

Degree of Hearing Loss and Working Memory in Adults

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The purpose of this study was to examine the relationship between hearing loss and working memory using an automated visual, verbal working memory task in adults with hearing loss. An exploratory, prospective, group design was used to evaluate the performance of 29 adults with varying hearing loss severity. Findings reported here are from a subset of data taken from a larger training study. Participants were assigned to one of two groups: Mild (PTA \leq 40 dB HL) and Moderate -Severe (PTA \geq 41dB HL). All participants also wore binaural hearing aids. Several measures were administered: a working memory test, a speech in noise test, a competing speaker test, and hearing aid verification. Overall, persons with more severe hearing losses had fewer errors during the working memory task than persons with mild hearing loss. Implications for use of an automated working memory task are discussed.

There is widespread evidence linking cognitive ability (i.e., attention, memory, and processing speed) with hearing ability (Humes, 2007; Lunner & Sundewall-Thoren, 2007; Rudner, Foo, Ronnberg, & Lunner, 2007). In fact, findings from a large-scale study suggested that persons with hearing loss presented with decreased

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Abbreviations: Working Memory = WM, hearing aid = HA, Reading Span Test = R-SPAN, Quick Speech in Noise = QuickSIN, SSI = Synthetic Sentence Identification

cognitive ability (Lin, 2011). Greater hearing loss was associated with poorer non-verbal (digits) cognitive ability using a visual modality assessment. More recently, authors have established a link between cognitive decline and hearing loss, suggesting that individuals with hearing loss experienced more accelerated annual cognitive decline (Lin, Ferrucci et al., 2011b). Possible hypotheses for the association between declines in hearing and cognition have been proposed. One such hypothesis is that hearing loss increases social isolation as well as loneliness and in turn reduces the amount of stimulation a person is exposed to and results in reduced cognitive ability (Lin, Ferrucci, et al., 2011). An alternative hypothesis is that understanding speech with hearing loss results in additional “cognitive load” (Zekveld, Kramer, & Festen, 2011). As speech perception becomes more difficult (i.e., in the presence of noise), cognitive load increases because listeners need additional resources for processing speech. Both of these hypotheses would explain the findings that cognitive ability is related to self-perception of hearing handicap (Zekveld, George, Houtgast, & Kramer, 2013), and listening effort of understanding speech in noise (Rudner, Lunner, Behrens, Thoren, & Ronnberg, 2012).

Recently, cognitive ability also has emerged as a variable that may affect the outcome of auditory rehabilitative efforts (Kricos, 2006). Of particular relevance for HA users is the observation that listening to speech in noise is a complex task; it requires listeners to attend to a primary target, yet ignore a distracting signal. To do this takes extra cognitive effort. Persons with greater cognitive ability (i.e., attention, memory, and processing) may have additional resources that can be allocated for such tasks in comparison to persons with poorer cognitive ability (Pichora-Fuller & Singh, 2006). Although early research suggested that speech recognition abilities were largely explained by the extent of the peripheral hearing loss (Humes, 1996), audiologists and hearing scientists have begun to include the role of cognition into current models of speech recognition (Pichora-Fuller, Arlinger, Lunner, & Lyxell, 2009; Ronnberg, Rudner, Foo, & Lunner, 2008). This paradigm shift reflects the acknowledgement of the dynamic interaction of bottom-up auditory factors (hearing sensitivity) with top-down central factors (cognitive abilities) that affect speech understanding. For clinicians, this means that variables beyond conventional audiometric measures are important to consider in outcomes with our patients. Given that most HA users are older adults who find listening in noise challenging; the role of cognition will be explored in this study. The focus of

the present study was to examine the performance of adults with varying degrees of hearing loss on a measure of one facet of cognition; working memory (WM).

Working memory is widely described as a critical component of cognitive ability (Redick et al., 2012) and is correlated most notably with intelligence (Salthouse & Pink, 2008) as well as reading ability (Norman, Kemper, & Kynette, 1992; Swanson, 1999). It can be described as a temporary storage mechanism that we engage while solving complex tasks (Baddeley, 1992). Working memory enables us to retain small amounts of visual or verbal information for at least short periods of times. It is thought to be activated in everyday life while reading, exchanging phone numbers, or even listening to conversation. Working memory appears to predict performance on a wide variety of tasks including reading comprehension (Daneman & Carpenter, 1980), phonological processing (Classon, Rudner, & Ronnberg, 2013), and attention (Kane & Engle, 2003). Of particular note, essential for clinicians, is the role of WM in relation to understanding speech. While listening to conversations, individuals must continually store and update auditory information that is spoken in real time. Therefore, a preserved WM is considered to be crucial for understanding speech and language (Caplan & Waters, 1999; Daneman & Carpenter, 1980). Furthermore, individual differences in WM are often observed (Brebion, 2003) and are thought to be responsible for variability often seen in aging research (Pichora-Fuller & Singh, 2006; Unsworth, 2007).

The effect that hearing loss and cognition have on speech understanding has been well described by Craik (2007). He proposed that WM would appear to be an important factor in persons with hearing loss relative to speech understanding. Whenever listening becomes challenging, particularly in noisy environments, resources typically allocated to storage are actually used to process the difficult speech signal, limiting an individual's WM storage ability. Given that humans do not have an infinite WM capacity, there is a tradeoff between processing resources and storage (Pichora-Fuller, Schneider, & Daneman, 1995). Miller (1956) suggested that WM is capacity limited, meaning that the amount of information an individual can process is fixed. He proposed that WM capacity in humans is approximately seven units of data, plus or minus two, and described this as the magical number seven.

