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Impact of Hearing Loss and Amplification on Performance on a Cognitive Screening Test

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Abstract

Background: There have been numerous recent reports on the association between hearing impairment and cognitive function, such that the cognition of adults with hearing loss is poorer relative to the cognition of adults with normal hearing (NH), even when amplification is used. However, it is not clear the extent to which this is testing artifact due to the individual with hearing loss being unable to accurately hear the test stimuli.

Purpose: The primary purpose of this study was to examine whether use of amplification during cognitive screening with the Montreal Cognitive Assessment (MoCA) improves performance on the MoCA. Secondarily, we investigated the effects of hearing ability on MoCA performance, by comparing the performance of individuals with and without hearing impairment.

Study Sample: Participants were 42 individuals with hearing impairment and 19 individuals with NH. Of the individuals with hearing impairment, 22 routinely used hearing aids; 20 did not use hearing aids.

Data Collection and Analysis: Following a written informec consent process, all participants completed pure tone audiometry, speech testing in quiet (Maryland consonant-nucleus-consonant [CNC] words) and in noise (Quick Speech in Noise [QuickSIN] test), and the MoCA. The speech testing and MoCA were completed twice. Individuals with hearing impairment completed testing once unaided and once with amplification, whereas individuals with NH completed unaided testing twice.

Results: The individuals with hearing impairment performed significantly less well on the MoCA than those without hearing impairment for unaided testing, and the use of amplification did not significantly change performance. This is despite the finding that amplification significantly improved the performance of the hearing aid users on the measures of speech in quiet and speech in noise. Furthermore, there were strong correlations between MoCA score and the four frequency pure tone average, Maryland CNC score and QuickSIN, which remain moderate to strong when the analyses were adjusted for age.

Conclusions: It is concluded that the individuals with hearing loss here performed less well on the MoCA than individuals with NH and that the use of amplification did not compensate for this performance deficit. Nonetheless, this should not be taken to suggest the use of amplification during testing is unnecessary because it might be that other unmeasured factors, such as effort required to perform or fatigue, were decreased with the use of amplification.

Key Words: amplification, cognition, hearing aids, hearing loss

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Abbreviations: 4F-PTA = 4-frequency pure tone average; ANOVA = analysis of variance; CNC = consonant-nucleus-consonant; HI-HA = hearing impaired hearing aid user; HI-no HA = hearing impaired nonhearing aid user; MCI/MCI+ = mild or greater cognitive impairment; MoCA = Montreal Cognitive Assessment; NH = normal hearing; no CI = no cognitive impairment; QuickSIN = Quick Speech in Noise; SII = speech intelligibility index; SNR = signal-to-noise ratio

INTRODUCTION

There have been numerous recent reports on the association between hearing impairment and cognitive function, such that the cognition of adults with hearing loss is poorer relative to the cognition of adults with normal hearing (NH), even when amplification is used (see Taljaard et al, 2016 for a meta-analysis). The underlying mechanism for this association is unclear, as is an understanding of whether the relationship is causal or associative. The role of amplification in preventing or limiting cognitive decline is thus of interest and has been the focus of a number of recent studies. These studies have typically compared over time the cognitive performance of individuals who did and did not use hearing aids. The findings are somewhat mixed. Some studies have suggested that the use of amplification positively impacts cognitive performance and/or slows the rate of cognitive decline relative to nonuse of amplification (Mulrow et al, 1990; Amieva et al, 2015; Qian et al, 2016), whereas others have suggested that amplification in part compensates for the impacts of hearing loss on cognitive decline, (Wong et al, 2014), or that it has no impact on cognition or cognitive decline (Tesch-Romer, 1997; van Hooren et al, 2005; Dawes et al, 2015). Furthermore, Qian et al (2016) who reported beneficial impacts of hearing aid use on cognition noted that this might not be not due to the hearing aids *per se*, but rather that cognitively more able individuals recognize and treat their HL more often relative to those who are less cognitively able.

