

# The Effect of Decreased Audibility on MMSE Performance: A Measure Commonly Used for Diagnosing Dementia

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## Abstract

**Background:** Hearing loss and dementia are both prevalent in late adulthood. The most common test used to determine cognitive status in late adulthood, the Mini–Mental State Examination (MMSE), is presented face to face, usually in the context of the physician’s office in the presence of background noise. Despite the problems of hearing loss and cognitive problems in late life, there is an absence of evidence linking hearing-related deficits to performance on the MMSE and dementia diagnoses.

**Purpose:** This study examined the effect of decreased audibility on performance on the MMSE.

**Research Design:** A between-subjects design was implemented. Participants were randomly assigned to one of five degrees of simulated hearing loss conditions and were blinded to condition assignment.

**Study Sample:** One hundred and twenty-five young normal-hearing participants were randomized into five conditions of varying degrees of simulated hearing loss.

**Data Collection and Analysis:** Performance on the MMSE was scored and cognitive status was categorized based on the scores. Analysis of variance with conditions as a between-subjects factor was conducted with post hoc multiple comparisons to determine the effect of audibility on performance.

**Results:** Reduced audibility significantly affected performance on the MMSE in a sample of young adults, resulting in greater apparent cognitive deficits as audibility decreased.

**Conclusions:** Apparent cognitive deficits based on MMSE scores obtained in test conditions in which audibility is reduced could result in incorrectly identified cognitive loss if clinicians are not alert to hearing loss when patients are evaluated. Furthermore, health care providers should be cautious when using family report of cognitive impairment to diagnose dementia without accounting for hearing loss because the impression of family members may be based on misinterpretation of the effects of hearing loss.

**Key Words:** aged, dementia, diagnosis, diagnostic errors, hearing loss

**Abbreviations:** ANOVA = analysis of variance; MMSE = Mini–Mental State Examination; NU-6 = Northwestern University Auditory Test Number 6; SII = Speech Intelligibility Index; SD = standard deviation

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## BACKGROUND

The United States Administration on Aging (2004) reports that adults aged  $\geq 85$  yr are the fastest growing section of the U.S. population. As a person ages the likelihood of living with a disability also increases; therefore, it can be presumed that with increasing numbers in the elderly population, there also will be an expanded number of persons with disabilities. For example, the U.S. Census Bureau estimated that 71.1% of individuals over the age of 80 live with a disability (Steinmetz, 2004). This estimate included sensory disorders, such as hearing loss, as well as cognitive disorders including dementia and Alzheimer disease.

Hearing loss is under-diagnosed in the general population and more so in persons with memory impairment (Yueh et al, 2003). Neurologists and primary care physicians continue to conduct hearing evaluations with bedside type hearing screenings (e.g., finger rub, whispered speech, watch tick) that lack sensitivity and reliability (Bagai et al, 2006; Boatman et al, 2007; Jorgensen, 2012). Patient self-identification of hearing loss also is unreliable with investigators reporting a 0.01–0.51 sensitivity (Boatman et al, 2007). Furthermore, widespread hearing screening programs are lacking for adults and referral rates for periodic hearing tests of persons  $\geq 70$  yr of age is  $\sim 38.5\%$  (CDC/NCHS, 2005). The lack of accurate and systematic hearing screening programs and subsequent diagnosis and treatment of hearing loss could potentially have an effect on the diagnosis of dementia because many of the overt behavioral symptoms of dementia and hearing loss are similar in older adults. Confusion-like behaviors often concern family members and other caregivers; they may presume that the person has dementia and bias the diagnostic process toward dementia rather than hearing loss.

Currently, initial diagnosis of dementia typically occurs in the primary care setting and is based on clinician suspicion related to patient symptoms or caregiver concerns (Brayne et al, 2007; Bradford et al, 2009). While neuropsychologists may complete a systematic evaluation, the primary care physician may not. *The Diagnosis and Statistical Manual of Mental Disorders Fifth Edition* does not specify diagnostic criteria for dementia (American Psychiatric Association, 2013) but rather indicates that the diagnosis of dementia should be made by a healthcare provider through a two-step process. First, the patient must present with significant cognitive decline as reported by self, family or physician. Second, the patient must score significantly lower than would be expected on tests of dementia.

*The Diagnosis and Statistical Manual of Mental Disorders Fifth Edition* (American Psychiatric Association, 2013), specifies different categories for patients who have a minor neurocognitive disorder and those with a major neurocognitive disorder. A minor neurocognitive

disorder is characterized by evidence of modest cognitive decline from previous level of performance based on concerns of the patient, family, or the clinician. Typically these changes would be defined as a decline in performance one or two standard deviations (SDs) below the norm. Additionally, the cognitive decline must impair the person in that they require greater cognitive effort, compensatory strategies, or accommodations to maintain independence, and the decline cannot be explained by any other disorder such as depression. A major neurocognitive disorder is an extension of the minor disorder. A major disorder is defined by performance of  $\geq 2$  SDs below appropriate norms on cognitive testing and sufficient decline to interfere with independence.