The *general capacity hypothesis* described above underlies assessment approaches to quantifying cognition using simple span loaded tasks and reflects

only recall of a number of items from a list. However, complex span loaded tasks such as a reading span task requires participants to perform a dual-task. For example, in reading span tasks, participants combine a reading comprehension task (i.e., read a sentence and judge it's meaning) with a recall task (i.e., recall of a series of words) (Daneman & Carpenter, 1980). Such tasks are considered complex and more difficult than simple span tasks. In a review of twenty studies examining speech perception and cognition, Akeroyd (2008) suggested that measures of WM (particularly span loaded tasks) were more highly correlated with speech understanding in adults with normal hearing and hearing loss, as compared to other broad cognitive assessments such as general intellect or IQ. This suggests that WM may be ideally measured by performance on complex span-loaded tasks.

Choosing the presentation mode needs careful examination given that WM tasks may be presented in an auditory, visual, or auditory and visual mode. Sauls and Cowan (2007) compared both visual and auditory WM tasks in normal hearing adults. They reported smaller WM capacity for auditory stimuli compared to visual or a visual/auditory stimuli combination. In contrast, some studies have suggested that presentation mode does not have an impact on WM performance (Uttl, 2006; Visscher, Kaplan, Kahana, & Sekuler, 2007). For example, Uttl (2006) investigated the differences in auditory or visually cued prospective memory tasks in both younger and older adults and found similar age-related declines on both tasks. However, for persons with hearing loss, the relationship between presentation modes is not clearly understood. Given the current body of knowledge related to the reorganization of the central auditory nervous system in the presence of sensory deprivation (Bavalier & Neville, 2002; Lee et al., 2003; Willott, 1996), it would seem plausible, that persons with hearing loss may present with a stronger visual WM mode compared to auditory WM mode. Furthermore, cognition may be assessed across varying domains including verbal, non-verbal, or spatial stimuli (Lehnert & Zimmer, 2008). The capacity of WM appears to be constant across domains (Glassman, 1999) as previously described. Cognitive skills (across domains) appear to decline with aging and are explained by the processing speed theory of adult aging (Salthouse, 1996). Interestingly, verbal cognition is the least susceptible to aging effects in comparison to visuospatial cognition (Jenkins, Myerson, Joerding, & Hale, 2000). Given that there are multiple domains of cognition (i.e., verbal, non-verbal, spatial) and multiple modes of presentation (auditory, visual, or both), conclusions from studies need to

be carefully considered within the context of the population studied. Researchers in the present study will reduce potential confounders while examining WM, by using a visual, verbal WM task in older adults.

Pichora-Fuller, Schneider and Daneman, (Pichora-Fuller et al., 1995) examined age-related declines in WM in older adults while controlling for hearing loss. These authors measured sentence recognition in noise for both older and younger adults using both “high context” and “low context” sentences. Listeners were asked to identify the final word of sentences in noise using an n-back WM task. An n-back task often requires the participant to recall not just the last item presented, but several previously presented items as well. Researchers found that both older and younger adults with normal hearing performed worse with increasing levels of noise. However, older listeners recalled fewer final words than younger listeners even though they could hear and repeat the words correctly. This illustrates that older adults even without hearing loss have greater difficulty integrating words in connected speech for comprehension.

A few studies have suggested that WM could be a predictor of overall success with amplification (Gatehouse, Naylor, & Elberling, 2003; Lunner, 2003; Lunner & Sundewall-Thoren, 2007). For example, the influence of WM on performance with signal processing in hearing aids (Ronnberg, Rudner, Lunner, & Zekveld, 2010) was examined. Given identical hearing losses and hearing aids, persons with higher WM scores performed better with faster signal processing speeds than persons with lower WM scores. However, another study by Cox and Xu (2010) reported that WM might be a more important factor for persons with lower WM than persons with high WM. In a randomized control trial, they examined the effect of compression settings for release time in adult hearing aid (HA) users. They concluded that in persons with lower WM, release time was actually dependent on the speech context. When greater redundancy in the speech signal was present, shorter release times were more beneficial, when there was less redundancy in the speech signal longer release times were more beneficial. Such relationships were not observed for persons with higher WM.

Understanding how amplification affects cognition over the long term is largely unknown. There has been some speculation that the use of amplification may in fact prevent cognitive decline (Arlinger, 2003; Lin, 2011). This could have significant implications for HA acquisition behavior. However, underlying amplification is the role of audibility. It would be logical to assume that the

degree of audibility provided by amplification may affect this outcome related to cognition (Humes, 2007). Using a spectral shaping approach, Humes (2007) reported that once audible speech is achieved, the role of cognition may affect performance with amplification. However, adequate audibility of amplified speech (through 4000 Hz) cannot be assumed across all HA users (Aazh & Moore, 2007). Therefore the role of audibility with amplification and its relationship to WM will be examined in the present study.