Among the previous studies reporting on the association between cognitive function and hearing loss, one aspect that was not addressed was whether amplification was used during the administration of the cognitive assessments. Audibility is an important consideration when dealing with an aging population, and it is possible that poor performance is due to the individual's inability to accurately hear the test stimuli. Indeed, it has been shown that scores on cognitive screening measures, such as the Montreal Cognitive Assessment (MoCA; Nasreddine et al, 2005) and the Mini-Mental State Exam (Folstein et al, 1975) are negatively impacted by the presence of hearing loss (Dupuis et al, 2015), background noise (Dupuis et al, 2016), and signal audibility (Jorgensen et al, 2016). The importance of this cannot be underestimated because, as noted by Roalf and Moberg (2016), cognitive screening is becoming routine in primary care settings. If performance on cognitive measures is related to sensory dysfunction, there will be false positive diagnoses, leading to unnecessary patient burden and a waste of healthcare resources.

One way to directly examine whether amplification does impact the outcome of cognitive assessment is to conduct the assessment with and without amplification. To our knowledge, there has been just one previous study in which this has been examined (Weinstein and Amsel, 1986). They showed that scores on a cognitive test improved when individuals with hearing loss and who had been diagnosed with "senile dementia" were tested using appropriate amplification relative to when tested without amplification. However, no mention is made of counterbalancing the order to testing (no amplification versus amplification) nor is mention made of the use of a second version of the cognitive screening test, thus the improvements seen could be due to a practice effect rather than a positive impact of amplification. To address these concerns and to further examine the impact of amplification on cognitive performance, we conducted this study in which individuals with hearing loss completed the MoCA with and without amplification. Two equivalent versions of the MoCA were used, and test order (no amplification versus amplification) was counterbalanced across participants. To investigate the effects of hearing ability on MoCA performance, we also tested individuals with NH.

MATERIALS AND METHODS

Study Synopsis

Participants were 42 individuals with hearing impairment and 19 individuals with NH. All completed pure tone audiometry, speech testing in quiet and in noise, and the MoCA. The speech testing and MoCA were completed twice. Individuals with hearing impairment completed testing once unaided and once with amplification, whereas individuals with NH completed unaided testing twice. The study was approved by the Institutional Review Board and the Research and Development Committee at the VA Portland Health Care System.

Participants

Sixty-one participants aged 50–80 yr were recruited between June 2015 to March 2016 from a database at the National Center for Rehabilitative Auditory

Research (NCRAR) in which contact information is stored for individuals who had participated in prior experiments and agreed to be contacted for future studies. Any individual aged 50–89 yr, who was a fluent speaker of English, had symmetrical hearing and was capable of completing the test protocol was eligible to participate. Symmetrical hearing was defined as <20 dB HL difference between the left and right ear 4-frequency pure tone average (4F-PTA; mean thresholds at 0.5, 1.0, 2.0, and 4 kHz). The goal was to recruit three equal-size groups of similar age. The groups were (a) 4F-PTA <25 dB HL, referred to as the NH group, (b) 4F-PTA between 25 dB HL and 70 dB HL who did not use hearing aids, referred to as the hearing impaired nonhearing aid user group (HI-no HA), and (c) 4F-PTA between 25 dB HL and 70 dB HL who used hearing aids, referred to the hearing impaired hearing-aid user group (HI-HA).

Test Conditions

All participants completed the MoCA and speech testing unaided. In addition, participants in the HI-HA group completed the MoCA and speech testing while wearing their own hearing aids that were set to the user default setting, whereas participants in the HI-no HA group completed the MoCA and speech testing while using a Williams Sound Pocketalker that they set to a comfortable listening level. During MoCA testing, the Pocketalker was placed on a table in front of the experimenter with the microphone pointed toward the experimenter's mouth. During speech testing, the Pocketalker was placed on a stand located about 6-inches away from the sound field speaker with the microphone pointing toward the sound field speaker. In order that group comparisons with the NH group were not impacted by practice and/or fatigue effects, participants in the NH group completed the MoCA and speech testing twice unaided.

Test Measures

Audiometric Evaluation

Routine clinical audiometry comprising air and bone conduction thresholds using clinically-recommended procedures (American Speech-Language-Hearing-Association, 2005) was used to assess peripheral hearing sensitivity. A binaural 4F-PTA averaged across both ears was computed for each participant.

Speech Testing

The Maryland consonant-nucleus-consonant (CNC) word lists presented at 40 dB SL referenced to the listener's 3-frequency PTA (mean of thresholds at 0.5, 1.0, and 2.0 kHz) were used to measure word recognition in quiet. A single 25-item word list was presented from which the percent correct was calculated. The Quick Speech in Noise (QuickSIN; Killion et al, 2004) was used to assess speech understanding in noise. For the QuickSIN, participants repeat sentences presented at six signal-to-noise ratios (SNRs) from which a "SNR loss" is computed. The SNR loss is the dB SNR relative to the SNR required for NH individuals to repeat back 50% of the key words correctly. Two QuickSIN lists per condition were used. All speech testing was completed for unaided and aided listening for the HI-non HA and HI-HA groups and twice unaided for the NH group. The order of testing and test lists used were counterbalanced across participants (see procedures for more details).

