments

Participants were asked to complete several questionnaires and assessments, including: a Demographic Information Sheet, a Health Information Sheet, a Hearing Health Information Sheet, a Language Experience Questionnaire, a Music Experience Questionnaire, and the Shipley Vocabulary Survey (Zachary, 1986). In addition, we used the Montreal Cognitive Assessment (MOCA) to screen for and rule out mild cognitive impairment. The
screening took approximately 10 minutes and consisted of the following subtests: alternating trail making, visuconstructional skills, naming, memory, attention, sentence repetition, verbal fluency, abstraction, delayed recall, and orientation (Nasreddine, 2010). Information obtained by the MOCA was used for later analysis. The experimenter administered the MOCA. Completing these questionnaires and assessments was voluntary. Original copies of these questionnaires and assessments can be found in Appendix A.

**Audiological Evaluation**

An audiological evaluation was performed to determine each participant’s hearing acuity and presentation levels for the experiment. Otoscopy was performed prior to placement of TDH-50P headphones. The audiological equipment, including the GSI-61 audiometer (Grason-Stadler, Inc., Madison, WI), is maintained and calibrated annually by the Washington University School of Medicine in St. Louis, Division of Aural Rehabilitation and Cochlear Implants. Both External A and External B input dials on the GSI-61 audiometer were calibrated via the VU meter and set to 0, before testing each day. The audiological assessment consisted of air conduction and bone conduction pure-tone audiometry, speech reception thresholds (SRT) and word recognition scores (WRS).

For Speech Reception Thresholds (SRT), participants heard recorded CID W-1 Spondee words (Hirsh et al., 1952; Auditec of St. Louis). Presentation of the words started at 50 dB HL and preceded in a Hughson-Westlake fashion until threshold, or the softest level at which participants were able to correctly repeat back 50% of the words, was found. This was considered the participant’s speech reception threshold (American Speech-Language-Hearing Association, 1988).
During pure-tone audiometry, participants heard pulsed frequency-specific tones and were instructed to press a button whenever they perceived the tone. Presentation for each frequency began at 30 dB HL, or 10 dB HL above the threshold for the previous (lower) frequency tested. The Hughson-Westlake procedure was used to find the softest level at which a tone was perceived 50% of the time, and this was considered the participant’s threshold for a given frequency. Air conduction thresholds were found in this manner for 250, 500, 1000, 2000, 3000, 4000, 6000, and 8000 Hz, for each ear separately. Interoctaves, 750 and 1500 Hz, were included if a 20 dB HL gap was found between 500 and 1000 Hz, or between 1000 and 2000 Hz. Bone conduction thresholds were also found in the fashion described above. For bone conduction, starting presentation levels were either 20 dB HL or 10 dB HL above air-conduction thresholds; the more conservative approach was always utilized. Bone-conduction thresholds were obtained for the following frequencies: 500, 1000, 2000 and 4000 Hz. Appropriate masking procedures were used as needed. These procedures are the current recommendations by ASHA for pure-tone threshold estimation (American Speech-Language-Hearing Association, 2005).

Word recognition scores were obtained when participants heard, and repeated back, up to 50 NU-6 (right ear: list 3; left ear: list 4) monosyllable words presented at 40 dB SL (RE: SRT) (Tillman & Carhart, 1966). Presentation levels never exceeded auditory comfort levels. If participants missed less than three words within the first 25 words presented, testing was discontinued for WRS (Hurley & Sells, 2003). Reported scores are the percentage words correct.

**Stimuli**

Experimental stimuli consisted of 192 sentences (9-12 words each), presented in 6 blocks of 32 sentences each. The sentences were recorded by a female native speaker of American
English onto a digital video recorder, with an audio sampling rate of 44.1 kHz. The audio track was subsequently stripped off and trimmed to eliminate silent periods preceding and following each sentence. Sentences were equated on RMS amplitude. Half of the sentences within each block were of high ambiguity and half were of low ambiguity context. An example of a sentence of high ambiguity would be “Emily found the band to be too tight around her waist,”—“band” could refer to a musical group or an item of clothing, with the intended meaning only apparent later in the sentence. An example of a sentence of low ambiguity would be “The ache in John's arm became worse during the winter.”

We used Match software (Van Casteren & Davis, 2007) to equate total number of words, number of content words, number of ambiguous words, mean frequency of the content words (Brysbaert & New, 2009), and sentence duration across presentation blocks. Sentence blocks were counterbalanced across acoustic conditions so that across participants all sentences were presented in all acoustic conditions. An additional 192 sentences from the Peelle lab sentence database, recorded and prepared as described above, were used as foils during the recognition memory task. Target sentences and foil sentences were matched, using Match software, with the above criteria.

The noise was 8-talker babble, which we combined with the target sentences using custom Matlab scripts. The babble was started prior to each list of sentences and ran continuously throughout the list. When adding babble to sentences, the amplitude of the target sentence was held constant while the level of babble was adjusted for each SNR.

The signal was presented via TDH-50P headphones at 40 dB SL (RE: SRT), with the noise level varying to produce SNRs of +15 and +5 dB. In addition, there was a condition in which no noise was added (SNR of ∞) and this condition was termed the clear condition. The
SNRs were counterbalanced so that each sentence block was paired with each SNR condition, allowing all blocks to be heard in all conditions across participants.