As the role of cognition appears to be inextricably linked to communication difficulties, audiologists will be treating persons with both hearing loss and cognitive deficits in the future. Therefore the central purpose of this study was to investigate the performance of individuals with hearing loss on a visual, verbal automated WM task in relation to several dependent variables such as speech understanding in noise, degree of hearing loss, audibility and age. We aimed to (1) describe the WM abilities of older adults with hearing loss on a visually presented, verbal task and (2) describe the relationship between amplification and performance on WM ability.

Methods

Participants

Data for the present article represents a subset of data from participants who were seen within the context of a larger prospective training study. An exploratory group design was used. Participants were grouped based on hearing loss severity (500, 1000 and 2000 Hz) such that they were assigned to either a Mild ($PTA < 40$ dB HL) or Moderate-Severe ($PTA \geq 41$ dB HL) hearing loss group. Participants were recruited through several methods including distributing a recruitment flyer across the campus, local health fairs, senior citizen's meetings, local neighborhood associations, a university hospital newsletter, and Craig's List. Several additional participants were recruited through word of mouth and from personal contacts of local HA dispensing audiologists.

Inclusion criteria required participants to be between the ages of 50 to 80 with a diagnosis of bilateral mild-severe sensorineural hearing loss. Pure tone hearing levels were no worse than 60 dB HL at 500 Hz and 90 dB HL at 2000 Hz. Participants were also bilateral HA users for at least one month and native English speakers. Furthermore, all participants demonstrated adequate vision

and motor skills by self-report to complete a computer assisted task. Participants were excluded if they reported a neurological or psychiatric disorder. In addition, persons with conductive hearing loss (defined as an air bone gap of > 15 dB), hearing levels outside established criteria, or asymmetric sensorineural hearing loss (defined as greater than 25 dB at two or more frequencies) were excluded.

Thirty individuals (12 females and 18 males) consented to participate in this study, which was approved by the local university Institutional Review Board (IRB). However, one participant, a 75 year old female in the moderate-severe group, was unable to complete one of the outcome measures requiring the ability to interact with a computer generated task and operate a mouse. Demographics of the remaining 29 participants are shown in Table 1 and include, age, education, degree of hearing loss, duration of hearing loss, and duration of HA use. The overall mean age was 66.6 years. All participants were bilateral HA users with 27 participants using digital signal processing and two using analog technology. Most (80%) participants reported using HAs more than four hours per day.

Table 1
Effect sizes, means and *SD* for demographic data.

	Mild	Moderate to Severe	Effect Size		
	(<i>n</i> = 13)	(<i>n</i> = 16)	(Cohen's <i>d</i>)	<i>t</i> -value	<i>p</i> -value
Age (years)	66.0 (7.2)	67.6 (7.4)	.22	-.437	.66
Pure Tone Air (dB HL)	30.5 (8.8)	52.6 (7.9)	2.66	-7.0	.00*
Education (years)	19.2 (2.8)	17.1 (3.6)	.11	1.66	.11
Duration of HL (years)	10.8 (9.2)	20.9 (14.1)	.77	-2.21	.03*
Duration of HA use (years)	3.0 (4.4)	9.2 (14.2)	.59	-1.5	.14
Self-Report HA Use (hours/day)	4.3 (.855)	4.56 (.727)	.33	-.868	.39

Note: Pure Tone Air calculated at 1000, 2000 and 4000 Hz; Effect Size calculated with pooled *SD*; HA = Hearing Aid, HL = Hearing Loss, **p* < .05, two-tailed

Measures and Procedures

Hearing Aid Verification

Hearing aid verification (Verifit) was completed on all participants prior to administering speech perception tests. A simulated speech passage presented at an average intensity level (65 dB SPL) was used to measure the output of the HA at the tympanic membrane. Output measures obtained were compared to an ideal target (see below for further detail) representing the amplified speech region for any given participant's hearing ability. Given that participants were fitted by different dispensing audiologists, reprogramming HAs was not possible. Therefore, verification of HA function was expected to deviate somewhat from specified targets. Minor HA adjustments, such as battery and wax guard replacements, were managed as needed. No specific target value was required for inclusion, but rather verification was used to document to what extent the aided HA performance approached target as audibility of aided speech was desirable but not assumed (Swan & Gatehouse, 1995).

Participants were positioned 24-inches from and directly in front of the loudspeaker linked to Audioscan's HA Verification System®. The probe tube and the HA were positioned and calibrated according to procedures outlined in the user manual. National Acoustics Laboratories–Non Linear (NAL-NL1) prescriptive fitting targets as described by Dillon (1999) were used to quantify speech audibility presented at average intensity levels. If averaged target values from Verifit measures for 500, 1000, 2000 and 4000 Hz deviated from NAL-NL1 targets by more than 10 dB SPL, then the presentation levels used during speech perception tests were adjusted to offset the reduction in audibility, which is further described below.