Cognitive Screening

The MoCA (Nasreddine et al, 2005) was used to screen cognitive function. The MoCA is a 26-item cognitive screening test that was developed to help detect mild cognitive impairment. It assesses cognitive abilities in six domains: visual executive, attention, language, abstraction, delayed recall, and orientation. Scores on each are combined. The MoCA is available in three equivalent versions that have been assessed for reliability (Costa et al, 2012). Version 7.1 Original and Version 7.3 Alternative were used here. As is standard practice, the MoCA was presented via live voice. The presenter read word-for-word instructions from the MoCA test form and recorded the participant's responses on the form. A total MoCA score was computed for each individual to which the standard MoCA cutpoint criteria used were applied: score ≥26 = no cognitive impairment (no CI) and score <26 = mild or greater cognitive impairment score (MCI/MCI+). The order of testing and the MoCA version used for each condition were counterbalanced across participants (see procedures for more details).

Hearing Aid Output

Real ear hearing aid output was assessed for individuals in the HI-HA group using an Audioscan Verift 2 system to obtain a speech intelligibility index (SII). The SII is a measure of audible and usable speech information (American National Standards Institute S3.5, 1997). SII scores are computed from an individual's pure-tone thresholds and a weighting of the importance of each frequency region to speech intelligibility. SII scores range between 0.0 and 1.0, where 0.0 implies no speech information is audible or useable, and 1.0 implies all of the speech information is audible and usable. Based on DePaolis et al (1996), a value of 0.7 or greater is considered to provide good audibility.

Payment

Participants received a $20 gift card to a local store as compensation for taking part in the study.

Procedures

Participants underwent a written consent process and signed a consent form to confirm that they understood the study purpose and procedures. The test measures were then completed in the following order: MoCA administration 1, audiometric evaluation, Maryland CNC word lists (unaided and aided), QuickSIN (unaided and aided), real ear hearing aid output measurement, and MoCA administration 2. As noted previously, aided and unaided testing, as well as the version of the MoCA and the CNC and QuickSIN test lists used were counterbalanced across participants. Table 1 illustrates the counterbalancing for the MoCA. Equivalent counterbalancing was used for testing with the Maryland CNC wordlists (lists used 1 and 3) and the QuickSIN (lists used 3 + 4 and 5 + 7).

MoCA testing was completed in a quiet well-lit room. The researcher was trained to administer the test using a prewritten script delivered at a comfortable speaking level and an average speaking rate. Although the level and rate were not formally measured, the training was completed to ensure that these were equivalent across participants. All other testing was conducted in a sound-attenuating booth. A calibrated Grason Stadler Inc. GSI 61 audiometer and TDH-50P headphones were used during the audiometric evaluation. Speech testing was conducted in the soundfield. The speech signals were routed from a Sony High Density Linear Converter Compact Disc Player through a calibrated GSI 61 audiometer to a GSI 61 loudspeaker. The testing took 1–2 h.

RESULTS

Analyses

Scores from all test measures were entered into a database and were double-checked by two individuals. Descriptive statistics were used to describe the study population; General Linear Model analyses of variance (analysis of variances [ANOVAs]) and χ^2 analyses were used to compare the characteristics of participants in each intervention group. χ^2 analyses were also used to compare the MoCA unaided and aided cutpoint data across groups, and ANOVAs were used to compare speech testing performance and MoCA total scores across study groups. Pearson correlations were used to examine the relationship between MoCA scores and degree of hearing loss. Significant main effects and interactions were analyzed further by post hoc examination using Bonferroni corrections for multiple comparisons. The significance level for each ANOVA and post hoc analysis was set to $p < 0.05$. All analyses were conducted using the Statistical Package for the Social Sciences (SPSS) Version 22.0.