Although several national and international guidelines exist, there is no one procedure or test suggested for diagnosing a person with dementia (Barton and Yaffe, 2010; Clinical Research Center for Dementia of South Korea, 2011; McKhann et al, 2011; Galvin et al, 2012; Hyman et al, 2012). There are many procedures available for screening memory impairment, but none have uniform acceptance. Shulman et al (2006) surveyed 334 psychiatrists about which tests they routinely use to diagnose dementia; by far, the most common test was the Mini-Mental State Exam (MMSE) which was routinely performed by 77.1% of the respondents. The high level of usage likely is associated with the high rating the respondents gave the MMSE for ease of use, scoring, and administration. Similar results have been reported on other surveys (Davey and Jamieson, 2004; Reilly et al, 2004) with  $\sim 9/10$  of responding physicians using the MMSE (Folstein et al, 1975) to diagnose dementia. Jorgensen (2012) completed a review of patient charts from a large university medical center and also found that the most commonly used diagnostic measure of dementia was the MMSE. The MMSE is a brief measure that includes items that assess orientation, short-term recall, long-term recall, the ability to follow three-step directions, calculation, language (naming, repetition, reading, and writing), and visual-constructional tasks designed to determine whether cognitive impairment is present. The test is scored on a 30-point scale. The authors of the MMSE (Folstein et al, 1975) reported that a score of  $\geq 27$  is consistent with normal cognitive function. Below the normal cutoff, 20–26 indicates mild dementia; 10–19 moderate dementia, and  $< 10$  severe dementia. Because the MMSE is biased by educational level, age and education-level-adjusted norms are available. Kahle-Wrobelski et al (2007) report sensitivity and specificity of  $\sim 0.80$  for identifying dementia in the oldest-old using the MMSE. However, the sensitivity and the specificity of the MMSE decreases when applied to the detection of mild dementia due to a possible ceiling effect (Simard and van Reekum, 1999).

The MMSE has numerous structural weaknesses. Nineteen of the 30 points (>60%) are directly related to orientation to person/place and require the perception and understanding of auditory language. This auditory language load could significantly decrease performance on MMSE by those who miss or misperceive speech and linguistic content because of hearing loss or compromised language skills. The elaborate copy design item derived from the Bender–Gestalt is a visual construction task and contributes only 1 point to the 30-point total. In a response to a Letter to the Editor, Folstein et al, (2007) argued that the problems of the MMSE include examiner modification of the test, and substitution of spelling “world” backward rather than serial 7s (counting backward from 100 by 7s). They also stressed that the MMSE should not be used as a substitute for a systematic evaluation. However, practicing physicians do not appear to heed this warning in that 9/10 physicians report solely using the MMSE for diagnosis (Davey and Jamieson, 2004; Reilly et al, 2004). Despite the weaknesses and limitations of the MMSE, it appears to be the standard tool for dementia diagnosis by front-line primary care physicians. One approach to improving test accuracy would be to reduce or eliminate confounds, such as hearing loss, which weaken the MMSE and put the diagnosis of dementia (or the severity category) into question. There is evidence to suggest an association between sensory function and cognitive decline (e.g., Sands and Meredith, 1989; Lindenberger and Baltes, 1994). Little research has been conducted on the relationship between reduced hearing sensitivity and the assessment of cognitive functioning. There are a number of field studies that suggest an association between hearing loss and dementia implying that hearing loss was most likely present at the diagnosis. Hearing loss is about twice as likely in individuals with dementia or other mental disorders than in those with age-appropriate cognitive function (Kay et al, 1964; Hodkinson, 1973; Uhlmann et al, 1989). Kiely et al (2012) described cohort data from 4,221 participants which examined audiological thresholds (500–8000 Hz), health data, and global cognitive status using the MMSE across four years. They suggested that after adjustments were made accounting for age and education, the pure-tone average was associated with cognitive performance. However, they did not describe the method of MMSE administration and they also did not look at the effect of hearing ability on the actual diagnosis of dementia in a controlled manner. Gold et al (1996) reported that hearing loss was more prevalent in those seeking care at a memory clinic which is consistent with a higher rate of hearing loss in those diagnosed with dementia.

There are examples of individuals with hearing loss appearing confused and labeled as senile but who improved after being appropriately fitted with amplification (Ronholt, 1986). (for an overview of fitting hearing assistive

technology on patients with cognitive impairment, see Pichora-Fuller et al, 2013; Jorgensen and Messersmith, 2015). Palmer et al (1998) reported that some of the difficult behaviors associated with dementia of the Alzheimer type were reduced as reported by caregivers after individuals with Alzheimer Disease received amplification. These studies focused on the population already diagnosed with dementia and provided evidence that hearing loss can negatively affect behavior in this population.

