THE POTENTIAL IMPACT OF UNDIAGNOSED HEARING LOSS ON THE DIAGNOSID OF DEMENTIA

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Hearing loss and dementia are conditions that impact similar populations. Many adults do not seek audiologic care for their hearing loss and thus are seen in the primary care physician's office with an undiagnosed hearing loss. This study sought to determine the impact of undiagnosed hearing loss and thus decreased audibility on the items of the Mini Mental State Examination (MMSE) commonly used to diagnose dementia. Many physicians use the MMSE along with self-report of cognitive decline to diagnose dementia. Previous studies have suggested that self-report of cognitive decline is impacted by hearing loss. This study suggests that a decrease in audibility that would be associated with an undiagnosed hearing loss significantly impacts performance on the MMSE. Physicians should be cautious when using the MMSE and self-report of cognitive impairment to diagnose dementia without accounting for hearing loss as both may be significantly impacted by undiagnosed hearing loss.

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PREFACE

For most graduates, this serves as a way to thank their family and mentors for their support. In my case, these are not separate groups of people as my mentors have become more like family and my family has provided me with lifelong guidance and teaching.

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INTRODUCTION

The United States Administration on Aging (2004) reports that the group of individuals aged 85 and older is the fastest growing section of the US population. With increasing age, the likelihood of living with a disability increases. In a US Census Bureau report, it was estimated that 71.1% of individuals over the age of 80 live with a disability (Steinmetz, 2004). This includes sensory disorders, such as hearing loss, as well as cognitive disorders including dementia and Alzheimer Disease. As these disorders often progress slowly, the awareness and subsequent diagnosis of these disorders is often delayed by the person and their family. This delay in diagnosis and the decrease in the use of treatment/assistive devices may lead to these disorders impacting one another or even confounding diagnosis and treatment.

Hearing loss is the third most prevalent chronic condition in elderly adults after hypertension and arthritis (Cruickshanks et al., 1998). Hearing loss is under-diagnosed in the elderly population due to the gradual progression of the hearing loss and the view that it may be seen as an inevitable part of aging (Yueh, Shapiro, MacLean, & Shekelle, 2003). Beyond the lack of identification, hearing loss is often undertreated. Only 25% of patients with aidable hearing loss acquire hearing aids (Kochkin, 2005). Poor audibility of sound corresponds to a lack of a person's ability to understand speech (Humes, 1991, 2007; Kamm, Dirks, & Mickey, 1978; Otto & McCandlis, 1982). This diminished understanding ability can impact conversations with family members and with medical professionals.

Dementia is characterized by acquired, persistent and progressive deterioration of multiple cognitive functions: language, memory, attention and executive function (American Psychiatric Association, 1994). Correct clinical identification of dementia is fundamental to pharmacological management and long term care. The diagnosis of dementia by a physician is dependent on self-report, report from family and in office testing. Doctors rely heavily on family report for an accurate diagnosis. Several surveys of healthcare professionals have reported the most frequently applied cognitive test used for dementia is the orally administered MMSE, used by approximately 9 out of 10 professionals (Davey & Jamieson, 2004; Reilly, Challis, Burns, & Hughes, 2004; Shulman et al., 2006). Family report and the orally administered Mini Mental State Exam may be significantly impacted by many factors including an undiagnosed hearing loss.

Statement of the Problem

Based on the premise that the most common criteria for a diagnosis of dementia consists of family report and MMSE criteria and recognizing that many of the symptoms of untreated hearing loss (e.g., repeating questions, withdrawal from social situations) may be reported by family members as an example of demented behavior and further recognizing that undiagnosed hearing loss can impact correct speech perception on an orally presented examination, it is hypothesized that an undiagnosed/untreated hearing loss could impact the diagnosis of dementia.

1.0 BACKGROUND

1.1 DEMENTIA

The word dementia is derived from the Latin word demens which means madness or insanity; it is also the root word of demon. While most with dementia are not insane or act in a demonic manner, the causes of dementia are broad as well as are the symptoms and the effects on the persona and their family. Dementia is a loss of brain function that occurs with certain diseases. It affects memory, thinking, language, judgment, and behavior. Dementia usually starts with forgetfulness that is often overlooked as typical cognitive aging or "having too much on my mind". As dementia becomes worse, symptoms become more obvious and start to interfere with daily activities. In previous centuries, dementia had a much broader symptomology, diagnosis protocol and treatment regimen (Wallin, 1996). Dementia is a non-specific illness syndrome that normally has to be present for at least 6 months to be diagnosed; it differs from mental retardation in that it is a change from the baseline otherwise described as a change in thinking abilities from the previous mental state (Wallin, 1996). In all types of cognitive dysfunction, higher mental functions are first affected. In later stages of dementia, the person may appear disoriented and may be unable to have an appropriate conversation. While dementia is typically thought of as an aging disorder, it may occur at any stage of life. For this discussion, the primary focus will be on those with typical age-related dementia and not those with atypical dementia, alcohol-induced early-age dementia or any other type of early onset dementia.

1.1.1 Prevalence

Approximately 3.4 million Americans have been diagnosed with dementia; this number is expected to double by 2025. The majority of these patients are over the age of 85. Although the incidence rate of men to women is equal up to age 85, the lifetime risk for dementia in women is twice as high due to increased life expectancy and the accompanying higher dementia rates in extremely old age (Ott, Brenteler, van Harskamp, Stijnen, & Hofman, 1998; Plassman, 2007). The range from normal cognitive changes to severe dementia is used to describe the cognitive difficulties of the geriatric population (see Figure 1). Although these categories are not specifically defined, they are generally accepted as categories.

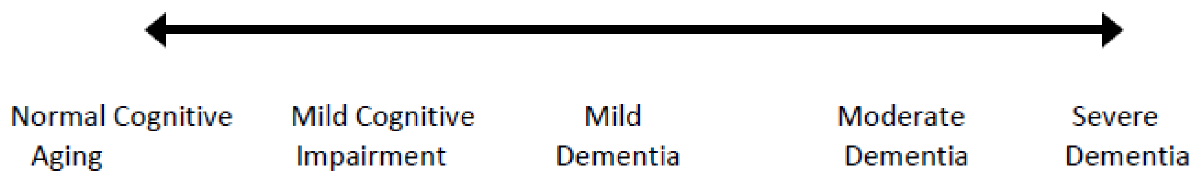


Figure 1: Range of Cognitive Difficulties

Many elderly individuals fear imminent dementia, yet few can imagine the actual risk of the disease. Ott et al (1998) reported on the incidence of dementia among elderly adults in the Netherlands. As part of a nationwide cross-sectional study, they reported that dementia incidence rates of men and women up to age 85 were similar; however, the overall risk of a woman aged 55 getting dementia is twice as high as a man (0.33 vs. 0.16). They attributed this to higher life expectancy of women and the high risk of dementia at very old age. Dementia is a major disabling disease in the elderly population, primarily affecting those over the age of 65. In addition to the suffering of the patient, the disease may induce increased distress, anxiety and depression among family members and caretakers (Downs, Cook, Rae, & Collins, 2000).

1.1.2 Subtypes of Dementia

Clinicians and researchers often split dementia into two different subtypes: cortical dementia and sub-cortical dementia (refer to Table 1). Cortical dementias arise from a disorder that affects the cerebral cortex. These are the outer most layers of the brain and are critical to memory and language. People with cortical dementias, such as Alzheimer Disease and Creutzfeldt-Jakob disease often present with severe memory impairment and aphasia. Subcortical dementias result from a dysfunction in the area below the cortex. Usually memory loss and language difficulties that are found with cortical dementias are not found with subcortical dementias; instead these people, such as those with Parkinson’s disease, HIV/AIDS dementia complex, and Huntington’s disease, tend to present with changes in their attention, motivation and emotionality. There are cases, such as vascular dementia, that can affect the person in both areas of the brain.

Table 1: Cortical vs. Subcortical Dementias

Feature	***Cortical Dementia***	***Subcortical Dementia***
Onset	Insidious	Insidious
Duration	Months to years	Months to years
Course	Progressive	Progressive or constant
Attention	Normal	Normal (slow response time)
Speech	Normal	Hypophonic, dysarthric, mute
Language	Aphasic	Normal or anomic
Memory	Learning deficit (Alzheimer)	Retrieval deficit
Cognition	Acalculia, concrete (Alzheimer)	Slow, dilapidated
Awareness	Impaired	Usually preserved
Demeanor	Unconcerned, disinhibited	Apathetic, abulic
Psychosis	May be present (visual hallucinations in Lewy-Body dementia)	May be present
Motor signs	None	Tremor, chorea, rigidity, dystonia
EEG	Mild diffuse slowing	Normal/mild slowing (diffuse or focal)

The most commonly recognized form of dementia is Alzheimer Disease (AD). This is also thought to be the most prevalent. AD was first described in 1907 and for the first half of the century was regarded as the most common cause of dementia. AD is now recognized as the most common form of non-reversible dementia. AD is a neurological disorder that can be traced to widening of the sulci and gyri, neurofibrillary tangles and senile plaques; however these can only truly be examined post-mortem (Tomlison, Blessed, & Roth, 1970). The etiology of AD is unknown but it has been hypothesized that it could be related to aluminum exposure, prior brain injury or may have a genetic component (Hardy, 1997). This disease first attacks the hippocampus presenting with the stereotypical memory loss associated with AD. AD most often presents with the insidious onset of memory disturbances, specifically short-term memory, and sometimes psychiatric disturbances such as severe paranoia. In the early stages, sensory, motor and visual systems are spared. On autopsy, the brain of a patient with AD may appear grossly normal or may show atrophy with the widening of the sulci and the shrinkage or atrophy of the gyri. On histologic examination, the brain of a person with AD will show significant neuronal death and synapse loss. The loss of cognitive abilities associated with AD is likely due to the breakdown in the complex communication system among neocortical regions provided by the corticocortical circuits that leads to a global neocortical disconnection syndrome that presents clinically as dementia (Morrison & Hof, 2007).