Demographic, Audiometric, and Hearing Aid Data

Figure 1 shows audiometric data for each study group and Table 2 shows the baseline demographic, audiometric averages, and hearing aid output data (where applicable) of the participants separated by study group. The groups differed significantly on age and 4F-PTA. Post hoc testing showed that participants in the NH group were significantly younger than those in the other two groups and that the 4F-PTAs of each group differed significantly, with the NH listeners having the best thresholds and HI-HA having the poorest thresholds. The SII data show that the hearing aid output during testing was generally below the desired value of 0.70. Just 18% of participants (4 participants) had an SII of ≥0.7 in at least one hearing aid, although 68% (15 participants) had an SII value ≥0.6 in one or both hearing aids.

Speech Data

Table 3 shows scores for the Maryland CNC words and QuickSIN for unaided and aided listening separated by group, along with results of between- and within-group comparisons. Aided data are not available for the NH group. The between-group ANOVAs comparing unaided and aided scores separately showed that for both speech tests, performance across the groups differed significantly for unaided listening but not for aided listening. Post hoc testing for unaided listening showed that participants in the HI-HA group had poorer unaided scores than those in the NH and HI-no

Table 1. Order of MoCA Testing and Versions of MoCA Used

Group	Participant no.	1st administration	MoCA version	2nd administration	MoCA version
NH	1, 3, 5, 7, 9, 11, 13, 15, 17, 19	Unaided	7.1	Unaided	7.3
	2, 4, 6, 8, 10, 12, 14, 16, 18, 20	Unaided	7.3	Unaided	7.1
HI-no HA and HI-HA	1, 5, 9, 13, 17, 21	Unaided	7.1	Aided	7.3
	2, 6, 10, 14, 18	Aided	7.1	Unaided	7.3
	3, 7, 11, 15, 19	Unaided	7.3	Aided	7.1
	4, 8, 12, 16, 20	Aided	7.3	Unaided	7.1

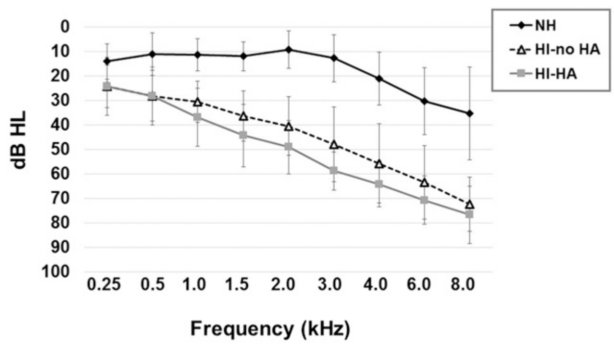

Figure 1. Audiometric data for each participant group. Data from left and right ears are combined because participants had symmetrical hearing loss. Error bars show ±1 SD.

HA, but that performance of those in the NH and HI-no HA groups did not differ. Within-group comparisons of unaided and aided scores (HI-no HA and HI-HA groups only) showed that the HI-HA group benefited from their hearing aids on both tests. Conversely, aided Maryland CNC words scores did not change and aided QuickSIN scores became significantly worse when the HI-no HA group used the Pocketalker. Maryland CNC word scores of the HI-no HA group may not have changed because unaided scores were at almost at ceiling. However, finding the QuickSIN scores became worse suggests that the use of the Pocketalker was detrimental to speech understanding in noise.

MoCA Performance

MoCA data were examined using both the MoCA cutpoint data (Table 4) and MoCA total scores (Table 5). First, examining data in Table 4, the table shows, for each group separately, in the upper left cell, the percentage of individuals whose MoCA score was <26 for both unaided and aided/unaided administration 2 testing (consistent with MCI/MCI+ on both occasions); in the lower right cell, the percentage of individuals whose MoCA total score was ≥26 for both unaided and aided/unaided administration 2 testing (consistent with no CI on both occasions); in the lower left cell, the percentage of individuals whose MoCA total score improved from being consistent with MCI/MCI+ (<26) when tested unaided to indicating no CI (≥26) when tested aided/unaided administration 2. Finally, in the upper right cell, the percentage of individuals whose MoCA total score worsened from being ≥26 when tested unaided to <26 when tested aided/unaided administration 2. The within-group totals for scores consistent with no CI, as well as MCI/MCI+ are also shown. Note that because the scores of the NH group are for unaided testing on both occasion, the value of 10.5% in the lower left cell (those whose MoCA performance "improved" on the second administration) likely reflects practice, whereas the value of 15.8% in the upper right cell (those whose MoCA performance became worse on the second administration) likely reflects testing fatigue. This should be taken into account when interpreting the data from the HI-no HA and HI-HA groups.