Weinstein and Amsel (1986) and Uhlmann et al (1989) provided evidence that hearing loss correlated with diminished performance on verbally administered cognitive tests for dementia. These studies were conducted in a clinical setting with individuals already labeled as demented and were not controlled or blinded. The criteria for dementia diagnosis were unclear for their populations. Dupuis et al (2015) reported in a study of >300 participants that sensory impairment (hearing and/or vision) negatively affected performance on a test of dementia. Lindenberger et al (2001) attempted to quantify the effect of peripheral hearing ability on a test of dementia for participants 30–50 yr of age using a single hearing protector to simulate high-frequency hearing decrement. They reported a significant decrease in performance on an intellectual test for those participants with simulated hearing loss. To date, there are no investigations indicating the consequences of differing degrees of undiagnosed peripheral hearing loss on the diagnosis of dementia and how this could not only determine whether a person is diagnosed with dementia but the degree of the labeled cognitive impairment.

The question remains as to whether hearing loss alone can make someone with normal cognitive function appear to be demented or appear to have a more advanced stage of dementia on a test of dementia. Lopes et al (2007) investigated adults who had mild cognitive impairment who performed similarly on tests of cognitive function. The investigators questioned the participants about their cognitive status and two groups emerged—those who reported normal cognitive function and those who reported cognitive impairment. The authors assessed the hearing status of the two groups and determined that those who reported cognitive impairment had significantly worse hearing than those who reported normal cognitive function. These results further call into question clinic-based protocols used to diagnose dementia as they generally rely on self- or family-report of cognitive impairment and do not often control for hearing impairment.

With the evidence suggesting that those with hearing loss are at a significant disadvantage when taking tests of intellectual ability such as the orally presented portions of the MMSE for reasons unrelated to their cognitive ability, this study sought to determine the direct

effect of audibility on performance on this test. The purpose of the present study is similar to studies that used simulations of age-related vision problems to demonstrate how vision loss could influence results on cognitive tests (e.g., Toner et al, 2012). We predicted that reduced audibility in a sample of cognitively healthy younger adults would diminish performance on the MMSE suggesting that hearing-related impairments could significantly interfere with accurate MMSE performance and compromise accurate dementia diagnoses.

**METHODS**

This study employed a between-subjects design and was approved by the University of Pittsburgh Institutional Review Board. After obtaining informed consent, participants were randomly assigned to one of five hearing conditions and were blinded to condition assignment. To protect from examiner bias, the participants' verbal responses to orally presented test items were recorded and scored by an independent examiner blinded to condition as well as being scored by the primary investigator who was present at testing. The scores were compared across the primary and independent examiners; if there were any disagreements in recorded responses between the first two reviewers, a third examiner was asked to review the responses and a consensus was reached.

**Participants**

The required sample size was estimated with a power analysis (Faul et al, 2011) based on a one-way, fixed-effects analysis of variance (ANOVA) with a targeted power of 0.80 and an alpha of 0.05. No previous studies were available where the MMSE was administered to young normal-hearing participants so the effect size was unknown. A large effect size was assumed (0.40, Cohen, 1988, 1992) given that this test is a clinical measurement and these data will potentially be used for clinical decision making. A total of 125 participants were needed with 25 participants in each of the five conditions.

To ensure normal central and peripheral auditory function, young adult participants (18–39 yr, mean = 18.83, SD = 1.46) were recruited. Additionally, young participants were recruited to reduce the effects of age-related cognitive deficits. Participants completed a series of audiometric tests and procedures with the results summarized in Table 1. Normal hearing was defined as air-conduction pure-tone thresholds better than 20 dB HL at all audiometric octave frequencies (250–8000 Hz). The participants had normal middle ear function as assessed with tympanometry using a 226-Hz probe tone (Wiley et al, 1996; Roup et al, 1998). Speech perception ability was assessed using the ten most difficult words from the Northwestern University Auditory Test Number 6 (NU-6) by Difficulty Version II; these were presented at 40 dB SL (Hurley and Sells, 2003) and participants were excluded if they missed more than one word in either ear. The participants also were assessed with the Randomized Dichotic Digits Test (Strouse and Wilson, 1999) to document normal central auditory processing of speech stimuli. The participants were presented a half-list in the directed mode (D. Moncrieff, Randomized Dichotic Digits Test—Young Normals, publication in progress, personal communication, 2011) at 40 dB SL. To be included, they had to perform within normal limits for their age (Strouse and Wilson, 1999).

Because items on the MMSE can be learned it was imperative that the participants do not have intimate knowledge of the test. To control for prior knowledge, participants were asked to rate their familiarity with a list of five cognitive tests on a three-point scale: “not familiar”, “heard of it but not able to describe,” or “highly familiar”. Of the five tests rated by participants, the MMSE was the only real test and the others were fictitious. The purpose of this procedure was to determine participants' familiarity with the MMSE without cueing them to the test being the focus of the study. None of the participants recruited were highly familiar with the MMSE.