The most recognizable subcortical type dementia is associated with Parkinson's disease. Parkinson's disease is usually classified as a motor disorder. It is most often associated with muscular weakness, rigidity and tremors. Currently, it is believed that these symptoms are associated with cellular death in the substantia nigra, the area of the brain that provides dopamine to the other parts of the brain. Twenty to forty percent of patients with Parkinson's disease also develop subcortical dementia, although, to date, there is not a way to predict which people with Parkinson's disease will progress with dementia as well (Camicioli & Fisher, 2004).

Vascular dementia is a degenerative disease of the cardiovascular system that leads to a progressive decline in memory and cognitive function. It occurs when the blood supply to the brain is interrupted by a diseased vascular system. Vascular dementia tends to affect people between the ages of 60-75 and affects more men than women. This is likely because men are more affected by the most common cause of vascular dementia which is multiple infarcts. These are a series of small strokes, or "mini-strokes," that often go unnoticed and cause damage to the cortex of the brain—the area associated with learning, memory, and language. These mini-strokes are sometimes referred to as transient ischemic attacks (TIAs), which result in only temporary, partial blockages of blood supply and brief impairments in consciousness or sight. Over time, however, the damage caused to brain tissue interferes with basic cognitive functions and disrupts everyday functioning.

Beyond these specific or disease-related non-reversible dementias are the general dementias. These people are diagnosed with dementia or significant memory problems. These patients do not fit into any other category, but are presenting with significant memory problems. These people range from presenting with symptoms associated with mild cognitive impairment to severe dementia (Figure 1).

Mild cognitive impairment (MCI) represents the transition between normal cognitive aging and mild dementia. Studies suggest that individuals with MCI progress to dementia at a rate of 10-15% per year (Bowen et al., 1997; Peterson et al., 1999). The general criteria for MCI have been modified and no one uniform definition exists in research or clinical practice. Most studies include: a cognitive complaint, preserved basic activities of daily living, cognitive impairment or decline from previous function, and absence of dementia. Researchers tend to agree that MCI represents the area that exists between when a person feels there is a problem and a change in function on a standardized test. It is likely that the current tests are not sensitive enough to verify these more subtle changes.

The prevalence of these milder forms of non-reversible dementia, such as MCI and mild dementia, is difficult to estimate as they are more difficult to diagnose (Eccles, Clarke, Livingstone, Freemantle, & Mason, 1998). Furthermore, as dementia does not present with the same symptomology in all patients, the diagnosis of dementia is not a simple one.

1.1.3 Diagnosis of Dementia

Unlike its predecessor, the Diagnosis and Statistical Manual of Mental Disorders Fourth Edition (DSM-IV) (American Psychiatric Association, 1994) does not specify a criterion for the diagnosis of dementia. The diagnosis, however, can be inferred from the common elements of the DSM-IV criteria for the dementia sub-type diagnosis. According to the DMS-IV, the diagnosis of dementia is made by a physician through a two-step process (refer to Table 2). First the person must present with memory impairment, this is usually described by the family members that accompany the patient to the appointment. Along with this, they also must have one of the following: aphasia, agnosia, apraxia, or loss of executive function. Also, these problems must not be able to be explained by any other diagnosis for example schizophrenia or other mental disorders.

Table 2: The Criteria for Diagnosis of Dementia – A-C must all be satisfied

A.	The development of multiple cognitive deficits manifested by both:		
	1.	Memory impairment	
	2.	One or more of the following cognitive disturbances:	
		a)	Aphasia
		b)	Apraxia
		c)	Agnosia
		d)	Disturbances in executive function
B.	The cognitive deficits in section A:		
	1.	Cause significant impairment	
	2.	Represent decline from previous level of functioning	
C.	The disturbance is not better explained by another axis 1 disorder		

It was recommended in the Evidence Based Guidelines for Diagnosing Dementia (Eccles et al., 1998), that a subjective complaint of memory impairment is not a good indicator of dementia; altered functioning is more important. This altered function may be reported by either the patient or their family member. This criterion is open for interpretation, as the definition of altered functioning or loss of executive function is not clearly defined in the DSM-IV. It was reported by Prince, et al (2008) that often the question of altered state is asked to patients or family as "do you notice a change in the ability to remember?" The presentation of the question is vague and thus may not give the specific information needed to meet the DSM-IV criteria, but could be accepted as altered function. The criterion has been widely used in both clinical and epidemiological research. While this seems to be a way to directly assess a person's cognitive status, without clearly defined parameters, the validity of the diagnosis of dementia through these means is questionable as it is a subjective diagnostic test.

In general, most medical experts conclude that the earlier a disorder or disease is diagnosed, the better. Dementia can be diagnosed as early as 65 years of age; below this age the diagnosis would be early-onset dementia (American Psychiatric Association, 1994). Evidence from the UK suggests that the majority of people with the diagnosis of dementia can live independently (Eccles et al., 1998). The primary care team is therefore the initial point of contact for patients and their families. There is a dichotomy in attitudes among general practitioners in relation to early diagnosis of dementia. Some feel that early diagnosis will reduce uncertainty, support awareness of prognosis, allow for resource planning and stabilize the family dynamics. Others feel that an early diagnosis will negatively affect the person and their family by creating anxiety, shame and stigma thus leading toward an increase in isolation and anxiety (Holroyd, Snustad, & Chalifoux, 1996). Increased emphasis has been placed on the value of early diagnosis for those with dementia. This is likely due to the perceived potential benefit from medications and gene based medical treatment (Iliffe, Walters, & Rait, 2000; Wilkson & Milne, 2003). With the desire for a fast and early diagnosis, a physician may be more likely to produce the diagnosis of dementia based on weak DSM-IV data. Even within structured assessments, the lack of clarity in the areas for diagnosis introduces a broad range in the diagnosis.

1.1.3.1 Self-Report

Complaints about declining memory or general cognitive ability are quite common in elderly persons (Jorm et al., 1994; National Insitutes on Aging, 2007; Poitrenaud, Mzlbezin, & Guez, 1989). The ability for older persons to estimate their own memory is often referred to as “metamemory”. Metamemory, derived from metacognition, is an individual’s knowledge perceptions and beliefs about functioning, development and capacities of one’s own memory and the human memory system. Some studies have suggested that metamemory is mostly accurate, while others have demonstrated little relationship between memory complaints and actual impairment; the association between objective test performance and complaints is weak (Folstein, Folstein, & McHugh, 1975; Jorm et al., 1994; National Insitutes on Aging, 2007). Metamemory is correlative with depression, anxiety and neuroticism (Cutler & Grams, 1998; Folstein et al., 1975; Jorm, Christensen, Korten, Jacomb, & Henderson, 2001; Jorm et al., 1994; Kahn, Zarit, Hilbert, & Niederehe, 1975; Ohenham & Plack, 1997).

One study found that the majority of the memory complaints were with those with mild dementia, with the non-demented and severely demented reporting few memory complaints (Grut et al., 1993); this study, however, is a cross-sectional study and did not follow people for an extended period of time. A number of longitudinal studies have followed those reporting memory impairment to see if they developed dementia or some objective cognitive decline; results suggested by some authors are that there is a positive predictive value to subjective memory complaints while others show little or no correlation (Flicker, Ferris, & Reisberg, 1993; O'Brien et al., 2004; Taylor, Miller, & Tinklenberg, 1992). These studies did not include a control group of those who did not complain of memory problems. Data from a follow-up of a community sample over three and a half years found that cognitive and memory complaints did not predict objective cognitive decline, dementia or mortality (Geerlings, Jonker, Bouter, Ader, & Schmand, 1999). If an incorrect prediction of one’s performance is portrayed, one’s metamemory would be considered inaccurate. Two types of inaccuracy could be reported: (1)

failure to perceive memory decline when it occurs and (2) perceived impairment in the presence of intact cognition. Failure to perceive a problem when one exists would likely be contributed to the onset of dementia. On the other hand, there are several ways to conceptualize why some people may report memory difficulties in the absence of any true impairment. It is possible that they may be sensitive to subtle memory changes and the tests given are not sensitive enough to quantify these changes. Schmand et al (1990) suggested that a subgroup of older individuals may be sensitive to manifestations of cognitive decline that are not reflected using current testing. With this information, physicians often ask patients if they have a subjective memory complaint, but may not base their diagnosis on the metamemory of the patient.