The table illustrates two important points. First, the percentage of individuals in each group who had a score indicating MCI/MCI+ for unaided testing (bottom left total) ranges from 31.6% in the NH group to 77.2% in the HI-HA group, with the HI-no HA group falling in between at 50.0%. Pearson χ^2 analysis shows these values to differ significantly ($\chi^2 = 13.49, p < 0.001$). Second, the percentage of individuals whose score improved with the use of amplification (lower left cell) was 5.0% and 13.6% for the HI-no HA and HI-HA groups, respectively. Comparing this to the 10.5% practice effect improvement seen for the NH group, it is reasonable to conclude that amplification had little effect on MoCA performance in this population. Indeed, Pearson χ^2 analyses for each group separately show the unaided-aided differences to be nonsignificant (NH: $\chi^2 = 3.35, p = 0.129$; HI-no HA: $\chi^2 = 3.81, p = 0.141$; HI-HA: $\chi^2 = 3.49, p = 0.100$). One note of caution here is that observing change when using a cutpoint criterion means that, unless changes in score were considerable, change will only be observed in those individuals whose unaided score fell close to the cutpoint of 26, thus it could be argued that examining total MoCA scores would be more revealing.

Total MoCA score data are shown in Table 5. Also in Table 5 are normative data from 4 studies (Nasreddine et al, 2005; Rossetti et al, 2011; Dupuis et al, 2015; Malek-Ahmadi et al, 2015) that used varying selection criteria for their participants. Nasreddine et al carefully selected participants in a priori diagnostic categories, whereas Rossetti et al, Dupuis et al, and Malek-Ahmadi et al collected data from ethnically-diverse community-living individuals. In the current study,

Table 2. Mean Participant Demographic Data (SD in Parentheses) and Range by Intervention Group

Variable	NH n = 19	HI-no HA n = 20	HI-HA n = 22	Comparison
Male (n)	12	13	19	$\chi^2 = 3.5$
Female (n)	7	7	3	$p = 0.175$
		Mean (SD) minimum–maximum		
Age	63.2 (6.2)	70.1 (6.3)	69.6 (5.6)	$F = 8.11$
(yr)	50–76	55–80	61–80	$p = 0.001$
4F-PTA	13.2 (5.6)	38.7 (5.4)	44.4 (7.8)	$F = 133.6$
(dB HL)	5–21.9	28.1–46.9	32.5–64.4	$p < 0.001$
SII left	NA	NA	0.60 (0.090)	
			40–77	
Right	NA	NA	0.57 (0.129)	
			40–77	

Notes: NA = not applicable; 4F-PTA = mean left and right thresholds at 0.5, 1.0, 2.0, and 4.0 kHz.

Table 3. Mean Unaided and Aided Speech Testing Data (SD in Parentheses) and Results of Between-Group Comparisons Using ANOVA

		NH n = 19	HI-no HA n = 19	HI-HA n = 22	Between-group comparison
Maryland CNC % correct Mean (SD)	Unaided	95.4 (3.6)	90.4 (5.6)	77.3 (18.1)	$F = 13.436$ $p > 0.001$
	Aided	NA	90.4 (8.9)	87.1 (7.5)	$F = 1.672$ $p = 0.204$
	Within-group comparison	NA	$t = 0.000$ $p = 1.000$	$t = -2.933$ $p = 0.008$	
QuickSIN SNR loss Mean (SD)	Unaided	1.5 (1.2)	4.1 (3.7)	9.2 (6.5)	$F = 15.731$ $p < 0.001$
	Aided	NA	5.9 (4.3)	4.9 (3.6)	$F = 0.638$ $p = 0.430$
	Within-group comparison	NA	$t = 2.970$ $p = 0.009$	$t = -4.137$ $p < 0.001$	

Note: NA = not applicable.

the total MoCA scores of the NH group are higher than those of the HI-no HA and HI-HA groups for both unaided and aided listening. A repeated measures ANOVA showed this difference to be significant ($F = 9.615$, $p < 0.001$), with post hoc analysis showing that the scores of the NH group were significantly higher than those of the HI-HA group but that the scores of the HI-no HA and HI-HA groups did not differ. The ANOVA also showed that scores did not improve for aided testing ($F = 0.003$, $p = 0.954$), nor was there a significant interaction between aiding and group ($F = 1.992$, $p = 0.146$). In other words, the use of amplification when conducting the MoCA did not change performance. In terms of comparison with the normative data, the scores of the participants in this study have scores that are very similar to those of Dupuis et al (2015), but which are generally lower than those of Malek-Ahmadi et al and the controls of Nasreddine et al, but are higher than those of Rossetti et al and the individuals of Nasreddine et al who had been diagnosed with MCI and Alzheimer's disease. The reasons for this variation are unclear, but might be in part associated with years of education completed.