**Table 1. Participant Inclusion/Exclusion Criteria**

Measure	Inclusion Criteria
Age	18–39 years of age
Language	English as first language
Pure-tone thresholds	Normal hearing sensitivity in both ears (thresholds <20 dB HL at frequencies 250–8000 Hz) ≤10 dB difference between ears at any frequency
Percent correct word recognition accuracy	Error on no more than one word of the ten most difficult words presented at 40 dB SL
Tympanometry	Ear canal volume: 0.8–2.1 cm <sup>3</sup> Peak Pressure: 0.2–1.8 mmhos
Random dichotic digits	Within 95% confidence interval
Familiarity with MMSE	Not highly familiar with the MMSE

## Stimuli

### MMSE

The study sought to determine the effect of audibility on the score obtained on the MMSE while controlling other presentation and participant variables. There are no published standard methods or guidelines for administration of the MMSE with regard to distance from the patient, ensuring the patient is attentive, ensuring eye contact for improved speech reading, loudness at which the test is presented, etc. In order to best simulate real-world presentation, physicians in a typical internal medicine clinic were observed to determine how they administered the test. Additional information on administration, such as how physicians spoke when administering the MMSE and common environmental conditions, was recorded. The factors that were observed and the methods for controlling these factors are described in Table 2.

An acoustic recording of a male physician administering the MMSE was chosen as the acoustic stimuli for this study. The recording was obtained from online teaching recordings (Internet Archive, 2012). Of note, the speaking rate of the recorded physician was 123 words per minute. Conversational speech rate for American English is between 160 and 200 words per minute whereas the speaking rate for read speech decreases

by an average of 50–100 words per minute (Picheny et al, 1986). The rate of the recording was slower than conversational speech and likely a rate common to instruction—a rate employed by speakers to ensure comprehension. The average root-mean-squared of the recording was increased to 70 dB SPL to simulate loud conversational levels (Olsen, 1998) and the level commonly observed in clinical settings. In addition, noise was added to simulate hospital/clinic noise. White noise at a level of 45 dB SPL is common in patient rooms where the MMSE generally is administered (Falk and Woods, 1973; Hilton, 1985; McLaughlin et al, 1996; Allaouchiche et al, 2002; Blomkvist et al, 2005). The Acoustics Research Council recommends that noise in patient rooms to be no more than 35–45 dBA (Acoustics Research Council, 2010). Previous research described by I.J. Busch-Vishniac (Data from 2005 Noise at Johns Hopkins Hospital, personal communication with L. Jorgensen, 2011) suggested there is a specific spectral shape to the noise that is heard within hospital rooms (Busch-Vishniac, 2011). The spectra are generally flat over the 63–2000 Hz octave bands, with higher sound levels at lower frequencies, and a gradual roll off above 2000 Hz. Specific data describing the frequency and intensity components of the typical hospital noise were obtained from Busch-Vishniac and white noise was manipulated to reflect this spectral shape and intensity. This noise was then

**Table 2. Factors Considered in Developing Simulations of Real-World Test Conditions**

Factor	Clinical Observation	Simulation Control	Justification/Citation
Hearing loss	Physicians generally do not take hearing loss into account when assessing dementia; patients may have varying degrees of hearing loss	Simulate four hearing losses	These five hearing conditions represented progressively decreasing audibility and thus progressively decreasing access to the acoustic information (Humes and Roberts, 1990; Jorgensen et al (2014)
Loudness level	Physicians spoke at loud conversational level	70 dB SPL	Olsen (1998)
Background noise	Significant background noise was present; 45–83 dB SPL A white noise from fan using sound level meter phone application measured at position of the patient	45 dB RMS white noise (average per published research) using published spectral shaping combined with original stimuli	Falk and Woods (1973), Hilton (1985), McLaughlin et al (1996), Allaouchiche et al (2002), Blomkvist et al (2005), Busch-Vishniac (2011)
Reverberation	The rooms were small and thus it is likely that the physician was within the critical distance	No reverberation will be added	Crandell and Smaldino (1994), Mijic and Masovic (2010)
Rate of speech	Physicians spoke not as fast as conversational speech (160–200 words per minute), not as slow as read speech (50–100 words per minute)—instructional rate (~120 words per minute)	Recording of experienced physician giving/instructing on MMSE	This rate most closely simulated real-world rate as physicians are very comfortable and familiar with this task and thus speak more quickly than read speech but slower than conversational
Visual cues	Physician inconsistently faced the patient directly	No visual cues were given	Audibility only is the desired task to be evaluated. Additionally, want to err on the side of difficulty

Note: RMS = root-mean-squared.

added to the MMSE recordings to ensure that the signal presented to participants was similar to the conditions within typical exam rooms.

### Simulation of Hearing Loss

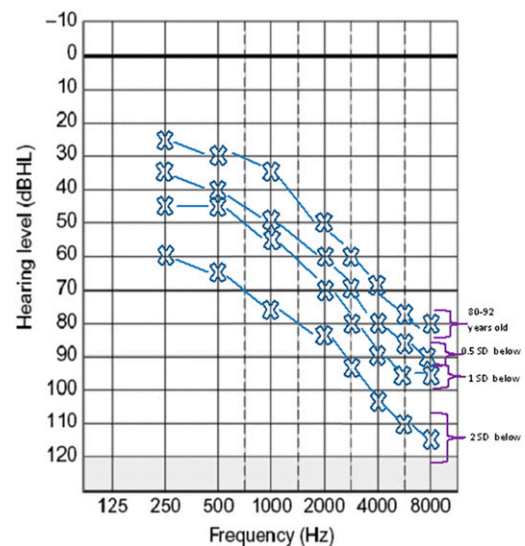
Five hearing conditions were created for the study with each condition assigned to a single set of participants. The conditions included: (a) normal hearing, (b) mild-to-moderately severe sloping hearing loss, (c) mild-to-severe sloping hearing loss, (d) moderate-to-severe sloping hearing loss, and (e) severe-to-profound sloping hearing loss. For Condition 1 (normal hearing) no modifications were made to the recorded MMSE, whereas the hearing loss configurations for Conditions 2–5 were simulated based on the Cruickshanks et al (1998) data using the procedures described below.