1.1.3.2 Family Report

Recently there has been an increase in television advertisements by pharmaceutical companies about medications for dementia (BBC, 2010). As the population continues to age and baby boomers find they are becoming primary caregivers for their aging parents, these types of advertisements and general worries about the health of their parents may influence adult children to question the mental status of their parents. With these concerns, people may start to look at the actions and reactions of their family member. They may start to see changes in behavior that are cause for concern. Family members are often the initiator of gathering medical information and making the appointment for the family member for a medical opinion.

When making a determination of dementia, physicians often rely on family report to help determine the diagnosis of dementia. Families are asked about changes in mental status. Symptoms of dementia that are reported by family members include (Finkel, Costa e Silva, Cohen, Miller, & Satrtoruis, 1997; Mega, Cummings, Fiorello, & Gornbein, 1996; Small et al., 1997):

- Having difficulty recalling recent events
- Not recognizing familiar people and places
- Having trouble finding the right words to express thoughts or name objects
- Having difficulty performing calculations
- Having problems planning and carrying out tasks
    - e.g.: balancing a checkbook, following a recipe, or writing a letter
- Having trouble exercising judgment
    - e.g.: knowing what to do in an emergency
- Having difficulty controlling moods or behaviors
    - depression
    - agitation
    - aggression
- Not keeping up personal care such as grooming or bathing
- Poor judgment

These signs will likely influence a family member to make an appointment with a family care physician. This primary care physician will take the family report into account when making the diagnosis of dementia.

1.1.3.3 Mini Mental State Exam

There is no one procedure for diagnosing a person with dementia. There are many screeners available for memory impairment, but none are used uniformly. Shulman and colleagues (2006) surveyed 334 psychiatrists about the tests that are routinely used to diagnose dementia. By far the most common was the Mini Mental State Exam reported as being used routinely by 77.1% of the respondents to the survey. This is likely due to the high rating the respondents gave it on ease of use, ease of scoring and ease of administration. These results have been reported on several other surveys of physicians (Davey & Jamieson, 2004; Reilly et al., 2004); about 9/10 respondents report using the *Mini Mental State Exam* (MMSE) (Folstein et al., 1975) to diagnose dementia. See Appendix A for a copy of the MMSE. While there are many tests that could be used for dementia screening, most screeners have been evaluated in studies with small sample sizes, and the populations of patients on whom screening instruments have been tested have varied greatly, making it difficult to determine the overall performance of screening tests for dementia. Jorgensen et al. (2012 - submitted) reported that the most commonly used measure for the diagnosis of dementia in a large University Medical Center was the MMSE.

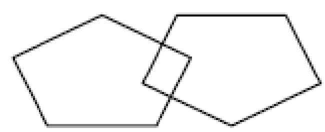
Specifically, the MMSE is a brief measure of cognitive function. It includes items that assess orientation, short term recall, long term recall, follow three step directions, calculation, language (naming, repetition, reading and writing) and visual-constructional tasks designed to determine whether or not cognitive impairment is present. The test is given on a 30 point scale. Opinion is divided about cut-offs and the diagnosis of dementia; however, the authors of the MMSE (Folstein et al., 1975) reported that a score of greater than or equal to 27 is considered normal. Below this, 20-26 indicates mild dementia; 10-19 moderate dementia, and below 10 severe dementia. The test is also biased by educational level – age and educational level adjusted norms are available (See Table 3).

Table 3: Median Scores on MMSE by Age/Education (adapted from Crum et al, 1993)

	Education Level			
Age	4th	8th	12th	College
18-24	22	24	29	29
25-29	25	27	29	29
30-34	25	26	29	29
35-39	23	26	28	29
40-44	23	27	28	29
45-49	23	26	28	29
50-54	23	27	28	29
55-59	23	26	28	29
60-64	23	26	28	29
65-69	22	26	28	29
70-74	22	25	27	28
75-79	21	25	27	28
80-84	20	25	25	27
>84	19	23	26	27

Nineteen out of the total thirty points for the MMSE, more than 60%, are directly related to orientation to person/place or have a heavy emphasis on language. This significantly impacts the scoring of the MMSE for those who miss minor components of the instrument or whose language ability is compromised. In contrast, the more elaborate copy design derived from the Bender-Gestalt which measures visual construction task, contributes only 1 point (See Table 4).

Table 4: Example Items from the MMSE designed for specific test areas

Orientation	"What is the year?"
Short-term recall	"Name these three items…"
Long-term recall	Recall later the same three items
Calculation	"Count backward from 100 by 7s"
Language – naming	Point to pencil and watch and ask for the name of the item.
Language – repetition	Repeat "No ifs, ands or buts"
Language – reading	Give a paper that says "close your eyes" and ask to follow the instructions
Language – writing	Give blank paper and ask patient to write a sentence
Visual – constructional	"Please copy this picture" 

Two of the authors of the MMSE were concerned about the lack of diagnosis of a score of 28-30 as dementia. This is because the true degree of cognitive function may have been incorrectly identified. One of the authors of the MMSE and colleagues noted several pitfalls including too many cutoff points and low reliability (Anthony, Le Resche, Niaz, Von-Korff, & Folstein, 1982). In a response to a Letter to the Editor, the authors of the MMSE, Folstein, Folstein, and McHugh (2007) responded by stating that the problems of the MMSE include: use of a modified version of the test, substitution of spelling "world" backwards rather than serial 7s (Table 4 – Calculation problem), and they stressed that the MMSE cannot and should not be used to substitute for systematic evaluation. Practicing physicians do not appear to heed this warning as 9/10 physicians report solely using the MMSE for diagnosis (Davey & Jamieson, 2004; Reilly et al., 2004).

Sensitivity and Specificity of MMSE

One of the ways to determine if a test is valid and reliable is by the sensitivity and specificity of the test. The sensitivity of a test is how well it gives a true positive measure. Many authors have reported on the sensitivity of the MMSE for dementia, ranging from 8 to 92 percent. Specificity, the probability that a test will give a true negative measure, ranges from 56 to 96 percent (Anthony et al., 1982; Black et al., 1999; Brayne & Calloway, 1990; Crinelli R., 2008; Rajji et al., 2009). This broad range gives even more doubt to the screening. Furthermore, Flicker, Loguidice, Carlin and Ames (1998) reported findings of a sensitivity of 78%, a specificity of 88%, and a positive predictive value of 43% for the MMSE in the general population. The test's primary predictive ability is to differentiate between normal age-associated cognitive decline and the pathological decline associated with dementia. These results question the MMSE on its ability to differentiate normal cognitive decline from dementia.

Attempts to determine changes over time have been done primarily within a short period of time (6 months) and with normal cognitively aging adults. The reliability estimates of this test generally fall between .80 and .95 (Tombaugh, 1992). However, when preformed clinically, the test is often given at longer intervals. Most often this test is given at the patient's yearly checkup, and the reliability drops to less than 0.50 when given in one year intervals (Escobar, 1986). The poor reliability of the score could cause some individuals to be classified as mildly impaired when in reality they are cognitively intact or those that were mildly impaired might be classified as cognitively intact. The test has a practice effect merely because the person has prior experience with the testing materials. Patients remember the questions and rehearse the answers given previously (Keeting, 1987).

Drawbacks of the MMSE

Major drawbacks of MMSE are that its accuracy depends on age, education, ethnicity and socio-economic status of the individual. It is most accurate for whites under the age of 80, with at least a high school education, who live in a moderate to high-income household (Brayne & Calloway, 1990; Espino, 2001; Jjorn, 1988; Murden, 1991). This raises questions to the efficacy of the MMSE when given to an elderly patient in a primary care clinic. It is unlikely that a patient will be asked their education level and/or income level even though this information is needed to accurately score the MMSE. Without this information, the validity of the MMSE is likely compromised. Furthermore, two studies have reported that the specificity of the MMSE is significantly lower for individuals whose age is over 65. Specificity of the MMSE was 0.64 for Participants 65 years of age or older compared to 0.92 for younger participants (Marshall, Mungas, Weldon, Reed, & Haan, 1997). Anthony et al (1982) also reported that those with less than an eighth-grade education had a mean specificity of 0.63 compared to 1.0 for those with higher education levels. It is likely that the MMSE would be used on those over the age of 65. For the majority of patients in a primary care clinic, this was the only measure used to determine diagnosis of dementia (Jorgensen et al., 2012 - submitted). The medical charts reviewed did not include education level or socioeconomic status that are needed for accurate scoring purposes; it is unclear as to which norms they used.

It was noted in the original article by Folstein et al (1975), that the normative data for the MMSE is based on white patients. Anthony et al (1982) reported that the specificity of the MMSE was lower for blacks than it was for whites (.78 vs .94); however, it is suspected that this discrepancy is an artifact of education levels rather than race. Significant differences have been reported between males and females; however, these usually occur in the oldest-age categories where there are few men and even fewer with AD, making estimates unreliable.

The Psychological Assessment Resource (Psychological Assessment Resources 2008), owners of the patent on the MMSE, advise that the screening is to be interpreted differently if the patient has less than 9 years of schooling or is more than 80 years of age. Furthermore, there are no corrections available for ethnicity and socio-economic status. Because of all the limitations of this test, it was recommended by the manufacturers that the MMSE should not be seen as a tool for measuring overall cognitive status and its use as a screening tool is limited (Crinelli, 2008). Despite this, physicians continue to use this test as their primary means of diagnosis for dementia. Concern for false diagnosis of dementia is recognized by the authors of the MMSE as well as the manufacturer, but does not appear to be taken into account by physicians who continue to use the MMSE beyond the stated recommendations. When considering potential interventions for community patients, it would seem most crucial to have a measure of good sensitivity and specificity to achieve accurate diagnoses.