Speech Perception Measures

After completing HA verification, two speech perception tests were administered in a double walled acoustically treated chamber (Industrialized Acoustics Corporation) with a single walled control room. A Madsen Orbiter 922 clinical audiometer calibrated to meet current specifications (ANSI, 1996) was used. Recorded stimuli for both speech perception tests were presented via a Sony Compact Disk player (CDP CD-375) via the audiometer and delivered through soundfield speakers. Administration occurred in the aided condition in soundfield with normal user HA settings. Stimuli were presented at 0 degree azimuth, with

both speech and noise coming from the same loudspeaker with the distance between the listener and speaker fixed at 1 meter. Presentation level of sentences was fixed at 70 dB HL for all sessions unless pure tone average hearing levels (at 500, 1000 and 2000 Hz) exceeded 45 dB HL, or if target Verifit deviations (averaged across 500, 1000, 2000 and 4000 Hz), exceeded 10 dB. In either of these conditions, presentation level was increased to the participant's desired sensation level according to a loudness judgment chart so that the presentation level was judged to be "loud, but okay." Instructions for the speech perception tests were read from pre-written scripts so that each participant received the same directions. Tests were administered in a balanced order to reduce any order effects.

Quick Speech in Noise. The QuickSIN™ (Killion, Niquette, Gudmundsen, Revit, & Banerjee, 2004) is a sentence based speech recognition test in noise where sentences (with five key words per sentence) are presented in "four-talker babble" as background noise. Test re-test reliability has been shown to be good, especially when multiple lists are used (Wilson, McArdle, & Smith, 2007). Furthermore, sentence materials are not highly predictable (e.g., The lake sparkled in the red hot sun.), which reduces the possibility of a listener guessing correctly based on understanding one key word.

One practice list of six sentences was given to familiarize participants with the task. Based on findings from McArdle and Wilson (2006), two lists (Form A and Form B) comprised of six lists of six sentences each were formed. Thus, Form A and Form B had a total of 36 sentences each which were presented in counterbalanced order across participants. The QuickSIN™ was administered and scored as described by Killion and colleagues (2004). This scoring method results in a metric called Signal to Noise Ratio (SNR) loss which reflects the dB SNR needed for persons with hearing loss to correctly repeat 50% of key words on the test. An average SNR loss score was derived from six lists of QuickSIN™ sentences. Higher SNR loss values suggest that persons have more difficulty understanding speech in noise.

Synthetic Sentence Identification. The Synthetic Sentence Identification task (SSI; Speaks & Jerger, 1965) is a competing speaker task where both the target and competing signal are presented simultaneously. During the SSI, listeners hear a nonsense sentence (i.e., *Go change your car color is red*) and an ongoing narrative about the life of Davy Crockett presented simultaneously. As such, it could be considered an informational masking task (Schneider, Li,

& Daneman, 2007) ,which has ecological validity because it simulates everyday real world listening tasks. Good test-retest reliability with this measure has been demonstrated in older adults when using three lists (Dubno & Dirks, 1983).

For the SSI, participants completed three practice lists, at varying Message to Competition Ratios (MCR) so that the competing signal was 0, 5, or 10 decibels louder than the message. This provided participants with an opportunity to adapt to the SSI listening task (Dubno & Dirks, 1983). Performance on the SSI was calculated using a -10 dB (MCR) on three separate lists. An average percent correct score was calculated from the three test lists.

Working Memory

The Reading Span Test (RSPAN; Conway et al., 2005) is a visual, dual task that reflects WM because it requires participants to complete two types of tasks (a primary task and a distractor task) in a sequential manner. It is an automated complex span task that is available for download from (using E-prime <http://www.psychology.gatech.edu/renglelab> or Inquisit <http://www.millisecond.com/download/library/RSPAN/>). The purpose of the RSPAN is to determine how many letters persons can recall (primary task) after reading a group of sentences and discerning if they are true or false (distractor task). Test-retest reliability of the automated RSPAN is considered good in a young adult population ($r = .627-.76$) (Unsworth, Heitz, Schrock, & Engle, 2005). These researchers have concluded that RSPAN taps WM capacity because construct validity has been demonstrated across a number of other WM measures. Additionally, the RSPAN is presented in a visual modality only, thereby avoiding additional confounding variables related to a participant's sensory loss. The primary benefit of this assessment was that it was completely computerized and therefore automatically scored. It could also be completed with simple scripted instructions (see below) and provided feedback to the participant about their progress at the end of each trial.

Each participant completed the automated RSPAN at the conclusion of speech perception testing via a standard desktop computer with a 17-inch LCD monitor (Conway et al., 2005). All persons were familiarized with each task involved in this test. First, they practiced recalling a series of letters which appeared on the screen one at a time at a rate of one letter per second. The letters were presented in sets ranging from three to seven letters. Participants demonstrated recall by using a mouse to enter their responses on a computer screen. The researcher emphasized that perfect recall was not be expected. Second, participants demonstrated

Table 2

Description of sub-scores on the automated RSPAN task that reflects WM

RSPAN sub-test score	Description	Scale
Absolute Score	Perfectly recalled sets; letters were correctly recalled, and recalled in correct order.	0-75
Total Score	Number of sets where letters were correctly recalled (regardless of order)	0-75
Speed Errors	Number of sentence presentations that participant was unable to answer as a result of time limits	0-75
Accuracy Errors	Number of sentences that participant incorrectly judged to be true or false	0-75

reading comprehension by reading sentences presented on the computer screen and judging if they were true or false. Visual stimuli were presented on the computer screen using a 32 font size. After reading each sentence, a response was entered accordingly. The third task combined the first and second tasks, so that participants would read a sentence, decide if it was true or false, and then view a letter. Sentences and letters were presented in varying set sizes which ranged from three to seven.