Cruickshanks et al (1998) reported age-related hearing loss in a population-based study of adults from a rural Midwestern community. The participants were grouped into four age categories: 48–59, 60–69, 70–79, 80–92 yr with average audiograms reported for each group by gender. Because people are not typically diagnosed with dementia until the age of 65, only the audiometric configurations of the 70–79 and 80–92 yr age groups were considered. The thresholds for the two groups were not clinically or statistically different but the males had greater loss than the females, so the hearing loss configuration associated with the 80- to 92-yr-old males was chosen for Condition 2 (mild to moderate). Three additional configurations were constructed by elevating the thresholds  $\frac{1}{2}$ , 1, and 2 SDs above those used for Condition 2; creating a mild-to-severe (Condition 3), moderate-to-severe (Condition 4) and severe-to-profound simulated hearing loss (Condition 5), respectively. The hearing loss configurations that were derived from this method are plotted in Figure 1, rounded to the nearest 5 dB HL.

The hearing losses were simulated using frequency-specific attenuation (filtering) achieved with a digital 10-band graphic equalizer (Adobe Audition 3). Acoustic information present <250 Hz and >8000 Hz was not manipulated because very little acoustic energy required for speech perception is present within those regions. Filtering was used as opposed to masking because it allowed a more straightforward inclusion of frequency-shaped white noise to simulate ambient hospital/clinic room noise. Filtering has been employed in the previous research to determine the effect of audibility on speech perception when additional noise is added (e.g., Grant, 2001; Oxenham and Simonson, 2009).

### NU-6 Word Recognition Testing

The NU-6 (male voice, 50-word lists, Auditec CD) was modified to conform to the same four hearing loss conditions. The purpose of including the NU-6 was to assess



**Figure 1.** Four hearing loss configurations derived from Cruickshanks et al (1998) that were used as the foundation of hearing loss simulations for this study. (This figure appears in color in the online version of this article.)

validity of the hearing loss simulations and replicate previously published data that showed that a decrease in audibility resulted in reduced Nu-6 accuracy scores (Martin, 1950; McCreery, 2011). The simulated hearing loss configurations were applied to lists 1 and 3 of the test resulting in ten versions—two 50-word lists for each of the five listening conditions. Using the same hearing conditions as the MMSE, one 50-word list was presented to each ear for each participant.

### Speech Intelligibility Index Calculations

To establish the audibility levels, the Speech Intelligibility Index (SII) was applied to the acoustic test stimuli for each of the five hearing conditions of the MMSE and the NU-6. The SII was calculated with the 21-band (critical bandwidth) method using software available from the Acoustical Society of America Workgroup S3-79 (ASA, 2010). Although the SII is not accurate in modeling changes in distortion, it does account for changes in audibility (Smith et al, 2012). Using the SII, band spectrum levels for the calculations were measured with a sound-editing program (Adobe Audition 3) from the original sound files after gain was applied to reach 70 dB SPL. The hearing loss configurations along with information about the background noise (45 dB SPL spectrally shaped white noise) also were inputted into Adobe Audition 3 for SII calculation by band spectrum. Using this approach, the SII was calculated for each of the five hearing conditions resulting in five SII audibility scores (see Table 3). SII calculations can yield values between 0.0 and 1.0. The stimuli for Condition 1 (no simulated hearing loss) had an SII of close to 1.0 but

**Table 3. SII Results for Each Condition and Test**

Condition	MMSE	NU-6
1 (normal hearing)	0.998	0.988
2 (mild-moderately Severe)	0.387	0.426
3 (mild-severe)	0.235	0.274
4 (moderate-severe)	0.109	0.158
5 (severe-profoundG5)	0.022	0.022

due to the addition of the 45 dB SPL noise there was a slight reduction in the SII as compared to the recording without the noise. The other four hearing conditions had a less audible signal, and therefore, received lower SII values.

Previous researchers have employed the SII to predict speech intelligibility for syllables, words and sentences (Killion and Mueller, 2010) and suggested that for sentences near perfect intelligibility is reached with an SII of 0.40. As such, it was predicted that the different simulated hearing losses in this study should result in different MMSE scores because they are known to result in different speech intelligibility scores. However, there are two distinct differences between the data presented here and the previously published data presented in Killion and Mueller (2010). Many of the studies looked at performance as a function of intensity where test materials were repeated, whereas this study included five distinct conditions with varying levels of audibility.