**Procedure**

Prior to beginning the experimental portion of the task, participants completed an intelligibility test to ensure understanding of the sentences in each of the acoustic conditions (SNRs). Two sentences 5-7 words in length were presented in each of the three acoustic conditions. Participants were asked to repeat back verbatim each sentence. Sentences were scored in real-time by the researcher, by word percentage correct. Only one participant scored below 97% correct on the intelligibility check.

A practice phase followed the intelligibility check. The first practice set consisted of 4 sentences presented in the no noise condition. Participants were asked to listen to all the sentences and then decide if the visually presented sentences were “old” or “new” sentences. The font size was ½ inch in height. Participants were instructed to press the “old” button if they believed they had heard a sentence in the preceding block, or the “new” button if they thought they had not heard it. Half of the sentence scripts presented visually were foils (not previously heard). The sentence scripts appeared on a 18” touchscreen, mounted 30” off the ground, and placed in front of the seated participants. As soon as the participant had made his/her decision by tapping on the touchscreen the next sentence appeared on the screen. All responses, and response times, were recorded. A second practice set consisted of 4 sentences presented at +15 dB SNR. The recognition task was the same as outlined above.

After the participant had successfully completed the practice, they were reminded of the task and response procedures, via written instructions on the touchscreen. Participants were
asked if they had any questions prior to beginning the experimental task. Participants always signaled that they were ready to continue by raising their hand.

There were 6 blocks in the experimental task, 2 blocks of each of the 3 SNR conditions (+15 dB, +5 dB and \( \infty \)). SNRs were held constant throughout each block, with 2 blocks devoted to each SNR condition. These blocks were counterbalanced across participants so that a third of participants received the following order of blocks: \( \infty \), +5 dB, +15 dB; a third of participants received the blocks in the following order: +15 dB, \( \infty \), +5 dB; a third of participants received the blocks in this order: +5 dB, +15 dB, \( \infty \). The recognition memory experimental portion of the task proceeded in the same procedure as the practice set. After either the 3\(^{rd}\) or 4\(^{th}\) block, participants were told that they were almost done, using the talk-forward button on the GSI audiometer.

**Working Memory Assessment**

We used Reading Span (Daneman & Carpenter, 1980) to assess working memory ability. Participants were asked to read a sentence, and indicate whether the sentence was true or false via a mouse click. A single letter appeared on the screen, which they were asked to remember, following the sentences. After several of these single sentence blocks followed by a single letter, participants were shown a list of 12 letters which they had to assign a number to sequence them from the first letter they saw to the last letter they saw within that trial. This process was repeated multiple times. Participants were asked to maintain 85% accuracy on the true/false task.

Testing was completed in the Department of Otolaryngology, McMillan Building, on the 8\(^{th}\) floor. All audiometric testing and the experimental recognition memory task were completed in a sound-treated booth in accordance with ANSI S3.1-1999. Testing took approximately 2
RESULTS

Participants were asked to complete several questionnaires (listed above), of which participants were asked about alertness, education level, language experience, music/dance experience, and to complete a vocabulary survey and cognitive assessment. Table 1 collectively shows demographic results for young versus older adult participants. At the time of the study, participants were asked to rate their level of alertness on a 5-point scale, with 1 being not alert at all and 5 being very alert. Young adults had an average alertness rating of 4.2 (SD = 0.6; range = 3-5) and older adults had an average alertness rating of 4.4 (SD = 0.7; range = 3-5) at time of testing. Participants were also asked to report their number of formal years of education. Young adults reported an average education level of 18.8 years (SD = 1.6 years; range = 17-21 years), while older adults reported an average education level of 17.1 years (SD = 3.7 years; range = 11-24 years). All participants reported a native language of English (this was an inclusion criteria), and exposure to English at least 90% of the time. The Shipley Vocabulary Survey revealed an average score of 13.1 (70% correct) (SD = 2.1; range = 11-18) for young adults and an average score of 15.8 (79% correct) (SD = 2.3; range = 11-19) for older adults. Scores from the MOCA are also reported here with young adults having an average score of 29 (SD = 1.6; range = 25-30) and older adults having an average score of 27 (SD = 1.8; range = 24-29). One young adult and two older adults had scores below the cutoff for normal functioning of 26 (Nasreddine, 2010); as there were no other indications of cognitive difficulty we included these subjects in the current analyses. Finally, participants were asked about music and dance experience; three-fourths of
young adults and half of older adults reported some musical training, while approximately 1/3 of older (30%) and younger adults (33%) reported some training in dance.

Prior to performing the recognition memory task, participants completed an intelligibility check to ensure they could correctly understand the degraded speech in all three SNR conditions (∞, +15 and +5 dB). The average intelligibility check, percentage correct, scores for young adults was 100% (SD = 0), and for older adults the average percentage correct was 97% (SD = 5.8; range = 80-100%). Only one participant scored below 97% on the intelligibility check. By these scores, it was determined that the speech stimuli were well understood at all SNRs presented.