Escobar et al. (1986), using a mathematical program, analyzed each question of the MMSE as a function of age, ethnicity, language and education. For each item, proportion of correct responses, incorrect response and no answers were calculated and items were analyzed to see if age, ethnicity, language, and education could be used as significant predictors (See Table 5). They determined that some items were significantly impacted by age of the patient while others were impacted by ethnicity or education. This causes great concern about use of this test as it has too many confounding variables which could impact the score.

Table 5: Significant Variables on Items of the MMSE (adapted from Escobar et al, 1986)

Item	Significant Variable
Orientation Items:	
A. What is the:	
1. Year?	1. Age
2. Season?	2. Education, ethnicity/language
3. Month?	3. None
4. Date?	4. None
5. Day?	5. None
B. Where are we?	
1. State	1. Ethnicity/language
2. County	2. Education, ethnicity/language
3. Town	3. None
4. Address/Hospital	4. None
5. Floor	5. Age
Memory Items	
A. Repeat 3 items	None
B. Count backward from 100 by 7s OR spell WORLD backward	
C. Recall previous 3 items	
Language Items	
A. Name – pencil, watch	A. None
B. Repeat: No ifs, ands, or buts,	B. Education, ethnicity, language
C. Follow 3 stage command	C. None
D. Read and obey sentence: close your eyes	D. Education
E. Write a spontaneous sentence	E. Education
Visual Construction Item:	
A. Copy design	A. Age, Education

False Diagnosis

The false diagnosis of any disorder is reason for concern. This may be especially true when the diagnosis affects a person's long-term prognosis. If a patient was diagnosed with dementia due to their complaints of impaired thinking and using only the MMSE as a diagnostic tool, it is plausible that the diagnosis might be incorrect. Yesavage (1979) published an editorial defining 8 subtypes of dementia that are reversible. These include: drug toxicity, emotional and psychiatric disorders, metabolic and endocrine disorders, visual and hearing impairments, nutritional state, intracranial masses, and infection arteriosclerotic complications. Table 6 shows the results in reviews of nine studies that reported findings of reversible dementia. Twelve plausible causes for diagnostic confusion were identified (Fox, Topel, & Huckman, 1975; Freemon, 1976; Harrison, 1977; Marsden & Harrison, 1972; McDaniel, Lukovits, & McDaniel, 1993; O'Boyle & Amadeo, 1989; Rabins, 1981; Ryan, 1994; Smith & Kiloh, 1981).

Table 6: Causes of Diagnostic Confusion

Causes	**Number of Patients**
Depression	56
Normal pressure or communicating hydrocephalus	33
Subdural hematoma	19
Other psychiatric disorder	16
Drugs	9
Thyroid disease	8
Creutzfeldt-Jakob	2
Pernicious anemia	1
Liver disease	1
Parkinson’s disease	1
CNS syphilis	1
Other or unspecified	9

In these nine studies, 156 people were misdiagnosed. Unfortunately, the diagnosis of dementia is difficult to remove from the medical record and could have a long-standing impact on a patient. If another physician or medical worker sees the diagnosis of dementia, they may treat the patient differently. Communication may be more directed toward family members rather than the patient, making them feel removed from their health care decisions. In addition, survey data suggest that nearly 70% of general practitioners feel inadequately trained to respond to the needs of people with dementia and their families (Downs et al., 2000; Wolff, Woods, & Reid, 1995).

Dementia is often diagnosed using a combination of self-report, which has varied reliability; family report; which can be inaccurate and impacted by a variety of confounding factors; and the MMSE, which has poor sensitivity and specificity. This wide variability of subjective complaints and a weak test leaves room for false diagnosis. Even with these limitations, currently this is the standard for dementia diagnosis. Wherever possible, one would want to reduce or eliminate confounds that might further put the diagnosis of dementia (or the severity category) into question.

1.2 HEARING LOSS

Hearing impairment is one of the most prevalent chronic disabilities in the U.S. Approximately 34.25 million Americans have hearing impairments (Schum, Matthews, & Lee, 1991). Wallhagen, Strawbridge, Cohen and Kaplan (1996) demonstrated over a series of studies that the prevalence of hearing loss nearly doubled from 1965 to 1994 and predicted the growth to continue. Hearing loss in the aging person is most commonly presbycusis, but the person may have hearing loss due to noise exposure, medications or other factors that combine to contribute to hearing loss. The most obvious and documented peripheral deficit in elderly individuals is the presence of high frequency sensorineural hearing loss (Cranston, 1986); this is called presbycusis. The word presbycusis is from the Greek words “presby” or “presybo” meaning old or in relation to old age and “akoustikos” meaning to hear or to listen. While presbycusis does not account for all of the hearing loss in elderly listeners, it does count for the majority of change in thresholds as we age. Cruishanks (1998) demonstrated through epidemiologic studies that the average hearing thresholds in Beaver Dam, Wisconsin decrease with increased age; the higher the age of the person, the more steeply sloping their high frequency hearing loss.

Changes in cochlear histopathology due to age were classified by Schuknecht (1955, 1964) into four types of presbycusis: sensory, neural, metabolic, mechanical. Sensory presbycusis is the degeneration of the organ of Corti. The loss of hair cells and supporting structures typically presents as a high frequency hearing loss. Schuknecht observed, with enough damage, that the supporting cells were involved and there also is secondary degeneration of the auditory neuron. He reported that the degenerative changes usually begins in the middle ages, but the progression is slow; thus it is limited to the most basal end of the cochlea and has less impact on the speech frequencies. If the loss of the auditory neuron is beyond that which can be explained by degeneration of the organ of Corti, Schuknecht described this as neural presbycusis. This type of presbycusis often occurs later in life when the number of functional neurons falls below that which is necessary for effective transmission. Metabolic presbycusis is visible in histopathology as damage to the stria vascularis. The stria vascularis is probably the source of the positive 80 mv DC potential of the scala media and has been characterized as the site of endolymph creation. Thus damage to the stria vascularis would affect the entire scala media, explaining the characteristic flat hearing loss associated with metabolic presbycusis. If no pathological correlates can be found in the organ of Corti, auditory neuron or strial tissue, Schuknecht characterized this hearing loss as mechanical presbycusis. He postulated that the slowly progressive descending audiometric curve could be caused by an abnormality in the structures that have to do with the motion of the cochlea, possibly the basilar membrane or the spiral ligament. As the differentiation of these four types of presbycusis cannot be defined while a person is still living, for the purposes of this discussion, presbycusis will be discussed in general.

When classifying hearing loss associated with aging, Otto and McCandlis' seminal article (1982) concluded that there is both behavioral and electrophysiological evidence of central and peripheral auditory disorder frequently accompanying senescence. They noted that there were changes due to peripheral hearing loss, but also changes on the electrophysiologic responses (auditory brainstem response) that were affected by age. The three participant groups: young normal hearing, young sensorineural hearing loss and hearing loss matched elderly sensorineural hearing loss groups had different ABR responses that could not be explained by only hearing loss. They concluded that peripheral hearing loss and central changes due to age both affected the responses. Humes and his colleagues at the University of Indiana also have conducted extensive research on the aging auditory system and have reported on the negative impact of hearing loss on the speech-understanding performance of older adults separating the different components of the peripheral auditory system (Humes, 1991, 1996; Humes, 2002, 2005; Humes & Christopherson, 1991; Humes & Roberts, 1990; Humes et al., 1994).

It is proposed that there are three components that affect an older person's ability to accurately perceive the intended auditory signal. Foremost, the signal may not be audible, meaning the sound is not loud enough to cause adequate movement of the auditory structures necessary to hear the signal. Second, in those with a sensorineural hearing loss, such as presbycusis, there is likely a cochlear pathology that contributes to the hearing loss beyond the audibility of the signal; for example reduced frequency discrimination, temporal encoding errors, etc. Finally, once the signal is transmitted beyond the peripheral structures, there could be a neuronal or cortex auditory processing problem contributing to the inability to hear, decode and understand the signal. While it is likely that these features overlap and contribute to one other, they will be described initially as separate components of hearing.

1.2.1 Diagnosis of Hearing Loss

To be able to discuss the components of the auditory system that contribute to hearing and hearing loss, it is important first to describe how a hearing loss is identified. In 1991, the National Institutes of Health set as a goal for the year 2010 that there would be a dramatic increase in the number of primary care providers that refer adults over age 65 for evaluation and treatment of hearing impairment; as of the interim update in 2000, this section of the Healthy People 2010 initiative was still developmental (National Institutes of Health, 2000).