Table 4. MoCA Data Using Severity Criteria No CI = Score ≥26, MCI/MCI+ = Score <26

			Unaided		
Study group			<26*	≥26†	Total
NH	Unaided 2	<26*	21.1%	15.8%	36.9%
		≥26†	10.5%	52.6%	63.1%
		TOTAL	31.6%	68.4%	
HI-No HA	Aided	<26*	45.0%	25.0%	70%
		≥26†	5.0%	25.0%	30%
		TOTAL	50.0%	50.0%	
HI-HA	Aided	<26*	63.6%	9.2%	72.8%
		≥26†	13.6%	13.6%	27.2%
		Total	77.2%	22.8%	

*Score consistent with MCI/MCI+.

†Score consistent with no CI.

Correlations between Audiometric Data, Speech Scores, SII and MoCA Scores

Pearson correlations were used to examine the relationship between unaided MoCA, 4F-PTA, and speech performance. Data are presented with and without adjusting for age because cognitive function changes with age, and there was a significant difference in age among the participants in our study groups. As seen from Table 6, there are strong correlations between MoCA score and the 4F-PTA, Maryland CNC score and QuickSIN, which remain moderate to strong when the analyses were adjusted for age. This indicates that performance on the MoCA was associated with unaided hearing sensitivity. To examine this further, correlations between 4F-PTA and unaided MoCA scores on each of the six MoCA domains were examined. There were significant negative correlations between 4F-PTA and the visual/executive domain ($r = -0.280$, $p = 0.023$), attention domain ($r = 0.405$, $p = 0.001$), language domain ($r = 0.265$, $p = 0.031$), delayed recall ($r = -0.535$, $p < 0.001$), and the orientation domain ($r = -0.347$, $p = 0.004$), but not between 4F-PTA and the naming domain ($r = 0.088$, $p = 0.480$) or abstraction domain ($r = 0.122$, $p = 0.329$). It is not clear why these differences exist since the items in the naming and abstract domains are no less reliant on hearing than are the items in the visuospatial/executive or orientation domains. Finally, the correlation between aided MoCA scores and SII was examined to assess whether aided MoCA performance was dependent on audibility ($r = 0.257$, $p = 0.237$). The nonsignificant correlation indicates it was not.

DISCUSSION

This study was conducted to investigate whether individuals with hearing loss would benefit from using amplification (a hearing aid or a Pocketalker)

Table 5. Mean MoCA Total Scores (SD in Parentheses) by Study Group

				Test Condition	
Study	Age	Education Mean yr (SD)	Hearing status	Unaided mean (SD)	Aided mean (SD)
Current study	63.2 (6.2)	NA	NH	25.9 (1.8)	26.1 (2.3)
	70.1 (6.3)	NA	HI-No HA	24.8 (2.1)	24.0 (2.5)
	69.6 (5.6)	NA	HI-HA	22.5 (2.9)	23.1 (3.5)
Nasreddine et al (2005)	72.8 (7.0)	13.3 (3.4)	NA (Controls)	27.4 (2.2)	
	75.2 (6.3)	12.3 (4.3)	NA (MCI)	22.1 (3.11)	
	76.7 (8.8)	10.0 (3.8)	NA (AD)	16.2 (4.8)	
Rossetti et al (2011)	60–70	All levels	NA	22.7 (4.1)	
	65–75	All levels	NA	22.1 (4.5)	
	70–80	All levels	NA	21.3 (4.8)	
Dupuis et al (2015)	69.0 (0.6)	16.1 (0.3)	NH	26.4 (0.2)	
	72.9 (0.7)	15.1 (0.3)	Hearing impaired	24.4 (0.3)	
Malek-Ahmadi et al (2015)	70–79	<13 yr	NA	25.3 (4.1)	
		13–15 yr	NA	27.8 (2.2)	
		>15 yr	NA	27.6 (2.0)	

Notes: AD = individuals clinically-diagnosed with Alzheimer's disease; NA = not available.

when conducting the MoCA—a cognitive screening measure. To this end, participants with hearing impairment completed the MoCA, along with audiometric and speech testing, unaided and aided using hearing aids if they routinely used amplification, or using a Pocketalker, if they did not. To compare their performance with that of individuals without hearing impairment, a group of NH listeners also participated in the study.