An example of the screen viewed during this dual task is shown in Figure 1. For example, if the set size was five, then the participant had to read a sentence, judge if each sentence was true or false, and view a letter. This same sequence would occur five times. After an entire set of five sentences and five letters had been presented, participants were asked to recall the five letters they had seen. Letters were selected from a closed set, visual template of pre-selected letters. Four practice items from each of the three types of tasks were provided before the test began. Three sets of each set size of sentences and letters were presented during the complete assessment which took approximately 25 minutes to administer. The RSPAN provides five types of scores for each participant and is described in Table 2. Calculation of speed errors is based on the average response time needed for participants to judge a sentence true or false. If the participant exceeds the average

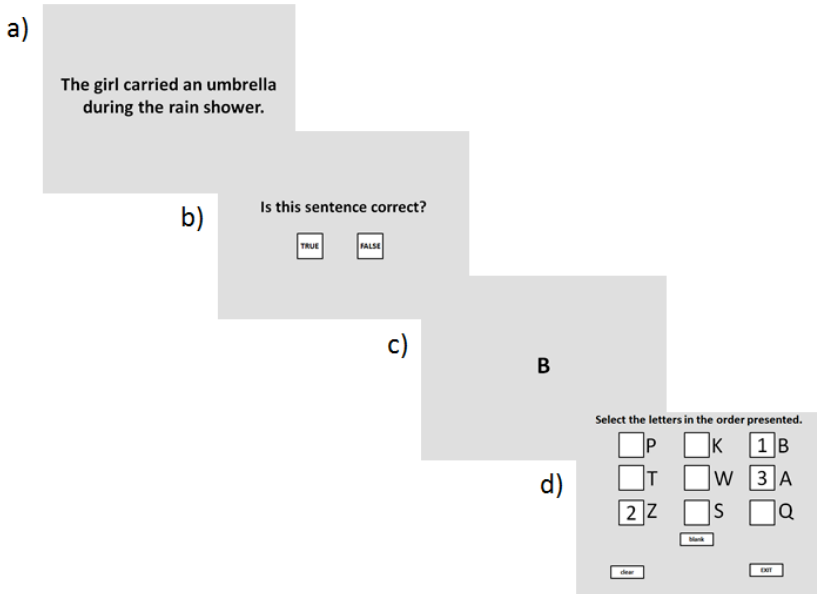


Figure 1. Example of one set of stimuli visually observed automatically during the RSPAN task: (a) sentence presentation screen (b) reading comprehension screen (c) individual letters presented for later recall and (d) the closed set template of letters from which participants selected the letters that they recalled and entered the order of those letters with the mouse. Screens a, b, and c were repeated depending on the set size. For example, for a set size of 6, screens a, b and c would be repeated a total of six times before the template of letters (d) is shown for recall.

judging time (plus 2.5 *SD*), compared to the time measured during the practice set, then a speed error is assigned.

Data Analysis

Data was organized in an Excel database and imported into Statistical Package for the Social Sciences (SPSS). All statistical analyses were performed using SPSS v. 15. For data analysis, group data was analyzed based on hearing level as previously described. To investigate differences between groups relative to dependent variables, independent t-tests were performed. Partial correlations were also conducted while controlling for hearing loss to evaluate relationships between variables within the data. An alpha level of .05 was used to test for significance and was not controlled for multiple comparisons. Given the exploratory nature of this investigation, authors were not concerned about Type 1 errors because data were not a set of random numbers, but rather actual observations obtained from

persons in the present study (Rothman, 1990). In fact, controlling for Type I errors in the present study could have resulted in a false interpretation of the data. Effect sizes were also calculated using a pooled *SD* across groups and are reported as Cohen's *d* (Cohen, 1992).

Results

Outcome measures are summarized in Table 3. As anticipated, significant differences were noted between groups for degree of hearing loss (Figure 2) and duration of reported hearing loss. There were no significant differences between groups in terms of age, education, reported hours of HA use, or duration of HA use. Significant differences were observed on the SSI, such that those with mild loss exhibited better recognition during the competing speaker task than those with moderate loss. No significant differences were observed on the QuickSIN between groups. Between-group differences on the RSPAN subtest scores were also examined. No significant differences were observed between groups on either the absolute or total recall, however there was a trend towards higher scores for persons with moderate to severe hearing loss (60% correct) compared to mild hearing loss (53% correct). The total number of errors made during the RSPAN