For the recognition memory task, we used signal detection theory to calculate d’, reflecting accuracy at discriminating old from new items (Macmillan & Creelman, 2004). These results are presented in Figure 1. We compared d’ across conditions and between older and younger adults using a mixed-design repeated measures ANOVA, with age (2: young, older) as a between-subject factor and condition (3 SNRs: ∞, +15 dB, +5 dB) as a within-subjects factor. There was a significant effect of condition, F(2,42) = 5.20, p < .05, consistent with acoustic challenge impacting memory performance. There was no effect of age, F(1,21) < 1, nor an age x condition interaction, F(2,42) < 1. To clarify the conditions contributing to the significant effect we conducted paired t-tests for young and older adults across SNR conditions. For young adults, there were no significant differences between the following SNRs: ∞ vs. +15 dB, t(11) = -0.02, p = 0.987, and ∞ vs. +5 dB, t(11) = 1.16, p = 0.269. However, there was a significant difference in memory accuracy d’ between SNRs +15 dB vs. +5 dB, t(11) = 2.25, p = 0.046, with young adults performing less accurately on the recognition memory tasks for sentences heard at a lower (worse) ratio of speech to background noise. For older adults, approaching significance on t-tests were the differences in accuracy on recognition memory between SNRs ∞ vs. +5 dB, t(10) =
2.17, $p = 0.055$, and $+15$ dB vs. $+5$ dB, $t(10) = 1.99, p = 0.074$. Accuracy on recognition memory for SNRs $\infty$ vs. $+15$ dB did not differ, $t(10) = -0.56, p = 0.585$. Therefore, these data provide evidence of a relationship between the SNRs of sentences heard in a background noise and recognition memory of those sentences, even when the speech is intelligible.

We performed a parallel ANOVA on the z-transformed reaction time data for correct responses. There was no significant effect of condition, $F(2, 42) = 1.47, p = 0.24$, nor of age group, $F(1,21) < 1$. The condition x age group interaction was also not significant, $F(2, 42) < 1$.

The Reading Span (Rspan) scores are reported in two different forms, Rspan total and Rspan score. The Rspan total results are the total number of correctly recalled items, in the correct order on the memory trials. The Rspan score results are scored only for trials in which the participant scored 100% on the items recalled within that trial. This means that the Rspan total results should better reflect differences amongst individuals’ working memory capacities due to greater variance in scores (Conway, et al., 2005). Here we focus on the Rspan total results. For young adults, the average Rspan total was 21.5 (SD = 4.1; range = 15-29). Older adults had an average Rspan total of 20.3 (SD = 9.7; range = 2-30). These results are also shown in Figure 2. Upon visual inspection of the data, the Rspan total and score for older adults show greater variation compared to young adults’ Rspan total and score. Statistical analysis of correlation coefficients were run on Rspan and $d'$ data, and a statistically significant correlation was found between Rspan totals and $d'$ for the $+5$ dB SNR condition (Pearson $r = 0.75, p = .008$). See Figure 3. Approaching significance was a correlation between Rspan totals and $d'$ for the $+15$ dB SNR condition; no significant correlations was found between Rspan totals and $d'$ for the $\infty$ SNR condition. Figures 4 and 5 show the absence of significant correlations between Rspan totals and $d'$ for the $+15$ dB, and between Rspan totals and the $\infty$ SNR condition. Higher Rspan totals were
positively correlated with greater accuracy on the recognition memory task. Therefore, listeners with a higher working memory capacity better remember sentences presented in noise.

Hearing acuity was the final variable evaluated in the current study. We calculated pure tone averages (PTAs) for comparison between individuals and groups using the following frequencies: 500, 1000, 2000, 3000 and 4000 Hz. These frequencies were chosen to allow for a clearer picture of audiometric thresholds across the audiogram, specifically those frequencies most important for speech understanding. Average PTAs for the right ear for young adults were 2.8 dB HL (SD = 4.1 dB HL; range = -1.3 to 11.3 dB HL) and for the left ear 2.2 dB HL (SD = 4.1 dB HL; range = -3 to 11.3 dB HL). For older adults the average right PTA was 17.2 dB HL (SD = 10.5 dB HL; range = -1.3 to 35 dB HL) and the average left PTA was 17.2 dB HL (SD = 11.0 dB HL; range = 0 to 35 dB HL). Participant specific audiograms and group averages may be seen in Figures 6 - 10. All SRTs were in good agreement with traditional PTAs (500, 1000 and 2000 Hz). Ear specific WRS were also obtained in the evaluation. The average WRS for young adults were 97.7% (SD = 3.2%; range = 92-100%) for the right ear and 98% (SD = 2.1%; range = 96-100%) for the left ear. Older adults had average WRS of 95.2% (SD = 4.9%; range = 82-100%) for the right ear and for the left ear, 97.3% (SD = 2.0%; range = 96-100%). A great deal of variability was seen for audiometric thresholds in the older adults and less variability was seen in the younger adults, as would be expected. Finally, we examined the correlation between audiologic results (PTA, SRT or WRS) in participants’ better ears and d’. There was no significant relationship for PTA (Pearson r = 0.28, p = 0.41), SRT (Pearson r = 0.41, p = 0.21), or WRS (Pearson r = 0.12, p = 0.73), with d’ for any of the SNR conditions.
DISCUSSION