There are two key findings. First, the individuals with hearing impairment performed considerably less well on the MoCA than did those with NH. This was reflected both by percentage of individuals whose scores indicated MCI/MCI+ using a cutpoint of a total MoCA score of 26 points and by the group mean total MoCA scores. However, unlike the studies of Qian et al (2016) and Mulrow et al (1990), in which individuals with hearing loss who routinely used hearing aids performed better on cognitive tests than did individuals who did not use hearing aids, the HI-HA participants performed less well than the HI-no HA participants. This might be because the HI-HA participants were significantly older and had significantly poorer hearing than the HI-no HA group. However, this was also the case in the study of Qian et al. Thus, like Tesch-Romer (1997), van Hooren et al (2005), and Dawes et al (2015), the data suggest that amplification has no long-term impacts on cognition or cognitive decline.

Table 6. Pearson Correlations between Unaided MoCA, 4F-PTA and Unaided Speech Performance, without and with Adjusting for Age

	Unaided MoCA	Unaided MoCA
	Raw correlation	Age-adjusted correlation
4F-PTA	−0.568*	−0.481*
Maryland CNC	0.511*	0.475*
QuickSIN	−0.604*	−0.548*

Notes: 4F-PTA = mean left and right thresholds at 0.5, 1.0, 2.0, and 4.0 kHz.
*$p < 0.001$.

The second key finding is that neither use of hearing aid nor a Pocketalker improved MoCA performance relative to unaided testing. Although the SII values obtained for aided listening for the HI-HA group were suboptimal, their hearing aids did significantly improve their speech understanding, thus their unimproved aided MoCA performance cannot be entirely attributed to a poor sensory signal. In contrast, the Pocketalker seemed to be detrimental to speech understanding, especially for listening in noise thus the lack of aided benefit on the MoCA is not surprising. It is concerning that the Pocketalker negatively impacted speech understanding in this study, and further this finding is contrary to anecdotal clinical reports which suggest that Pocketalkers are effective for patients. It might be that the Pocketalker or the headphones had poor quality output or that the amplification selected by the participants was insufficient as to yield benefit. Another possibility is that individuals need time to adjust to and benefit from an amplified signal. This has certainly been proposed by others although findings are mixed (Arlinger et al, 1996 for a review). Regardless, these data lead to the conclusion that a lack of audibility during testing cannot fully explain the decreased cognitive performance of individuals with hearing loss, or if it does, current hearing aids cannot fully provide compensation. The finding of moderate to strong correlations between 4F-PTA and MoCA scores adds further credence to this conclusion.

There are at least two methodological limitations to bear in mind when interpreting our findings. First, the

MoCA was presented via live voice. It is possible, that despite training and practice, the testers subconsciously raised their voice when conducting unaided testing. If this were the case, the effects of amplification would have been diminished or negated. However, whether this was the case, it still holds that the MoCA scores of the HI-no HA and HI-HA groups were lower than those of the NH group, indicating that hearing loss impacted MoCA performance and that amplification did not compensate for this. To address this and other issues associated with live voice presentation, we would recommend administering the MoCA from a calibrated recording, using the soon-to-be-available version of the MoCA that can be administered via a tablet (see www.mocatest.org for more information), and/or for individuals with severe hearing impairment, using the "Hearing Impaired MoCA (HI-MoCA)" in which stimuli are presented visually rather than orally (Lin et al, 2017). The second limitation is the small sample size that was not determined using power analysis. As a result any statistically nonsignificant findings might be due to lack of power and/or the findings here might not be generalizable to other populations.

In summary, this study has shown that individuals with hearing loss performed less well on the MoCA than individuals with NH and that the use of amplification did not compensate for this performance deficit. Nonetheless, this should not be taken to suggest that the use of amplification during testing is unnecessary because it might be that other unmeasured factors, such as effort required to perform or fatigue were decreased with the use of amplification. Furthermore, these data should not be interpreted to indicate that hearing loss causes cognitive decline, rather it simply shows that the two are associated.

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