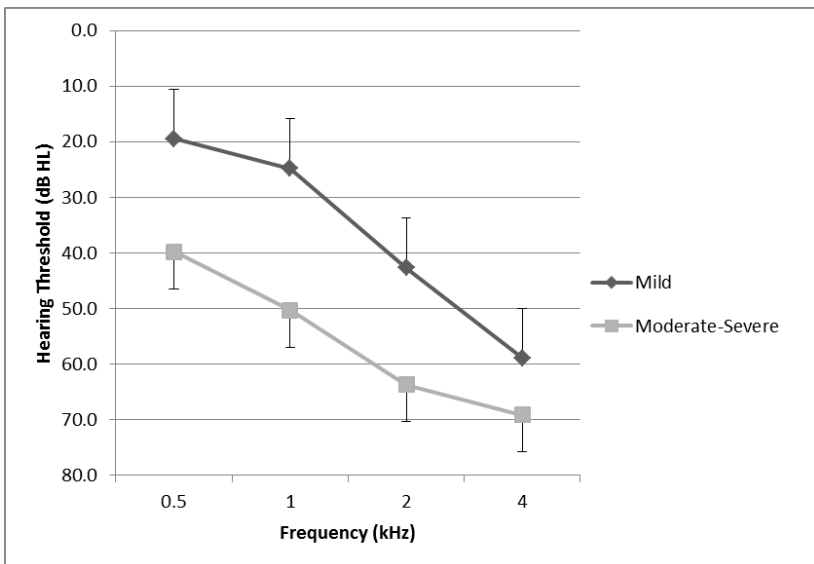


Figure 2. Mean hearing thresholds per group.

Table 3
Effect sizes, means and *SD* for outcome measures

	Mil (<i>n</i> = 13)	Moderate to Severe (<i>n</i> = 16)	Effect Size Cohen's <i>d</i>	<i>t</i> -value	<i>p</i> -value
Deviation from NAL-NL1 Target (dB SPL)	-6.8 (2.6)	-9.5 (2.9)	.97	2.53	.018*
Quick SIN (dB SNR loss)	5.2 (2.6)	7.0 (3.4)	.59	-1.6	.114
SSI (percent correct)	68.9 (11.5)	55.0 (17.2)	.93	2.48	.019*
RSPAN Absolute (Perfect) Score	21.2 (14.8)	23.8 (15.3)	.17	-.46	.649
RSPAN Total Score	39.5 (20.5)	44.3 (16.0)	.27	-.69	.494
RSPAN Speed Errors	4.3 (5.07)	1.6 (1.5)	.76	2.02	.053
RSPAN Accuracy Errors	4.0 (2.9)	1.5 (1.6)	1.54	2.8	.007*
RSPAN Total Errors	7.6 (7.8)	3.1 (2.0)	.833	2.2	.035*

Note. **p* < .05, two-tailed, Effect Size calculated with pooled *SD*

did vary significantly between groups such that fewer total errors and fewer accuracy errors were made for the moderate-severe group compared to the mild hearing loss group. These findings were supported by large effect sizes that all exceeded *d* = .75 (Cohen, 1992). Furthermore, there was no observed relationship between age and any RSPAN sub-score (Table 4). Nor were there any observed relationships between listening tasks on the QuickSIN or the SSI and RSPAN sub-scores.

To examine the role of amplification and WM, several observations were made. First, the amount of deviation from NAL-NL1 targets based on a compiled average of both ears at 500, 1000, 2000 and 4000 Hz, was significantly worse for persons with moderate to severe loss (-9.5 dB SPL, *SD* = 2.9) compared to mild loss (-6.8 dB SPL, *SD* = 2.6). Overall, 17% (5/29) of participants were within 5 dB of prescribed NAL-NL1 targets, 65 % (19/29) were greater than 5 dB and less than 10 dB of prescribed targets and 17% exceeded target values by more than 10 dB. Performance on RSPAN sub-scores was not correlated with reported HA use

Table 4

Partical Correlations between RSPAN sub-tests and demographic variables
(controlled for hearing loss)

	Years of Ed.	Deviation from Target	Duration of HL	QSIN	SSI	Absolute (Perfect) Recall	Total Recall	Speed Errors	Accuracy Errors	Total Errors
Age in Years	$r = .134$ $p = .497$.029 .883	-.186 .344	.167 .395	.113 .567	-.295 .128	-.267 .169	.078 .695	.221 .259	.069 .729
Years of Ed.		-.009 .964	.014 .944	.059 .764	.144 .466	.377 .048*	.357 .062	.169 .391	.417 .027*	.230 .240
Deviation from Target			-.266 .172	-.341 .076	-.015 .939	-.031 .876	.019 .923	-.040 .840	.002 .991	-.027 .892
Duration of HL				.280 .150	.107 .587	-.072 .717	.037 .850	-.280 .149	-.396 .037*	-.302 .118
QSIN					-.281 .148	-.039 .844	.052 .791	.018 .928	.026 .895	-.041 .836
SSI						-.144 .465	-.219 .264	.178 .366	-.031 .876	.119 .547
Absolute (Perfect) Recall							.908 .000*	-.356 .063	.074 .710	-.181 .357
Total Recall								-.411 .030*	-.128 .516	-.331 .086
Speed Errors									.614 .001*	.914 .000*
Accuracy Errors										.806 .000*

Note. Ed = Education, HL = Hearing Loss, * $p < .05$, two-tailed, correlations of interest highlighted,