## Procedures

Qualified participants were randomly assigned to one of the five hearing conditions: no alteration (normal hearing, Condition 1), mild-to-moderately severe simulated hearing loss (Condition 2), mild-to-severe simulated hearing loss (Condition 3), moderate-to-severe simulated hearing loss (Condition 4), and severe-to-profound simulated hearing loss (Condition 5). Participants were blinded as to the hearing condition to which they were assigned. Participants were seated in a single-walled sound-treated booth. The condition-specific NU-6 recordings were routed through a Beltone 2000 audiometer (Type 1, 2-channel audiometer) to each participant via insert earphones (ER-3A). Ear-specific data were collected to replicate previously published data (Killion and Mueller, 2010) to ensure validity of the simulated hearing losses. Presentation order of ear and lists was randomized. The participant was instructed to repeat each word. The responses were recorded and a percent correct accuracy score was calculated for each list of words. For data analysis, the participant responses were converted to rationalized arcsine transform units (Studebaker et al, 1995). This conversion allows for stabilization of the variance across a range of percent correct scores which leads to easier comparison of differences in percent correct scores from across the entire range from 0 to 100%. The results for NU-6 testing are reported here rather

than in the results section because they confirm that the filtering method yielded the expected results on word recognition and support the choice of the filtering method in processing the MMSE materials to simulate hearing loss. Decreasing audibility significantly decreased the percent correct score obtained on the NU-6. Table 4 includes the means and 1 SD for each hearing condition. Although the right and left ear scores were significantly different in a pairwise comparison [ $t_{(124)} = -3.506, p = 0.001$ ], they likely were not clinically ( $>5$  dB) different for any participant (Dubno et al, 1995). These findings verified that significant differences in audibility between conditions were achieved in this experiment.

The condition-specific MMSE recordings were routed through a Beltone 2000 audiometer to a single loud-speaker with the participant facing the speaker at 0° azimuth, 4' from the speaker as if the person was facing a practitioner. As some of the MMSE instructions require visual cues, the examiner was seated in the test booth with the participant to provide the visual cues. A frequency sweep of 50–10,000 Hz was played via sound-field speakers with and without the examiner in the booth; there was no change to the acoustic response with the examiner seated in the booth. The recordings were played only once and were not repeated with the exception of the initial repetition of the three items in the Repetition Section of the MMSE (Folstein et al, 1975). The stimuli were paused between each item to give participants adequate time to verbally respond. Responses to the NU6 repetition task and the MMSE questions were recorded by the experimenter and also were digitally recorded. To ensure accuracy and to protect from examiner bias, these recordings were reviewed by a scorer blinded to the conditions. The blinded scorer's evaluation of responses was compared to the experimenter's evaluation of responses for agreement. The examiners only disagreed on 2 of the 5,000 recorded responses; a third reviewer determined the response in these two cases.

## Statistical Analyses

The following analyses were conducted to evaluate the research question using SPSS version 21:

- Do differing amounts of audibility (e.g., simulated hearing loss) systematically change MMSE scores?

**Table 4. Effect of Degraded Audibility on NU6 % Correct**

Condition	SII	Right-Ear % Correct		Left-Ear % Correct	
		Mean	SD	Mean	SD
1	0.988	100	1.2	99	2.1
2	0.426	89	7	93	3.8
3	0.274	67	13.1	70	12
4	0.158	33	15.2	39	14
5	0.022	10	6.3	13	7

- An ANOVA was conducted to answer the initial question as to whether audibility changes the MMSE. Post hoc multiple *t*-tests were conducted to investigate significant differences. Each of the conditions (as defined by audibility) was compared to each other. There was no difference in the ANOVA results with or without a correcting alpha for multiple comparisons.

**RESULTS**

**MMSE Score**

An ANOVA revealed significant differences in performance on the MMSE among conditions with differing audibility [ $F_{(4)} = 19.0849, p < 0.001, \eta^2 = 0.864$ ]. The mean and SD for each group is shown in Table 5. A post hoc analysis revealed that condition 1 (normal hearing) and condition 2 (mild-to-moderately severe hearing loss) were not significantly different from each other, but all other conditions were different from one another with a *p* value <0.001. Figure 2 illustrates the deleterious effect of audibility (as represented by SII) on the MMSE score.

Each participant’s MMSE score was calculated and a determination of dementia status was made. The classification of cognitive status was adjusted for college experience or higher degree (Crum et al, 1993) as all participants had been enrolled in college at some time. The participants were then labeled with what would have been their assigned cognitive status based on their MMSE score: normal cognitive status, mild dementia, moderate dementia, and severe dementia (Mungas, 1991). These labels are commonly used in the medical field to determine the degree of dementia experienced by the patients when the diagnosis is made or the disease has progressed. The findings of this study directly demonstrate the effect of hearing loss on the cognitive status diagnosis as these are cognitively normal participants, but would be labeled as having dementia. With increases in the amount of simulated hearing loss, there was a decrease in the MMSE score (see Figure 3).

**DISCUSSION**

This study sought to determine the effect of audibility on the diagnosis of dementia when the MMSE is

used for diagnosis. The results of this study suggest that audibility significantly influences the score on this test and therefore could change the diagnosis of dementia.