In this project, we investigated whether recognition memory would reflect any additional cognitive processing required for listeners to understand speech in the presence of background noise. We found that with increased SNR, participants performed significantly better on sentence recognition memory tasks compared to a reduced SNR. When participants were asked to listen to sentences in varying levels of background noise (8-talker babble) of SNRs of ∞ (quiet), +15 dB and +5 dB, they were able to successfully understand speech above the level of noise in all conditions. That is, speech intelligibility was excellent. However, participants had greater difficulty remembering sentences embedded in lower SNRs: recognition memory was significantly poorer for the hardest condition (+5 dB SNR) than the easier conditions (quiet or +15 dB SNR). For the audiologist, psychologist, speech language pathologist, physician, or any other health-care worker, listening in a noisy environment is not only frustrating for patients, but they are likely to remember less when listening in the presence of background noise.

Of particular interest was the correlation of verbal short-term memory capacity (measured by the Reading Span) and memory performance: listeners with better verbal short-term memory showed significantly better recognition memory for our sentences. These findings are consistent with the fact that listening to speech in noise results in increased demands on verbal short-term memory (a resource also required for encoding speech into memory). Listeners with more verbal short-term memory capacity are thus less impacted by the challenge of listening in noise and their memory is better. Together, our findings suggest that memory challenges can be caused by background noise, and may be further confounded with a possible additional drain of cognitive resources for age and/or hearing loss. Therefore, it is important to counsel patients in a quiet environment, not only for considerations of hearing loss, but also to
accommodate any cognitive drain of listening in background noise. Our findings do not only pertain to health-care workers; as found in our study, even young, otherwise healthy adults struggle to remember sentences when presented in background noise. This has implications for classrooms or other learning environments, business meetings held in noisy restaurants, and even friends catching up over coffee. According to Sato and Bradley (2008) the average SNR of 27 classrooms (grades 1-6) was 11.0 dB (SD = 4.3 dB). Participants in our study included healthy young adults with mature auditory pathways; imagine the implications for our study on children trying to learn in classrooms. Our results have widespread implications and are in agreement with the effortfulness hypothesis.

Our data also suggested the possibility of a difference in recognition memory abilities for younger versus older adults, although this was not statistically significant in our modest sample of participants. The effects of age on speech in noise tasks have been found in other studies (Veneman, et al., 2013). For those working with the geriatric population, health-care providers should give even greater consideration to the acoustic conditions of counseling, therapy or treatment rooms. In addition, family members may want to consider the effects of background noise on recognition memory when talking with older relatives to reduce later frustrations. Talking with the older relative in a quiet environment, may not only aid in his/her speech understanding, but may also aid in later memory of the conversation.

The relationship, if any, between hearing acuity and performance on memory tasks was explored here, as several studies have found a correlation (Gordon-Salant & Fitzgibbons, 1997; Janse & Jesse, 2014; McCoy, et al., 2005; Rabbitt, 1991; Stewart & Wingfield, 2009; Tun, et al., 2009). Participants in the current study had a continuum of hearing acuity. In the young adult group, two participants (17%) had a slight, high frequency sensorineural hearing loss in at least
one ear. In the older adult group, all participants (100%) had at least a slight, high frequency sensorineural hearing loss, in at least one ear. Hearing loss is considered when a threshold is worse than 15 dB HL at any frequency (American Speech-Language-Hearing Association, 2011). Hearing acuity was accounted for in the current study; presentation of the auditory stimuli was at a set interval, and based on each individual’s SRTs (SL: 40 dB). No significant correlations between PTA, SRT or WRS, and accuracy (d’) were found in this study. See Figures 11 - 13 to observe the absence of these relationships. The effortfulness hypothesis assumes that when another variable requiring additional cognitive resources, such as a hearing loss, is added to an already adverse listening environment, there will be an even greater decline of memory recognition.

Additionally, no significant correlation between reaction times and d’ accuracy were observed in the current study. It is thought that reaction times reflect cognitive effort, but this was not observed in our study. Although older adults were in general slower responders on the recognition memory task compared to young adults, reaction times were not correlated with performance on this memory task.

Stimuli for the current study were chosen methodically. Eight-talker babble was employed because it provides primarily energetic masking of sentences. That is, its effects are limited to the auditory periphery (Durlach, et al., 2002; Rosen, et al., 2013) rather than more cognitive regions. Rabbitt (1968) understood that energetic masking effects alone cannot explain a decrement in memory recognition when speech is audible and intelligible. Results from the current study, using an energetic masker, agree with Rabbitt’s ideas and are consistent with the effortfulness hypothesis. Furthermore, we chose sentences in the current study because of their increased context compared to words, and the relatively easy ability to score recognition memory
for sentences compared to short stories. Sentences are also more like the speech samples people encounter every day. Many previous studies have used words, word lists, or short stories in testing the effortfulness hypothesis. However, due to a lack of contextual cues, words may be more difficult to remember or recognize than stories or sentences. In several studies, older adults appear to use context better than young adults, and are able to decrease their speech comprehension gap with young adults (Pichora-Fuller, et al., 1994; Rogers, et al., 2012). However, Rabbitt (1968) found that even with high contextual cues, background noise still influenced memory recall. Sentences are a reasonable compromise between words and short stories. Sentences have some contextual information, and yet they represent to everyday stimuli. Several studies have been conducted using the perception of sentences to test the effortfulness hypothesis. However, no study, to our knowledge, has tested the effortfulness hypothesis using recognition memory of sentences in noise as we have done here.