Hearing tests are conducted by audiologists in a sound proof booth in order to ensure that noise does not impact the threshold determination. The assessment includes both obtaining thresholds using pure tones as well as speech understanding testing at enhanced signal levels. While this is currently the most accurate way of determining hearing status, very few physicians refer patients for a diagnostic hearing evaluation prior to the diagnosis of dementia (Jorgensen et al., 2012 - submitted). Jorgensen, et al (2012) reported that only one medical text book out of the 84 reviewed mentioned hearing loss potentially impacting the diagnosis of dementia. These texts reported that self-report of hearing loss is a good measure of hearing ability as well as using bedside hearing tests. Yet data indicate that these tests are not an accurate reflection of the person's hearing ability as they have a 5-60% accuracy in the diagnosis of hearing loss (Boatman, Miglioretti, Eberwein, Alidoost, & Reich, 2007).

1.2.1.1 Self-Report

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 physicians 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 US Preventative Task Force (1996). Several studies have been completed comparing audiometric thresholds with patient report of hearing status. Many of these studies are not controlled as they were clinical retrospective studies and take the pure tone average to determine audiometric status. Clark, Sowers, Wallace, and Anderson (1991) reported that in a group of 267 women in rural Iowa, the positive predictive values of hearing loss were low; however this was comparing the self-response to the pure tone average of either 1000 and 2000 or 1000-4000 Hz. As this gives a general number and does not always accurately reflect the configuration of the hearing loss, it is likely that two people with very different hearing losses could present with similar pure tone averages. It is difficult to compare self-responses to such varying audiometric configurations. Similar results were reported by Gomez, Hwang, Sovotva, and Stark (2001) who divided the audiometric information from their 376 participants into 5 groups: binaural low frequency, better ear mid frequency, worse ear mid frequency, binaural mid frequency, binaural high frequency. They found the best positive predictive value for reporting hearing loss when one existed is for those with low frequency hearing loss and the least predictive was for those with high frequency hearing loss. This means that for those with high frequency hearing loss, they are less likely to notice the effects of hearing loss on their daily lives and are less likely to report it when asked if they have hearing loss. This high frequency hearing loss is also the audiometric configuration most common in the elderly population. On a self-diagnostic questionnaire, Boatmann, Miglioretti, Eberwein, Aldoost, and Reich (2007) reported that the questions had a sensitivity of 0.01 to 0.51 in predicting hearing loss on an audiometric test. The best questions included questions about hearing in noisy situations such as a party; while the poorest questions were about hearing specific types of voices. Directly asking if the person feels they had a hearing loss had a sensitivity of 0.27 and a positive predictive value of 0.29. Overall, asking a patient if they feel that they have a hearing loss does not accurately assess their ability to hear. Using this as the only predictor of hearing ability will lead to missing more than 2/3 of people with hearing loss. Self-report of hearing loss is not an accurate or reliable assessment of hearing ability.

1.2.1.2 Non-Audiometric Hearing Testing

It is often thought by neurologists and primary care doctors that they are conducting an accurate hearing test with whispered speech, finger rub, watch tick, and the Rinne and Weber tuning fork tests or assessing their abilities when speaking to the patient (Bagai, Thavendiranathan, & Detsky, 2006). Use of these measures was the only recommended standard procedure in many of the clinical procedures textbooks used by physicians (Jorgensen, et al, 2012). The quality or intensity of the finger rub test is not standardized among physicians and thus is difficult to categorize. Watch ticks are low intensity click-like sounds that cover a wide range of frequencies; conversely whispered speech testing has attenuated low frequency information due to the lack of vibration of the vocal folds and is further impacted by distance. It would appear, based on this psychoacoustic information, that these tests would be good at detecting high frequency hearing loss such as presbycusis. However, Boatman et al (2007) reported that the sensitivity of the finger rub is 0.35, watch tick is 0.60 and whispered speech is 0.46 for those with a pure tone average above 40 dB HL. While the watch tick's broad-band signal is the most sensitive to hearing loss, it is still not accurate for true measurement of hearing sensitivity. The poor diagnostic accuracy of the tuning fork tests such as Rinne and Weber has been reported in several studies (Bagai et al., 2006; Boatman et al., 2007; Yueh et al., 2003). These tests were designed to identify unilateral hearing losses of less than 512 Hz using the Weber or conductive hearing losses using Rinne. These tests miss most people with high frequency, bilateral and sensorineural hearing losses like presbycusis and have very low sensitivity (Boatman et al., 2007). While many physicians believe that using non-audiometric hearing screenings will allow them to have an accurate assessment of hearing status, this is not the case and the only way to truly quantify a person's current audiologic status is by a referral for full audiometric testing.

1.2.1.3 Audiologic Evaluation

An audiologic evaluation is the most accurate way to quantify hearing status. Mild to moderate hearing losses are commonly overlooked without an audiologic evaluation (Corbin, Reed, Nobbs, Eastwood, & Eastwood, 1984; Powers & Powers, 1978; Williamson, Stokeoe, & Gray, 1964). The current audiologic test battery for adults includes behavioral testing using pure tones and speech testing including Speech Reception Threshold and Word Recognition (Katz, 2002). The speech testing is completed in quiet, which does not tax the central auditory system and older adults perform similarly to younger adults with similar hearing losses (Dubno, Lee, Matthews & Mills, 1997). While this is good for audiologic testing to determine hearing sensitivity, it does not reveal how a person performs in the "real world". Patients often report "I can hear alright if it is just you and me, but in a crowd, or if there is any other noise, I don't do very well". This problem seems to be more evident in the 70 and 80 year olds than in the 20 and 30 year olds. The idea that there is something that is different about the elderly population was first postulated by John Gaeth (1949). In his dissertation, he studied word recognition ability in elderly adults with varying degrees of hearing loss and suggested that the differences in young and older adults may be due to central as well as peripheral changes in the auditory system.

1.2.2 Audibility

Audibility is the initial confound for signal perception for those with hearing loss. Signals are not loud enough to be accurately perceived by the system. The most important factor for speech understanding is an audible signal (Humes, 1991, 2007; Kamm et al., 1978; Otto & McCandlis, 1982). Speech consists of a succession of sounds that vary rapidly in intensity and frequency from instant to instant. The overall decrease in intensity caused by a hearing loss is a disadvantage, but also it is this variability in intensity that makes parts of speech inaudible and thus makes understanding difficult.

With the assumption that the desired speech signal reaches the ear without any acoustic distortion such as phase distortion, echoes and reverberation (Grose, 1996; Wingfield, 1996), the success of the listener in recognizing and interpreting these sounds depends on the intensity of the signal to their ear, the intensity of other interfering acoustic signals and the hearing loss. In 1947, French and Steinberg described the relationship between fundamental characteristics of speech and hearing and the capability of the ear in recognizing these sounds. The frequency analysis of idealized conversational speech recorded at 1 meter from the speaker's mouth peaks around 500 Hz then slopes downward giving less acoustic information at higher frequencies. The information from French and Steinberg (1947) as well as Dunn and White's (1996) conclusions about intensity differences along the speech spectrum, lead one to believe that even for normal hearing people, listening is a difficult task; this is even more so for higher frequencies. However, some of the discrepancy across frequency is overcome by the natural resonance of the ear which provides increased amplitude at higher frequencies (Humes & Roberts, 1990; Ohenham & Plack, 1997; Plack, Drga, & Lopez-Poveda, 2004). This, however, does not provide enough amplification to overcome the lack of audibility in the high frequencies experienced by those with presbycusis.

The development of the Articulation Index was a way to predict the effects of hearing loss on audibility. Kryter (1991) validated the Articulation Index and demonstrated that with decreased audibility there is a significant decrease in the ability to understand phonetically balanced words as well as nonsense syllables. This would lead one to believe that with decreased audibility one would not be able to understand normal speech. Pavlovic (2007) demonstrated similar findings as Kryter for those with normal hearing and for those with a moderate high frequency hearing loss. The prediction did not hold true for those with a severe or precipitous high frequency hearing loss; these people did worse than the Articulation Index predicted. However, these findings do support the theory that those with a hearing loss will be highly affected by their inability to have audibility of the desired speech signal.

Figure 2 illustrates the prominent role of high frequency hearing loss on unamplified speech. The portion of the dashed lines (hearing thresholds) which are above the 60 dB SPL long term average speech spectrum line, the level of average speech (Pearson, Bennett, & Fidell, 1977), would not be audible. This would indicate that those speech sounds which are above approximately 3000 Hz for people aged 70 and above approximately 2000 Hz for those who are 80 would not be heard. Comparing Figure 2 to Figure 3, the high frequency sounds, such as f, s and th would be inaudible for those with high frequency hearing loss. This lack of audibility would be expected to significantly impact speech understanding for these people.