**NU-6**

The results of the NU-6 with reduced audibility were in agreement with previously published data on the effect of audibility on the NU-6 words (Killion and Mueller, 2010) The simulated hearing losses did, in fact, decrease audibility as expected and support the design of the experiment to evaluate the effect of audibility on MMSE results.

**MMSE**

The effect of reduced audibility on the MMSE overall score is in agreement with currently published data on the effect of audibility on speech perception tests (see Figure 4). In order to compare the currently published percent correct data with the MMSE which is scored on a 0- to 30-point scale, the MMSE scores were converted to *z* scores. The MMSE is different from the previously published data on three dimensions: (a) the published data are based on the word recognition performance on tasks that required the repetition of auditory test materials while this study employed a comprehension task; (b) the published studies evaluated the same participants for each of the conditions of altered audibility while this study tested different participants for each of the five data points; and (c) the published data use acoustically and linguistically similar items while this study test is comprised of 30 different performance points. While these differences are significant, results consistently demonstrate that for a young normal-hearing person, ~40% audibility is necessary for accurate speech perception. Below this 40% cutoff, the amount of available acoustical information determines the slope of the curve rather than any linguistic knowledge filling in the missing acoustic information. The performance on the MMSE of Conditions 1 and 2 were not significantly different from one another, but all other conditions were different from one another forming a steep slope <38% audibility suggesting that the participants were able to use linguistic and contextual information to fill in the missing or limited acoustic cues when audibility was >40% consistent with previous findings on other materials (Pavlovic, 1987; Lunner, 2003; Pichora-Fuller and Singh, 2006; Akeroyd, 2008). The MMSE scores also are consistent with previously published data regarding steepness of the slope and decrement in performance below ~40% audibility (Killion and Mueller, 2010). Based on Figure 3, the majority of participants in this study who were provided with reduced audibility would have obtained a dementia diagnosis although participants were known to be cognitively intact.

**Table 5. MMSE Performance as a Function of Audibility Condition**

Condition	SII (Audibility)	Mean	SD
1	0.998	28.72	1.370
2	0.387	27.64	2.885
3	0.235	16.84	4.888
4	0.109	10.36	5.715
5	0.022	4.20	2.843



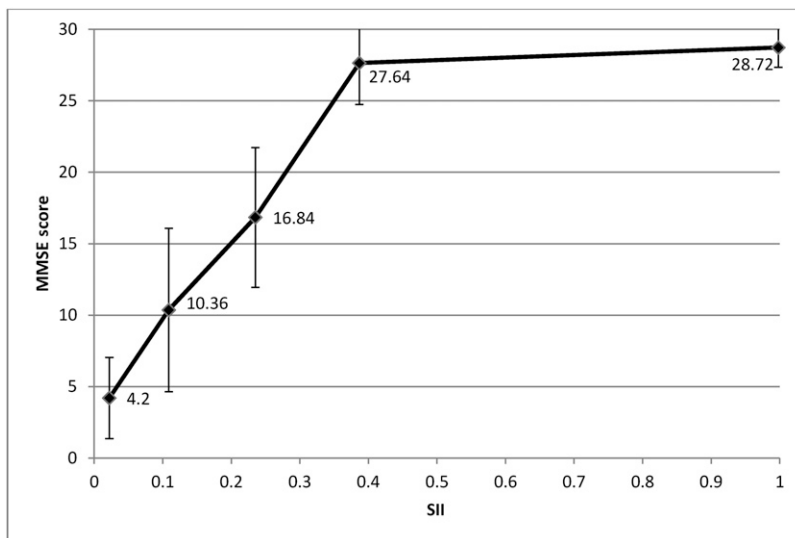


Figure 2. Effect of audibility as measured by the SII on MMSE score with SD bars.

Furthermore, decreasing audibility predicts more severe dementia labels.

A large proportion of the older population has a mild-to-moderately severe hearing loss which is commonly overlooked (Williamson et al, 1964; Powers and Powers, 1978; Corbin et al, 1984). The results of this study suggest that 16% of participants with a mild-to-moderately severe simulated hearing loss (Condition 2) were misdiagnosed as having dementia. As audibility decreases, the rate of misdiagnosis of dementia becomes higher and more concerning. However, it should be noted that while it is important to consider and to attempt to restore audibility during dementia testing, people with hearing loss may very well still be at greater risk for clinically significant cognitive decline compared to peers with good hearing.

Patients with hearing loss are at a significantly higher likelihood of being diagnosed with dementia (Dupuis et al, 2015) and there is a much higher rate of hearing loss in clinics specializing in memory disorders (Gold et al, 1996). It is possible that global sensory processing deficit (Humes et al, 2013) or a declining sen-

sory function, in conjunction with processing speed and auditory working memory (Baldwin and Ash, 2011), could cause a significant decline in cognitive function. To combat the confounds introduced by the aging auditory system for the purposes of this study, participants were young adults with normal hearing ability.