This project is in agreement with fMRI neuroimaging studies that have measured localized neural activity during listening. For example, results consistent with an effortfulness hypothesis have been found utilizing semantic ambiguity (Davis, et al., 2011; Golestani, et al., 2013; Rodd, et al., 2005), syntactic complexity (Peelle, et al., 2010), and speech intelligibility/SNR (Golestani, et al., 2013; Davis, et al., 2011). In each of these cases of increased listening challenge, there is an increase in activity in the frontal and temporal lobes. Therefore, an increase in listening challenge leads to an increase in neural activity outside the typical pathways. Behaviorally, this type of neural activity is associated with a decrease in accuracy for memory tasks.

There are several limitations to the current study. The sample size in our study was small (N= 23). It is possible that our small sample size was not large enough to uncover relationships
such as age and recognition memory accuracy, or hearing acuity and recognition memory accuracy, as observed in other studies. Another limitation to the generalizability of the current results is our participants are highly educated compared to the national average. Nationally, 28% of domestic-born individuals hold a Bachelor’s degree or higher (Ryan & Siebens, 2012). In the current study, 100% of the younger adults and 91% of the older adults, hold a Bachelor’s degree or higher. Our small participant sample was highly educated.

One important consideration for future research is the effect of presentation level on memory recognition. That is, would allowing individuals to set his/her own listening level yield different results from experiments in which listening levels are based on the individual’s hearing acuity (such as in the current study). Finally, further research could compare behavioral results with imaging results of participants listening to sentences in noise.

**CONCLUSIONS**

Our results show good agreement with the efforfulness hypothesis. When listening in adverse environments, there is a degradation of recognition memory even when speech is audible and understandable. In our study recognition memory performance was not significantly correlated with age, hearing loss or reaction times. However, there was a significant correlation between performance (d’) on the recognition memory task and working memory capacity as measured by the Reading Span. That is, greater working memory ability was correlated with greater accuracy on the recognition memory task. These findings are consistent with an increased cognitive processing during speech perception that can impact listeners’ memory for what has been heard.
REFERENCES


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Auditec of St. Louis (8613 Rosalie Ave., Brentwood, MO 63144)


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http://digitalcommons.wustl.edu/pacs_capstones/693


Table 1: Demographic Results

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<thead>
<tr>
<th></th>
<th>Young Adults</th>
<th>Older Adults</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Alertness Rating</strong></td>
<td></td>
<td></td>
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<tr>
<td>Average</td>
<td>4.2</td>
<td>4.4</td>
</tr>
<tr>
<td>SD</td>
<td>0.6</td>
<td>0.7</td>
</tr>
<tr>
<td>Range</td>
<td>3 to 5</td>
<td>3 to 5</td>
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<tr>
<td><strong>Years of Education</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average</td>
<td>18.8 years</td>
<td>17.1 years</td>
</tr>
<tr>
<td>SD</td>
<td>1.6 years</td>
<td>3.7 years</td>
</tr>
<tr>
<td>Range</td>
<td>17-21 years</td>
<td>11-24 years</td>
</tr>
<tr>
<td><strong>Music Experience/Training</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Training in Dance</td>
<td>75%</td>
<td>50%</td>
</tr>
<tr>
<td><strong>Shipley Vocabulary Survey</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average Percent Correct</td>
<td>70%</td>
<td>79%</td>
</tr>
<tr>
<td>Average Score</td>
<td>13.1</td>
<td>15.8</td>
</tr>
<tr>
<td>SD</td>
<td>2.1</td>
<td>2.3</td>
</tr>
<tr>
<td>Range</td>
<td>11 to 18</td>
<td>11 to 19</td>
</tr>
<tr>
<td><strong>MOCA</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average</td>
<td>28.8</td>
<td>26.9</td>
</tr>
<tr>
<td>SD</td>
<td>1.6</td>
<td>1.8</td>
</tr>
<tr>
<td>Range</td>
<td>25 to 30</td>
<td>24 to 29</td>
</tr>
</tbody>
</table>
Figure 1: D’ for each SNR condition for young versus older adults. Error bars show one standard error.
Figure 2: Reading Span Averages of Rspan totals and scores for young versus older adults. Error bars represent one standard deviation.
Figure 3: D’ versus Reading Span totals for young and older adults. A statistically significant relationship was found; higher Rspan totals were correlated with greater accuracy on the recognition memory task.
**Figure 4:** Rspan totals versus $d'$ for the +15 dB SNR condition.
Figure 5: Rspan totals versus d’ of the ∞ SNR condition.
**Figure 6:** Participant-specific right ear air conduction audiograms for young adults.
Figure 7: Participant-specific left ear air conduction audiograms for young adults.
Figure 8: Participant-specific right ear air conduction audiograms for older adults.
Figure 9: Participant-specific left ear air conduction audiograms for older adult
Figure 10: Older and younger adult average air conduction audiogram for the right and left ears.