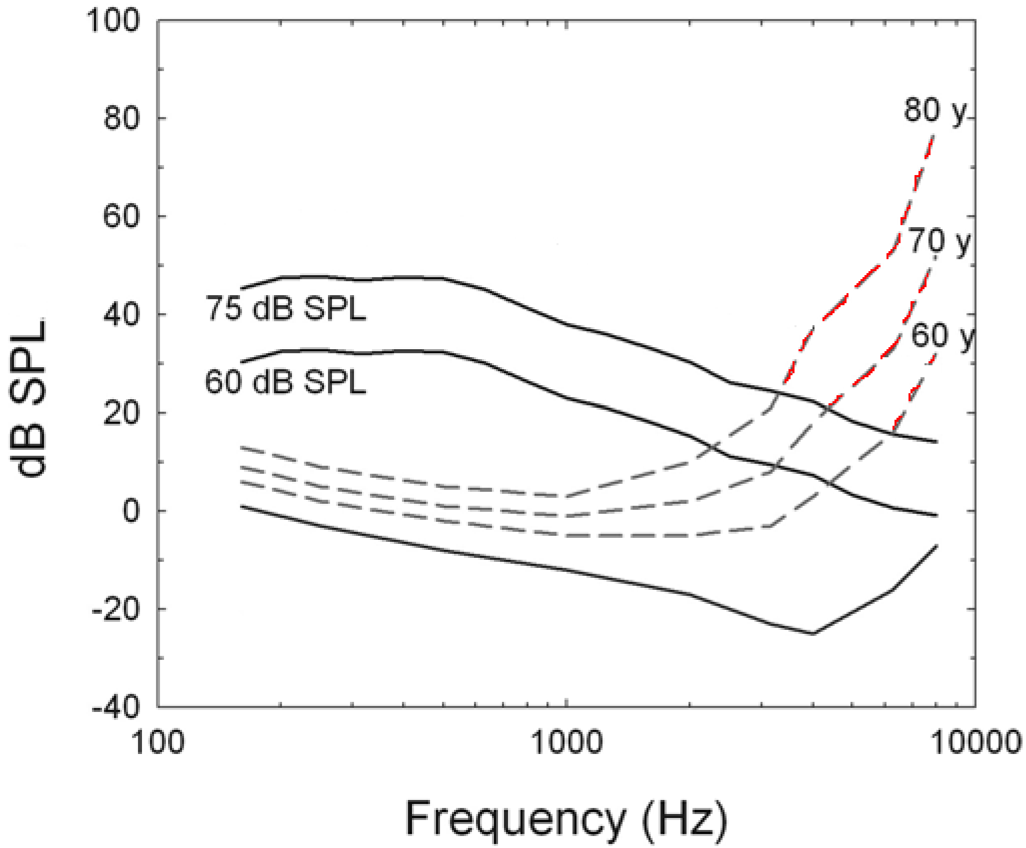


Figure 2: Hearing Loss Compared to Speech (adapted from Humes, 2007) – reprinted with permission

Solid lines: Lowest solid line is normal hearing sensitivity converted from HL to SPL. The other three solid lines are the long-term average speech signal (LTASS) at different intensity levels. Dotted lines: The average hearing thresholds for different ages converted from HL to SPL.

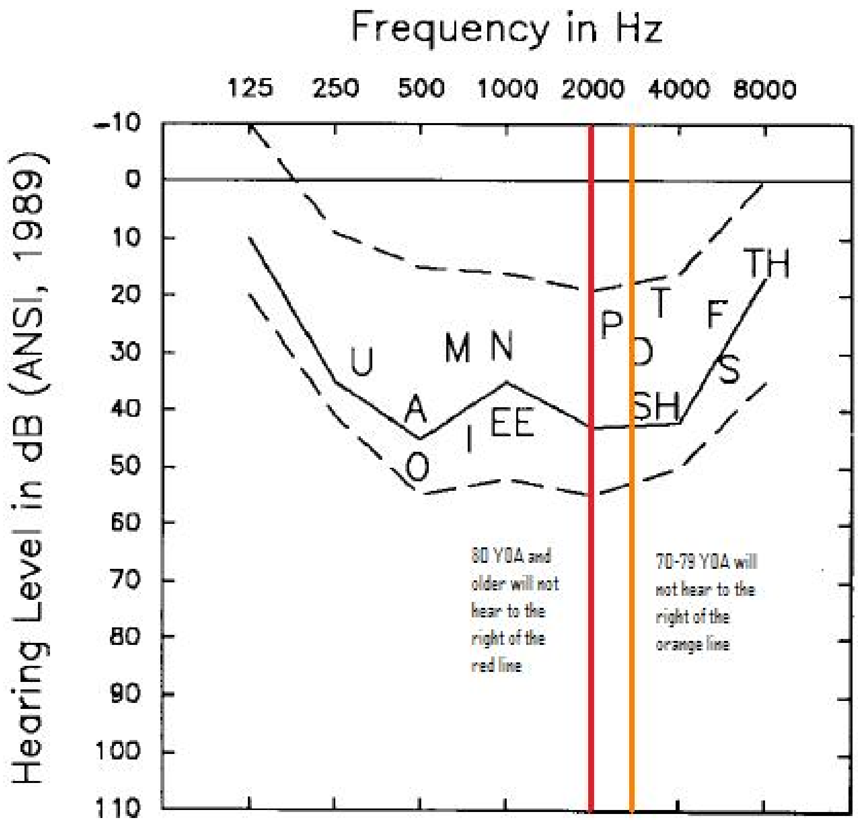


Figure 3: English Speech Sounds (adapted from Humes, 1991) – reprinted with permission

The solid horizontal line is the RMS for speech at 65 dB SPL. The dashed lines represent the fluctuation about the RMS for normal speech. The orthographic representations of speech sounds have been superimposed on the audiogram. The right most vertical line represents the approximate line at which the 70-79 year olds will not hear sounds to the right at 65 dB SPL. The left most vertical line represents the approximate line at which 80 and older year olds will not hear the sounds to the right at 65 dB SPL.

Humes and Roberts (1990) attempted to determine the role of audibility on speech in noise as well as high-frequency dependent nonsense syllables. They determined that using spectrally shaped noise caused normal-hearing people to perform similarly to the elderly people with high frequency sensorineural hearing loss. As those young normal-hearing people had normal cochleae and just had difficulty with audibility, it could be concluded that audibility is the primary determiner of speech recognition ability in this elderly group with high frequency hearing loss.

Recent research suggests that cerumen removal, thus improving audibility by removing the cause of the conductive hearing loss, improves performance on cognitive tests (Moore, Voytask, Kowalski, & Maddens, 2002; Oron, Zwecker-Lazar, Levy, Kereitler, & Roth, 2011). While both of these articles looked at the influence cerumen impaction, which leads to a conductive hearing loss, has on cognitive performance, neither of them accurately measured hearing loss/acuity or used tests that are widely used in general practice. It was most likely the return of audibility produced by cerumen removal that produced the positive results on the cognitive tests.

The difficulty with audibility is the first disruption to an auditory signal for those with a hearing loss. However, studies from Fletcher and Galt (1950), Wilber (1964), and Dugal, et al (1980) suggest that individuals with sensorineural hearing loss exhibit disproportionately poor understanding of speech compared to the prediction based on the Audibility Index. While they all had different theories on why this was the case, they all inferred that it could be due to an underlying cochlear pathology that caused those with a sensorineural hearing loss to do poorer than the Articulation Index had predicted.

1.2.3 Cochlear Pathology

1.2.3.1 Frequency Issues

Pavlovic (2007) noted that beyond audibility, hearing impairment is also impacted based on some cochlear pathology that affected the high frequencies more than low frequencies. He noted that the Articulation Index was a good predictor at those thresholds with mild to moderate hearing impairment. However, for those with significant cochlear damage, prediction of performance according to the AI is much less accurate. It can be inferred from these data that hearing impairment is affected beyond audibility by cochlear pathology. And while the case for inability to hear high frequency sounds has been shown with Figure 2, it also could be the case that the hearing thresholds in sensorineural hearing loss could serve as an initial marker for an underlying cochlear pathology. The decreased understanding ability of those with high frequency hearing loss could be due to lack of audibility or underlying cochlear damage because as there is more high frequency sensorineural hearing loss, there is a greater amount of damage to the hair cells at the base of the cochlea (Bredberg, 1968 as cited in Moore, 1995)

With loss of outer hair cell function in sensorineural hearing loss, there is a disruption in the non-linearity of the cochlea. In normal cochlear function, the movement of the basilar membrane is distinctly non-linear and compressive (Humes, 1991, 2007; Kamm et al., 1978). With sensorineural hearing loss, the damage to the outer hair cells, results in loss of this normal non-linear functionality of the basilar membrane (Otto & McCandlis, 1982). This loss of non-linearity explains the abnormally rapid growth in loudness resulting in reduced dynamic range (Grose, 1996), the abnormal nonlinear growth of masking (Wingfield, 1996), and reduced frequency selectivity (Glasberg & Moore, 1986; Grose, 1996). These changes in the cochlea impact speech recognition of those with sensorineural hearing loss such as elderly individuals with presbycusis. However, as indicated by Humes and Roberts (1990), primarily these listeners need an increased signal to achieve audibility.

In 1958, Zwicker (1990) proposed that loudness summation could be estimated from excitation patterns based on masking patterns. This model was successful in predicting loudness summation of both normally-hearing individuals (Hellman & Zwicker, 1987; Scharf, 1967) and those with high frequency hearing loss (Florentine & Zwicker, 1979). The excitation pattern of tones widens as the level of the tone increases. The spread of excitation for those with sensorineural hearing loss is broader and expands more quickly. This would lead to an abnormal growth in loudness for those with sensorineural hearing loss.