Results from this study suggest that audibility alone could affect the diagnosis of dementia; however, it cannot be concluded that those older adults with hearing loss would act the same way as predicted in this study. With a slowly progressive hearing loss, those with undiagnosed hearing loss may recruit more top-down central processing to fill in the missing auditory information—information that the research study participants were

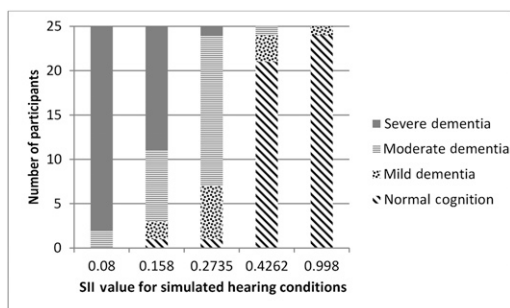


Figure 3. Classification of performance on the MMSE by dementia severity per condition of simulated hearing loss.

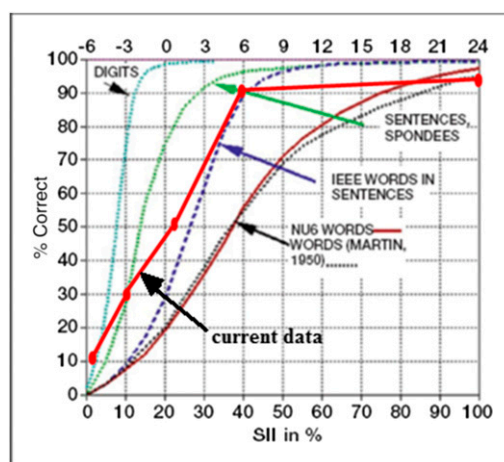


Figure 4. Performance as a function of audibility (SII) on the stimuli used in the current investigation (MMSE) compared to previously determined performance on speech materials (Killian and Mueller, 2010, used with permission). Scores were converted to z score (proportion correct) for comparison to other tests. (This figure appears in color in the online version of this article.)

not able to use. Older adults are more likely than young adults to use context and, by doing so, the older adults have greater accuracy when context is facilitative. Nevertheless, older adults with untreated hearing loss would likely depend on the top-down processing of contextual cues when auditory cues are not available (Whiting et al, 2014). However, those who depend on contextual cues risk inaccuracies when context is incongruent with what is actually spoken (Rogers et al, 2012). In the context of this study, inaccurately interpreting the auditory information could have a deleterious effect on a medical diagnosis of dementia.

The obvious question resulting from this study is what can be done about reduced audibility and the potential effect on the diagnosis of dementia. The first suggestion would be to ensure the physician is aware of the auditory status of a patient before administering tests of dementia. This would be done through a full audiological evaluation. Additionally, physicians should be aware of the influence of audibility on the verbally presented tests of dementia. One possible solution would be the use of a noncustom, personal sound amplifier with all patients who do not wear hearing assistive technology to provide audibility.

Ensuring patients can hear is key to quality care and thus good communication techniques such as controlling the acoustic environment, facing the patient, and good lighting should be implemented in all medical settings. Additionally, a physician may choose to provide the written versions of tests rather than verbal versions with the understanding of the effect of visual deficits, but there may be significant problems with this strategy given vision deficits and literacy issues (Wittich et al, 2010). Wittich et al report that when presenting a test of cognitive function to those with visual impairment the specificity of the test remained high, but the sensitivity was significantly reduced. They suggested changes in the cutoff values for people with visual impairment by removing those items requiring this modality. This suggestion could be expanded to using verbally presented tests for those with auditory impairment; however, the majority of the MMSE is presented without visual information. Furthermore, if only presenting the visual items or using the available written version of the MMSE, Keller et al (1999) reported that ~13% of those with hearing loss in their study had worse than 20/70 vision which would significantly decrease their performance on the exam. Those with dual sensory impairment have greater overall health disparities than those with hearing loss alone (Crews and Campbell, 2004). Dupuis et al (2015) reported a significant disparity in the performance of participants with sensory impairments. They tested 301 participants with hearing loss or vision impairment or both, the majority of which reported either average or excellent health. They reported a significantly higher proportion of those with normal hearing and vision

performed within the normal range on the test of cognitive ability. Specifically, they reported that 66% of those with normal hearing scored in the normal range while only 6% of those with hearing impairment had similar scores. These data suggest that those with hearing impairment are at a significant disadvantage when given tests of cognitive ability.

It is often thought that, as with many disorders, asking the patient if they have hearing loss will suffice in the diagnosis of hearing loss. Many providers feel that by asking their patients “do you have a hearing loss” the answer is an accurate reflection of their hearing status as this is what is recommended by the American Academy of Family Physicians (2010) and the U.S. Preventative Task Force (1996). Several studies have compared audiometric thresholds with patient report of hearing status and have found low predictive value (e.g., Clark et al, 1991 reports 28% positive predictive value). The results from the present study support the need for hearing evaluation in that the degree of hearing loss and not just the presence or absence of hearing loss impacted the diagnosis.

The accuracy of any diagnosis depends on the sensitivity of the tests used in clinical decision making. This study demonstrated that the most commonly performed test to diagnose dementia, the MMSE, is highly influenced by changes in audibility. The data from this study support the need for identification and remediation or at least consideration of hearing loss before the evaluation of dementia.

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