Error bars represent one standard deviation.
**Figure 11:** Pure-tone averages of 500, 1000, 2000, 3000 and 4000 Hz versus d’ differences between SNR conditions.
Figure 12: Speech reception thresholds plotted against d’ differences between SNR conditions.
**Figure 13:** Word recognition scores versus d’ differences between SNR conditions.
Appendix A

1. Demographic Information
2. Health Information
3. Hearing Health Information
4. Music Experience Questionnaire
5. Language Experience Questionnaire
6. Vocabulary Survey
7. MOCA
Demographic Information

Please write your answers in the space provided.

What is your date of birth? __________________________

What was the first language you learned to speak? __________________________

Did you learn other languages at the same time? No Yes: __________________________

How many years of formal schooling have you had? __________________________

What is the highest degree you hold? __________________________

What is your handedness? (Circle one) Left Right Ambidextrous/Mixed

We gather sex, gender, race, and ethnicity data both for our own analysis as well as reporting to funding agencies. Please circle the response that best describes you. Answers to all questions are optional.

What is your sex? Male Female Prefer not to reply Other: ________

What is your gender? Man Woman Prefer not to reply Other: ________

Which best describes you? Hispanic or Latino Non-Hispanic or Non-Latino

What is your ethnicity? Please circle all that apply.

American Indian/Alaska Native Asian
Black or African American Other: _____________
White or Caucasian Prefer not to reply
Native Hawaiian or Other Pacific Islander
Health Information

Please write your answers in the space provided.

On a scale of 1-5, with 1 being poor and 5 being excellent, how would you rate your overall health? 1 2 3 4 5

Have you been diagnosed with any neurological condition, such as a stroke or neurodegenerative disease? Yes No

If yes, please describe.

On a scale of 1-5, with 1 being poor and 5 being excellent, how would you rate your overall hearing? 1 2 3 4 5

Have you ever been diagnosed with any condition relating to your hearing, such as tinnitus or hearing impairment? Yes No

If yes, please describe.

How many hours of sleep did you get last night? __________

On a scale of 1-5, with 1 being not alert at all, and 5 being very alert, how alert do you feel? 1 2 3 4 5
Hearing Health Information
Please write your answers in the space provided.

Part 1

Do you think you have a hearing loss?  Yes  No

Do you have ringing in your ears?  Yes  No
    Which ear(s)?  Right  Left  Both

Please circle all loud noises you have been exposed to:
    Farm machinery
    Hunting/shooting
    Jet engines
    Factory noise
    Power tools
    Military
    Use of MP3/Ipod player: __ hrs/day
    Music/concerts
    Other: _____________

Please briefly state your occupational history_________________________________________

Part 2

Do you hear better in your right ear or your left ear?  Right  Left

How long have you noticed your difficulty hearing?
    < 6 months  6 months – 2 years  2 - 5 years  5 - 10 years  > 10 years

Approximately, how often do you ask for repetition of speech (times/day)?
    1x/day  2-5x/day  5-10x/day  10-20x/day  >20x/day
How long have you noticed the ringing in your ears?

- < 6 months
- 6 months – 2 years
- 2 - 5 years
- 5 - 10 years
- > 10 years

On a scale of 1-5 (1 = very little; 5 = extremely bothersome), how bothersome is the ringing in your ears?

- 1
- 2
- 3
- 4
- 5

Please list and explain any ear disorders you have been diagnosed with:

______________________________________________________________________________

______________________________________________________________________________

**Part 3** [Please answer if you are, or have ever, worn hearing aid(s)]

Which ear(s) were/are you wearing a hearing aid on?

- Right
- Left
- Both

How long have you worn hearing aid(s)?

______________________________________________________________________________

Where did you receive your hearing aid(s)?

______________________________________________________________________________

**Part 4**

In the past 5 years, have you experienced dizziness, or vertigo?  

- Yes
- No

Please explain:

______________________________________________________________________________

Have you ever been diagnosed with a balance disorder?  

- Yes
- No

Please explain.

______________________________________________________________________________

Approximately, how many ear infections have you had?

<table>
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<tr>
<th>Adult:</th>
<th>0</th>
<th>1-3</th>
<th>3-6</th>
<th>3-10</th>
<th>10-15</th>
<th>&gt;15</th>
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<tbody>
<tr>
<td>Child:</td>
<td>0</td>
<td>1-3</td>
<td>3-6</td>
<td>3-10</td>
<td>10-15</td>
<td>&gt;15</td>
</tr>
</tbody>
</table>

Have you ever had surgery that may have affected your hearing?  