In the normally functioning basilar membrane, when a masking level is well below the signal in frequency, the response is linear to a tone with a frequency below the characteristic frequency (Baer & Moore, 1993; Humes, 1991). An increase in the masking level will be reflected by a proportional increase in basilar membrane motion at the signal frequency. The basilar membrane at the characteristic frequency is compressive, so the signal level must be increased by more than the masker level to produce the same change at the characteristic frequency. This phenomenon is known as nonlinear growth of masking (Oxenham & Plack, 1997). In a normally functioning system, the masker becomes relatively less effective as the level increases because a given increase in the masker requires a proportionally smaller increase in the signal. Therefore, the loss in compression experienced by those with sensorineural hearing loss would affect the growth of masking. This results in a proportional growth of masking level to the signal level; people with sensorineural hearing loss are more affected by noise than those who have a normal functioning cochlea.

A common complaint by those with sensorineural hearing loss is a problem with speech discrimination and increased difficulty in noise. It is postulated that this is due to reduced frequency resolution or selectivity of the damaged ear. Frequency selectivity is the ability to differentiate frequency components of a complex sound – such as speech in the presence of background noise. Florentine, Buus, Scharf, and Zwicker (1980) demonstrated that there is reduced frequency selectivity for those with sensorineural hearing loss. This would suggest that sounds that would normally be heard as distinct sounds would not be distinguishable. This would significantly decrease speech perception. Baer and Moore (1993) indicate that reduced frequency selectivity contributes significantly to the speech communication difficulties of hearing-impaired individuals.

1.2.3.2 Spectral and Temporal Issues

Speech has additional spectral and temporal cues that are necessary to decode for speech to be accurately understood. Recently, it has been suggested that those with cochlear hearing loss have a reduced ability to process temporal fine structure (TFS) information. Temporal resolution refers to the ability to detect changes in acoustic stimuli over time. Classically, the measure used to determine temporal resolution is gap detection threshold (GDT). This is completed by measuring the smallest silent interval a person can detect. Additionally, other tests of temporal resolution include amplitude modulation distortion, duration discrimination, temporal order judgment and temporal masking. Many studies have been conducted to evaluate the patterns of temporal resolution in persons with hearing loss (Fitzgibbons & Gordon-Salant, 1987; Maddens & Feth, 1992; Tyler, Summerfield, Wood, & Fernandes, 1982). Hearing-impaired listeners perform more poorly than normal hearing listeners at tasks that are thought to depend heavily on TFS information such as inter-aural phase difference discrimination (Lacher-Fougere &

Demany, 2005) and low-rate frequency modulation (Lacher-Fougere & Demany, 1998). Fitzgibbons & Gordon-Salant (1987) reported those with hearing loss had difficulty with TFS by looking at gap detection. They reported that the gap resolution in listeners with hearing loss was significantly poorer than in listeners with normal hearing.

There are several mechanisms that could account for those with cochlear hearing loss' inability to process TFS information. Those with hearing loss have poorer frequency selectivity (Florentine et al., 1980), if this is true than the information sent to the central system could be distorted and therefore un-interpretable by the central auditory system. Rose, et al (1967) investigated phase locking of a single nerve of the squirrel monkey; several authors have cited this article suggesting that a deficit in phase-locking and, therefore, TFS information cannot be coded. However, it is not clear if this same mechanism is used in live animals. Other research has yielded conflicting results from the Rose, et al results (Woolf, Ryan, & Bone, 1981). Those with hearing loss have a reduction in the number of auditory nerve fibers (Spoendlin, 1971). If this is true, this could affect the ability for information to be phase locked as the auditory fiber information must be compiled in order to obtain accurate information and a decrease in auditory fibers would degrade this representation.

TFS information may be extracted by the cross-correlation of information collected along different points of the basilar membrane (Shamma & Klein, 2000). Those with cochlear hearing loss have an abnormal basilar membrane (Ruggero, Rich, Robles, & Recio, 1996) and therefore may have difficulty coding an accurate TFS. Temporal fine structure information is important in understanding speech and is vital to understand speech in the presence of background noise. Additionally, spectral cues are impacted by cochlear hearing loss, but not to the extent that TFS has been demonstrated. Spectral cues, such as formant frequencies and formant transitions, are related to the spectrum of the sound energy in a particular phoneme. Spectral information is an important cue for the identification of segmental phonemes and leads to effective frequency resolution of the auditory mechanism. The accurate perception and identification of these cues is essential to accurate speech perception. As described earlier, studies have shown that cochlear hearing loss is strongly associated with widened auditory filters, resulting in poor frequency resolution. Thus, listeners with cochlear damage will not be able to effectively use some of the spectral cues in speech (Turner & Robb, 1987). Several authors have reported that listeners with hearing loss have poorer than normal speech recognition when compared to listeners with normal hearing (Godfrey & Millay, 1977; Leek & Dorman, 1987; Turner & Robb, 1987). Some investigators suggest that poor frequency resolution and spectral smearing underlie this deficit (Turner & Henn, 1989).

For accurate perception of sound, it is necessary for the distinct frequency cues of speech sounds to be accurately perceived. Additionally, the spectral and temporal cues are essential for accurate discrimination of the speech cues. Although accurate auditory perception information is important to accurate speech perception, listening is a cognitive task and requires processing by a central system for speech perception and translation.

1.2.4 Auditory Processing

Evaluation of the speech understanding problem in elderly listeners is difficult because speech recognition itself is a complex process. Most models of speech perception maintain similar underlying mechanisms that rely on a central system for cognitive processing of speech (Fitzgibbons & Gordon-Salant, 1996; Ohenham & Plack, 1997; Plack et al., 2004).

While audibility and cochlear pathology both impact speech perception, it is also important that a person understands the message that is received and processed by the peripheral system. Most people from the United States do not understand Sinhala (language from Shri Lanka); this would mean that even with proper audibility and no cochlear pathology there would be a lack of speech understanding for someone who was speaking Sinhala to a person who does not speak the language. This is because proper auditory processing is necessary for proper speech perception. Although pure-tone thresholds are frequently used to define auditory handicap, this ignores the fact that speech discrimination ability is dependent on supra-threshold auditory processing. What was discussed previously was how sound is processed by the ear. These sounds then need to be transmitted to the brain via the auditory nerve, through the brainstem to the brain where they can be processed. Without a central auditory nervous system and a central cognitive system, these are just sounds. Speech is usually the intended signal in communication. Speech requires decoding and cognitive effort to process these sounds into a meaningful message. It is "what we do with what we hear" (Katz, Stecker, & Henderson, 1992, p. 5) that matters.

There is a need for a distinction between central as referring to the central auditory nervous system (e.g., binaural hearing) and cognitive factors that are more central than the brainstem. These distinctions are not explicit in the literature and therefore difficult to discriminate. Furthermore, the impact of peripheral factors such as audibility and cochlear pathology on the central system are unknown and undefined in the literature. These impacts have not been systematically investigated and are often overlooked when reviewing the central system in the aging auditory system. For the purposes of this review, "central" will refer to cortical portions of the auditory system.

Examination of the auditory nervous system in the elderly population has shown degenerative anatomical changes on post-mortem inspection, although a majority of studies have analyzed a small sample of the brain (Brody, 1955; Ellis, 1920; Hansen & Reske-Nielsen, 1965; Kirikae, Sato, & Shitara, 1964; Konigsmark & Murphy, 1974). Brody (1955) sampled the cerebral cortex and concluded that there was a decrease in neurons with age particularly in the superior temporal gyri, precentral gyri and area striata. Ellis (1920) studied the Purkinje cells of the cerebellum and demonstrated that there was loss with age. Although it was initially concluded by Koningmark and Murphy (1970) that there was not a significant change in the ventral cochlear nucleus in terms of the number of neurons, in 1974 they published a paper demonstrating that there was a significant decrease in volume of the ventral cochlear nucleus beyond the fifth decade of life. This decrease in volume was not due to a decrease in neurons, but is likely due to decreased size of the neurons, decreased number of glial cells, loss of axis cylinders, loss of neuronal processes including dendrites, decrease in the size or number of blood vessels or decrease in the extracellular space. They noted the axons in middle age were robust and well myelinated however, in old age there was a decrease in these fibers. They concluded that their previous work from 1970 was not incorrect but was slightly misinformed. This decrease in the overall volume of the ventral cochlear nucleus would likely decrease the efficiency or accuracy of the transmission of auditory signals to and within the central auditory system. Histological and quantitative changes were reported by Brody (1955) who reported that there are significant changes in the human cerebral cortex due to aging. These changes in the anatomical structure with age could lead one to believe that there also are changes in the ability of elderly adults in the processing of signals, such as speech.