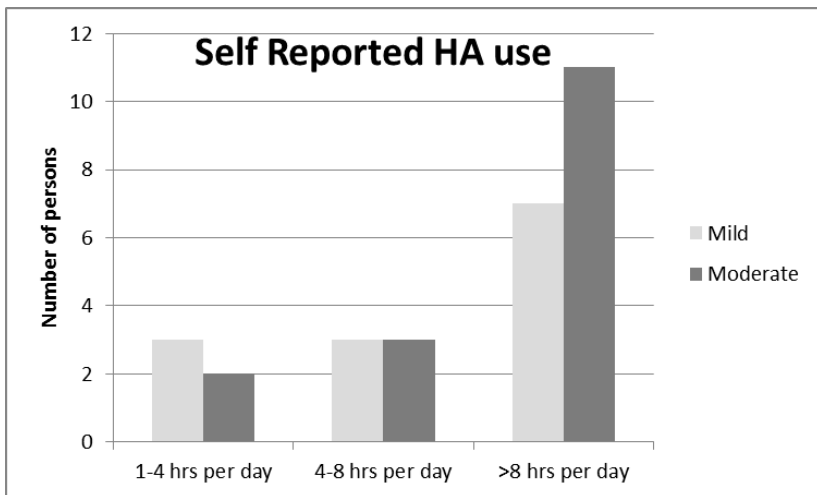


Figure 3. Self-reported hearing aid use as a function of hearing loss.

(Figure 3) or average deviation from target, however duration of hearing loss was negatively correlated with the number of accuracy errors ($r = -.483, p = 0.008$).

Discussion

The overall purpose of this study was to examine cognition in adults with hearing loss using a visually presented, verbal WM task. Specifically, we aimed to (1) describe the WM abilities of older adults with hearing loss based on performance with the RSPAN test and (2) describe the relationship between audibility, amplification, and WM.

The primary question examined the WM of older adults with hearing loss. The weak negative relationship between all RSPAN subtests and age was surprising in light of seminal aging research showing that WM declines with age (Salthouse, 1998; Salthouse & Coon, 1993). In fact, participants actually performed better than might be predicted for their age in comparison to other studies. For example, Hallgren and colleagues (2001) examined WM in older and younger adults with hearing loss using a similar automated divided attention reading span task. They reported that older adults obtained an average of only 41% correct response rate compared to the 56% correct response rate observed in this study. While variability in results is one possible explanation, another is that the higher education levels reported by this sample of participants may have resulted in larger WM spans than expected for their age. Furthermore, Redick and colleagues (2012) reported the RSPAN sub-scores for normal hearing adults ($n = 5537$) from a mix of college and non-college students. Sub-scores were as follows: mean absolute score = 36.51 ($SD = 18.83$), total score = 52.81 ($SD = 15.09$), accuracy errors = 3.66 ($SD = 4.21$), speed errors = 1.41 (1.67) and total errors = 5.08 ($SD = 4.7$). Although the average age in the present study was significantly older than in the Redick study, comparisons were interesting. As anticipated, younger adults outperformed older adults on all recall subtests. However, persons with moderate to severe hearing loss actually had similar error score patterns comparable to the young normal hearing adults in the Redick, and colleagues (2012) study. This is remarkable considering the advanced age of participants as well as the additional sensory loss.

An alternative explanation for the better-than-expected performance on the RSPAN test is duration of hearing loss. Here, duration of hearing loss was almost twice as long for persons with moderate to severe hearing loss compared to mild hearing loss. While this is logical given the known trajectories of hearing loss over

time, individuals with longer durations of loss may have adapted to the auditory sensory deprivation such that their visual sensory abilities actually improved. Although the *general capacity hypothesis* of WM discussed earlier, posits that the individual differences observed in WM reflect a stable characteristic in individuals over time (Engle, Cantor, & Carullo, 1992), the authors also report that individuals can become more efficient in their WM abilities with practice. As such, improved efficiency in visual WM appears possible, and further, is consistent with the large base of evidence demonstrating neural plasticity of the central nervous system (Hallett, 2005; Irvine, Rajan, & Brown, 2001; Kilgard & Merzenich, 1998; Kraus et al., 1995; Moore, 1993; Munro, Walker, & Purdy, 2007; Syka, 2002) as well as cross modal reorganization where auditory cortical regions are responsive to visual stimuli in persons with deafness (Lomber, Meredith, & Kral, 2010; Sandmann et al., 2012).

The secondary question examined was the relationship between amplification and WM. The Verifit results showed that audibility of speech was in fact worse for persons with moderate to severe loss compared to mild hearing loss users as deviations from target values were -9.9 dB SPL and -6.8 dB respectively. However, this lack of audibility of amplified speech did not appear to influence RSPAN performance as no correlation was observed between the reported deviations and performance on any of the RSPAN subtests. Given that there was not a significant difference in years of education between groups, or duration of HA use, or hours of self-reported HA use, none of these factors contribute to the observed performance. So, despite presenting with greater hearing loss and poorer audibility of speech, persons with moderate to severe hearing loss, still made fewer errors. Humes (2007) described similar results from this series of studies examining audibility and cognitive factors in relation to speech understanding of older adults. His interpretation of a series of studies was that while high frequency audibility was the primary predictor of speech recognition, variability in performance was in part affected by cognitive variables. Humes (2007) also concluded that studies using spectrally shaped speech to offset limitations in audibility, suggest that cognitive factors account for variability in performance among older adults once audibility has been restored. This means that for older adults, cognitive factors may be observed once audibility is achieved through well fitted HAs that are meeting prescribed targets. Recall that in the present study, amplified speech for most people did not obtain prescribed target values. This implies that audibility was not widely achieved which could also explain why we