- Yes
- No

Please state what/when it was performed:

______________________________________________________________________________
Is there a history of hearing loss in your family? Circle all that apply. Yes No
Children Parents Grandparents Aunts/Uncles Cousins

Please circle the following conditions you have been diagnosed with:
Bell’s Palsy Diabetes HIV Stroke/TIA
Meningitis Head injury Scarlet fever Mumps
Malaria Cancer Sudden hearing loss

Part 5

Have you ever received special education services? Yes No
Please explain: __________________________________________________________

Do you experience difficulty following spoken directions? Circle all that apply. Yes No
Simple directions Multistep directions Both, simple and multistep directions

Are you easily distracted by background noise? Yes No

Do you forget names, dates, times and other information that you recently heard? Yes No

Do you ever experience difficulty with spelling and/or reading? Yes No

Is daydreaming or a lack of attention a common problem for you? Yes No

On a scale of 1-5, how difficult is it to understand rapid speech?
1 = very easy
2 = easy
3 = not easy, but not difficult
4 = difficult
5 = very difficult
Do you have difficulty locating where a sound is coming from?   Yes   No

In general, do you find that you are unorganized or messy?   Yes   No

Do you sometimes have difficulty understanding subtle meanings within social conversations or in social gatherings?   Yes   No
**Music Experience Questionnaire**

Please write your answers in the space provided.

Do you have any formal music training, for either voice or an instrument?  Yes  No

If yes, for each instrument, please fill in the following:

<table>
<thead>
<tr>
<th>Instrument</th>
<th>Age started</th>
<th># Years trained</th>
<th># Years Played</th>
<th>Training type* (list all)</th>
<th>Last practiced or performed?</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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<td></td>
<td>Month, YYYY</td>
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<td></td>
<td></td>
<td></td>
<td>Month, YYYY</td>
</tr>
</tbody>
</table>

*1=school music group, 2=private lessons, 3=religious/community, 4=friends/family, 5=self taught, or 6=other (please explain)

Do you have any formal dance training?  Yes  No

If yes, for each style, please fill in the following:

<table>
<thead>
<tr>
<th>Dance style</th>
<th>Age started</th>
<th># Years trained</th>
<th># Years dancing</th>
<th>Training type* (list all)</th>
<th>Last practiced or performed?</th>
</tr>
</thead>
<tbody>
<tr>
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<td>Month, YYYY</td>
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</tr>
</tbody>
</table>

*1=school music group, 2=private lessons, 3=religious/community, 4=friends/family, 5=self taught, or 6=other (please explain)
Language Experience Questionnaire
Please write your answers in the space provided.

In what country were you born?  

In what country/countries were you raised?  

What do you consider your native language(s)?  

Parent/guardian #1’s native language:  

Parent/guardian #1’s other languages:  

Parent/guardian #2’s native language:  

Parent/guardian #2’s other languages:  

Please list the languages you know (or have known):

(a) in the order you learned them:  

(b) from the one you know best to the one you know least:  

Approximately what percentage of the time are you currently exposed to each of these languages in your daily activities? These should total 100%.

Language 1: ___________________________ Percent: _____%  

Language 2: ___________________________ Percent: _____%  

Language 3: ___________________________ Percent: _____%  

Language 4: ___________________________ Percent: _____%  

(More on next page)
Please rate your experience with each language that you know. For each, please note the age at which you first started to acquire the language, the place you learned it (e.g., home, school, study abroad, etc.), and rate the level at which you currently perform the skill.

Language: __________________________

<table>
<thead>
<tr>
<th>starting age</th>
<th>where</th>
<th>Proficiency (circle) adequate</th>
<th>perfect</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>none</td>
<td>0 1 2</td>
</tr>
<tr>
<td>Understanding</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Speaking</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reading</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Writing</td>
<td></td>
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</tbody>
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<td></td>
<td></td>
</tr>
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<td>Writing</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Writing</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
## Vocabulary Survey

In each group of six words below, underline or circle the word which means the same thing as the word in capital letters above the group, as it has been done in the first example.

<table>
<thead>
<tr>
<th>1. CONNECT</th>
<th>2. PRECISE</th>
<th>3. PROVIDE</th>
</tr>
</thead>
<tbody>
<tr>
<td>accident</td>
<td>natural</td>
<td>harmonize</td>
</tr>
<tr>
<td>face</td>
<td>faulty</td>
<td>hurt</td>
</tr>
<tr>
<td>hint</td>
<td>small</td>
<td>annoy</td>
</tr>
<tr>
<td>join</td>
<td>stupid</td>
<td>commit</td>
</tr>
<tr>
<td>lace</td>
<td>grand</td>
<td>supply</td>
</tr>
<tr>
<td>bean</td>
<td>exact</td>
<td>divide</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>4. STUBBORN</th>
<th>5. ELEVATE</th>
<th>6. QUERULOUS</th>
</tr>
</thead>
<tbody>
<tr>
<td>obstinate</td>
<td>revolve</td>
<td>astringent</td>
</tr>
<tr>
<td>hopeful</td>
<td>work</td>
<td>fearful</td>
</tr>
<tr>
<td>orderly</td>
<td>waver</td>
<td>petulant</td>
</tr>
<tr>
<td>steady</td>
<td>disperse</td>
<td>curious</td>
</tr>
<tr>
<td>hollow</td>
<td></td>
<td>inquiring</td>
</tr>
<tr>
<td>slack</td>
<td></td>
<td>spurious</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>7. LAVISH</th>
<th>8. FECUND</th>
<th>9. ABNEGATE</th>
</tr>
</thead>
<tbody>
<tr>
<td>unaccountable</td>
<td>asculent</td>
<td>contradict</td>
</tr>
<tr>
<td>selfish</td>
<td>optative</td>
<td>decry</td>
</tr>
<tr>
<td>romantic</td>
<td>profound</td>
<td>renounce</td>
</tr>
<tr>
<td>lawful</td>
<td>prolific</td>
<td>execute</td>
</tr>
<tr>
<td>extravagant</td>
<td>salic</td>
<td>belie</td>
</tr>
<tr>
<td>praise</td>
<td></td>
<td>assemble</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>10. TRADUCE</th>
<th>11. SCHOONER</th>
<th>12. SURMOUNT</th>
</tr>
</thead>
<tbody>
<tr>
<td>challenge</td>
<td>building</td>
<td>mountain</td>
</tr>
<tr>
<td>attenuate</td>
<td>man</td>
<td>descend</td>
</tr>
<tr>
<td>suspend</td>
<td>ship</td>
<td>overcome</td>
</tr>
<tr>
<td>establish</td>
<td>singer</td>
<td>concede</td>
</tr>
<tr>
<td>misrepresent</td>
<td>plant</td>
<td>appease</td>
</tr>
<tr>
<td>conclude</td>
<td>scholar</td>
<td>snub</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>13. TEMERITY</th>
<th>14. LIBERTY</th>
<th>15. BOMBASTIC</th>
</tr>
</thead>
<tbody>
<tr>
<td>impermanence</td>
<td>worry</td>
<td>democratic</td>
</tr>
<tr>
<td>rashness</td>
<td>freedom</td>
<td>pompous</td>
</tr>
<tr>
<td>nervousness</td>
<td>rich</td>
<td>bickering</td>
</tr>
<tr>
<td>stability</td>
<td>serviette</td>
<td>cautious</td>
</tr>
<tr>
<td>punctuality</td>
<td>forest</td>
<td>destructive</td>
</tr>
<tr>
<td>submissiveness</td>
<td>cheerful</td>
<td>anxious</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>16. COURTEOUS</th>
<th>17. ENVISAGE</th>
<th>18. RESEMBLANCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>dreadful</td>
<td>contemplate</td>
<td>attendance</td>
</tr>
<tr>
<td>proud</td>
<td>activate</td>
<td>fondness</td>
</tr>
<tr>
<td>truthful</td>
<td>surround</td>
<td>assemble</td>
</tr>
<tr>
<td>short</td>
<td>estrange</td>
<td>repose</td>
</tr>
<tr>
<td>curtesy</td>
<td>enfeeble</td>
<td>likeness</td>
</tr>
<tr>
<td>polite</td>
<td>regress</td>
<td>memory</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>19. PERPETRATE</th>
<th>20. THRIVE</th>
<th>16. LIBERTINE</th>
</tr>
</thead>
<tbody>
<tr>
<td>appropriate</td>
<td>flourish</td>
<td>missionary</td>
</tr>
<tr>
<td>commit</td>
<td>try</td>
<td>rescuer</td>
</tr>
<tr>
<td>propitiate</td>
<td>thrash</td>
<td>profligate</td>
</tr>
<tr>
<td>deface</td>
<td>reap</td>
<td>canard</td>
</tr>
<tr>
<td>control</td>
<td>think</td>
<td>regicide</td>
</tr>
<tr>
<td>pierce</td>
<td>blame</td>
<td>farrago</td>
</tr>
</tbody>
</table>

Zachary (1986), used with permission from Taylor & Francis.
**Montreal Cognitive Assessment (MOCA)**

**Version 7.1 Original Version**

**Visuospatial / Executive**
- **Copy Cube**: Points: 5
- **Draw Clock**: (Ten past eleven) (3 points)

**Naming**
- [ ] Contour
- [ ] Numbers
- [ ] Hands

**Memory**
- Read list of words, subject must repeat them. Do 2 trials, even if 1st trial is successful. Do a recall after 5 minutes.
- **FACE**: 2nd trial
- **VELVET**: 2nd trial
- **CHURCH**: 2nd trial
- **DAISY**: 2nd trial
- **RED**: 2nd trial

**Attention**
- Read list of digits (1 digit/sec.).
  - Subject has to repeat them in the forward order: [ ] 2 1 8 5 4
  - Subject has to repeat them in the backward order: [ ] 7 4 2

**Language**
- Repeat: I only know that John is the one to help today. [ ]
- The cat always hid under the couch when dogs were in the room. [ ]
- Fluency / Name maximum number of words in one minute that begin with the letter F: [ ] ______ (N ≥ 11 words)

**Abstraction**
- Similarity between e.g. banana = orange = fruit [ ] train = bicycle [ ] watch = ruler

**Delayed Recall**
- Has to recall words with no cue:
  - **FACE**: Category cue
  - **VELVET**: Category cue
  - **CHURCH**: Category cue
  - **DAISY**: Category cue
  - **RED**: Category cue

**Optional**
- **Date**: Category cue
- **Month**: Category cue
- **Year**: Category cue
- **Day**: Category cue
- **Place**: Category cue
- **City**: Category cue

**Orientation**
- Date: [ ]
- Month: [ ]
- Year: [ ]
- Day: [ ]
- Place: [ ]
- City: [ ]

**Total**: /30

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Administered by: ____________________________

Add 1 point if ≤ 12 yr edu