did not observe a clear pattern between audibility and WM. Therefore in future studies, it would be most important to be certain that audibility is achieved among HA users. This finding is consistent with research from Zekveld, Deijen, Goverts, and Kramer (2007) who showed that hearing loss was not associated with a decrease in memory or attention tests. In fact, they reported that persons with more severe hearing loss demonstrated more efficient strategies on a visuospatial WM subtest. They concluded that these findings might reflect a more active use of visual WM in daily life to offset the loss of auditory speech cues, supporting the idea that a learning effect occurs within the sensory modalities. This conclusion is logical within the larger context of neuroplasticity discussed earlier. The present findings are in contrast to van Boxtel and colleagues (2000) who found that mild to moderate hearing loss predicted a reduction in verbal WM task performance. However, their findings were based on an auditory administered verbal WM tests rather than a visual, verbal WM test as was used in the present study. They concluded that an auditory administered WM task can underestimate true memory performance, particularly in older individuals who likely present with hearing loss. These contrasting findings, where auditory WM appears to decline with hearing loss, yet visual WM could improve could be easily misinterpreted. Therefore, a more complete explanation of the relationship between WM across modalities may be beneficial for clinicians providing interventions. For example, it would seem important for audiologists to reinforce during counseling that while auditory WM may in fact decline with hearing loss, visual WM may actually be enhanced which is important for communication exchanges.

Some limitations should be noted with this study. Although the RSPAN test has been normed on a healthy cohort of college aged adults, no norms exist with healthy older adults. Therefore researchers could not compare the findings here with any previously obtained results. Though verbal cognition is least likely to be affected by aging (Jenkins et. al., 2000), alternative cognitive assessments were not administered. Additionally, overall, the participants were highly educated and therefore, may not represent a typical HA population. Several persons ($n= 14$) held degrees of a master's level or above. Thus, it is difficult to determine if the outcomes would be generalized to the typical HA population. Also, participants were not screened for vision even though low vision frequently occurs in older adults (Eye Diseases Prevalence Research Group, 2004). Researchers reasoned that the use of large font (32) during administration of the RSPAN task, with highly contrasting background and good lighting, potentially offset this concern.

Furthermore, all participants reported anecdotally that they were able to see the RSPAN stimuli without difficulty. Finally, the present study's findings have limited generalizability given its small sample size and low power. While it's likely that additional participants may have strengthened the findings, there is also conflicting evidence in aging research that suggests wide variability occurs even in large data sets (Balota et al., 2010).

Conclusion and Future Directions

All participants in the present study were HA users. While it is unknown if this affected outcomes, evidence to support an interaction between the use of amplification and cognition is growing (Kalurri & Humes, 2012). This relationship is not well understood, especially in cases of longer durations of hearing loss as were evident in the present study. Given that there were no differences in education levels between groups, it would appear that the degree of hearing loss could have influenced the fact that persons with more hearing loss made fewer errors on subtests.

Although the focus of this study was on hearing loss severity, clearly the effects of long-term use of amplification on visual verbal cognition cannot be ignored. The extended HA experience of persons with moderate-severe hearing loss may have contributed to their enhanced WM performance as reflected in fewer errors. Although no definitive conclusions can be made about the relationship between acquisition of amplification and cognitive decline, it does suggest that this may be an interesting area for future research. Analysis of cognitive and audiological data from the NHANES (National Health and Nutritional Examination Survey) for adults between the ages of 60-69 suggested that persons with greater hearing loss were more likely to develop dementia than those with better hearing (Lin, Metter et al., 2011b). However, higher cognitive scores on the Digit Symbol Substitution Test (a visual WM test) were associated with persons who used HAs compared to those who did not (Lin, 2011). In the present study, similar findings were observed such that persons who had fewer errors on a WM task also had more hearing loss. The fact that persons with longer HA use may have had more opportunity to practice visual processing may be an important counseling tip for setting expectations for HA users. While additional research is still needed to better understand the role of amplification in WM, encouraging patients to use their visual processing skills may enhance communication function.

If WM has the potential to influence speech processing ability (Pichora-Fuller & Souza, 2003) and possibly HA fittings (Cox & Xu, 2010), then it seems reasonable that future clinicians may seek ways to assess WM in the clinical setting. The need for assessments that extend beyond the traditional paper and pencil approach has generated several computerized assessment approaches. Potential benefits of such technological approaches include; increased precision, efficiency and engagement (Schatz & Browndyke, 2002). In a clinical setting, time saving methods could make such assessments feasible, particularly using self-assessment techniques. Our current knowledge of the efficacy of computerized measures in clinical populations is scarce (Kalluri & Humes, 2012) and needs further exploration.

This study investigated one aspect of cognition (WM) in relation to multiple demographic variables in individuals with hearing loss. As WM is important to understanding speech and language, it is essential to appreciate the impact that a hearing loss may have. In the present study, investigators found participants with more severe hearing loss, and longer durations of HA use performed better on a visual WM task. This supports the idea that individuals with a hearing loss may adapt to their deficit by focusing cognitive efforts through other sensory modalities, specifically visual processing. While auditory WM may decline, clients need to be informed that visual WM abilities may in fact improve and thus affect overall communication. This could be a positive message for clinicians to reinforce for HA users. Research is warranted to further explore use of the RSPAN task as a tool to evaluate WM in older adults, as well as the role of hearing loss and amplification in preservation of visual WM.

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