As reported in the previous discussion of cochlear hearing loss, temporal fine structure cues (TFS) are essential to the accurate perception of speech. Changes in the ability to process TFS has been shown in the aging population. However, unlike with hearing loss, the impact of aging on spectral cues has not been shown. An age-related decline in temporal resolution ability has been observed in studies conducted by numerous investigators (Fitzgibbons & Gordon-Salant, 1994; Lister, Besing, & Koehnke, 2002; Snell, 1997; Strouse, Ashmead, Ohde, & Grantham, 1998). In attempts to determine whether temporal resolution deteriorates with age alone, many studies control for hearing loss by recruiting older participants with normal pure tone thresholds. Carefully matching young and old participants with normal hearing, Snell (1997) measured gap thresholds in noise bursts. She found that gap thresholds were larger for the older participants across a variety of listening conditions. Fitzgibbons and Gordon-Salant (1994) found poorer overall duration discrimination and gap discrimination in older listeners (ages 65-70 years) as compared to young listeners (ages 20-40 years), regardless of hearing sensitivity. These studies have been replicated by multiple investigators and evidence suggests a strong effect of age for TFS processing. (Bertoli, Smurzynski, & Probst, 2002; Grose & Mamo, 2010; Strouse et al., 1998)

Age related changes are evident in the processing of speech such as during difficult listening situations. The odds of demonstrating an auditory processing deficit in average older adults increases by 4-9% per year of age over the age of 55 (Golding, Taylor, Cupples, & Mitchell, 2006). In a sample of 232 patients with no signs of cognitive deficit, 64 with mild memory impairment and 17 with Alzheimer Disease, Gates et al (2008) found that performance on three central auditory processing tests were significantly poorer for those with mild memory impairment when compared to normally aging individuals; those with Alzheimer Disease had even poorer performance. Gates et al (2008) did attempt to control for audibility and cochlear pathology by excluding those potential participants with asymmetric hearing loss, word recognition score below 70% for either ear, evidence of middle ear disease or those with greater than 48 dB HL thresholds. Due to these factors, tests were presented at 50 dB SL. Two out of the three tests used for assessing central auditory function are resistant to a moderate hearing loss. Fifer, Jerger, Berlin, Tobey and Campbell (1983), demonstrated that the Dichotic Sentence Test is relatively resistant to the effects of hearing loss below 50 dB HL. The Dichotic Digits Test is relatively immune to the effects of hearing loss for those with a mild to moderate hearing loss when the test is presented at an elevated level (Strouse, Hall, & Burger, 1995). Scores on the Synthetic Sentence Identification with Ipsilateral Competing Message do decrease with hearing loss (Strouse et al., 1995). Recognition of undistorted speech in quiet listening situations with proper audibility does not show a decline with age (Dubno et al., 1997). In tests of speech in noise with favorable speech to noise ratios, results show age related changes were negligible (Dubno et al., 1997; Gordon-Salant & Fitzgibbons, 1995); however, in less favorable signal to noise ratios there were significant age related changes. Dubno, Dirks and Morgan (1984) reported in their study of young and elderly adults that there were differences in performance of normal-hearing and hearing-impaired individuals on the test of the Speech In Noise Test (SPIN). The elderly participants did not perform as well as the young participants independent of hearing loss when tested on both high and low context sentences. These data would suggest that the elderly participants had a more difficult time with separating the speech from the noise. This task is demanding on the central auditory system as it asks the listener to distinguish the most important or desirable signal from the unimportant information, an ability that Dubno, Dirks and Morgan (1984) show decreases with age. Furthermore, elderly listeners have difficulty with time-compressed speech and reverberant speech even when the speech is presented in quiet (Gordon-Salant & Fitzgibbons, 1993; Vaughan & Letowski, 1997).

All of these findings point to a general effect of aging on central auditory processing ability. The elderly individual, however, has preserved linguistic knowledge that they are able to use to their benefit. Older adults are skilled in using phonologic and syntactic structure, prosodic cues and knowledge of pragmatics to help cue them into speech and follow conversations in highly contextual situations of social interactions (M. Pichora-Fuller & G. Singh, 2006). So while elderly adults struggle with central auditory processing their ability to use additional cues in the presence of highly contextual situations may help them. This could help explain why central auditory processing in elderly patients is often overlooked.

Cognitive changes may occur with normal aging that may affect working memory. Even if a person is accurately hearing the intended signal, they are required to then process the information; this is done in their working memory. Working memory describes the processes used for temporarily storing and manipulating information. Working memory has been described as a dual-function system where information is temporarily stored and processed with existing information until new information is either forgotten or consolidated into long term memory (Baddeley, 1986, 2010). Speech is a complex signal that requires an increased demand on the brain for processing. When an adult has a hearing loss, they depend even more on their stored knowledge, top-down processing, as a supporting context to compensate for the degraded signal; the energy required to do this leaves less space in the working memory for processing of incoming information (Pichora-Fuller, 2006). Because of this demand on the working memory to fill in the missing auditory information, it is proposed that this is another reason hearing loss may masquerade as dementia, including problems remembering or comprehending spoken language (Pichora-Fuller, 2003).

Gordon-Salant & Fitzgibbons (1997) reported that elderly listeners have a longer response time to recall tasks compared to younger listeners with similar hearing abilities. This could be due to a longer processing time within the working memory resulting in cognitive slowing. Babcock and Salthouse (1990) suggested that this cognitive slowing may be due to a decrease in the ability to perform dual tasks as it is a stress on the working memory functions due to decrease in storage capacity. Free recall lists have often been used in assessing aging differences in working memory. Participants are given auditory and sometimes visual lists of words and asked to recall as many of them as possible after hearing or seeing the list. Erber (1974) presented a list of 24 words to remember for later recall to young and elderly women and reported that young women recalled significantly more words than the elderly women. Schonfield (1965) examined age differences in the ability to recall and recognize word lists. He determined that there is not an age related change in recognition memory, but there is a consistent decline associated with age in the ability to freely recall these words. Results of these studies are consistent with other studies that demonstrate declines in recall performance but little or no changes in the recognition ability (Ardenberg, 1976; Hulsch, 1975; Taub, 1977). Similar testing has been conducted using sentences and, once again, elderly participants demonstrated more difficulty than the young adults in the recall of sentence information (Davis & Ball, 1989; Emery, 1985; Feier & Gerstman, 1980)

These studies demonstrate that there is a significant difference in the auditory processing ability in the elderly population as compared with younger adults. They have a changed anatomy, decreased working memory capacity, and decreased ability to sort out information in difficult listening situations. These difficulties affect their ability to understand speech especially if it is something that is unfamiliar. It is unclear if auditory processing alone accounts for changes in the processing or if there are compounding effects of the auditory periphery. The difficulty in auditory processing is likely compounded by any lack of audibility. Ability also is likely compounded by the cochlear pathology associated with sensorineural hearing loss. The combination of these factors may influence understanding. This lack of the ability to process intended messages could have an impact on communication between a physician and their patient.

Processing of acoustic information relies on the passing of information through a complex series of steps. First is the speaker produces a potentially audible signal. Factors including intensity, clarity and whether or not they are looking at the communication partner all impact the signal. The signal then travels through the environment to the intended signal recipient. Environmental impacts such as noise, reverberation and distance between the communication partners can alter the signal. Then, the auditory periphery must accurately transmit the sound to the cochlea which must accurately send the sound through the nervous system to the cortex for processing. At this point, there must be accurate attention and effort allocated for the person to process the sound. The sound must be comprehended requiring interpretation of context, linguistics and grammar. Finally the person must react to the signal requiring sorting of the information and then developing a reaction or responding appropriately to the signal. All these steps must be in proper working order for accurate and appropriate reactions to the intended signals. If any of these steps are missed or distorted, the signal may not be processed correctly, the message may not be understood correctly, and the subsequent response may be inaccurate or inappropriate. For an aging adult being assessed with oral questions and instructions, untreated hearing loss may confound an appropriate diagnosis and subsequent treatment.

1.2.5 Simulations of Hearing loss

One approach to estimating the effects of hearing loss in a particular condition is to conduct the experimental procedure with a group of individuals with hearing loss of a specified type and degree. The problem with this methodology is the lack of homogeneity of participants, and difficulty in finding participants with specified hearing losses. Another popular approach is to simulate hearing loss. This gives researchers the ability to control for hearing sensitivity in their studies. There are two primary ways of manipulating stimuli to simulate hearing loss: frequency specific attenuation and masking.

1.2.5.1 Frequency Specific Attenuation

Frequency specific attenuation, also known as filtering, simulates hearing loss by passing the stimuli through a pass or notch filter. This method of low pass filtering speech to simulate high frequency hearing loss has been used by a number of researchers to simulate loss of audibility (Humes, Dirks, Bell, Ahlstrom, & Kincaid, 1986; Kumar & Yathiraj, 2009). This method uses software which allows for frequency specific attenuation of the signal. The signal is attenuated at each frequency by an amount desired. The signal is thereby changed so that the longterm average sensation level of speech is decreased so to simulate the reduction in audibility perceived by a person with hearing loss. Additionally, this method allows for frequency specific attenuation. Wang, Reed and Bilger (1978) and Bilger and Wang (1976) used this method of simulating hearing loss. They used the method of filtering the speech and reported that the responses of the participants with simulated hearing loss very closely represented the responses of those with hearing loss. They were thereby able to determine that this method of simulation produces a good approximation of the effects of hearing loss on consonant feature recognition. As these are the features of speech that are most important for speech recognition, it can be assumed that the spectral smearing that occurs with filtering does not further compromise the signal further beyond limiting the audibility. Additionally, if the stimuli used in the study uses additional background noise to simulate other noises, this along with the desired stimuli can be sent through the filter (just as it would be filtered by the hearing loss). This is the only method available if a researcher desires to use not only the desired stimuli, but also additional noise; the other method of simulating hearing loss uses noise to create hearing loss.

1.2.5.2 Masking

Addition of narrow band masking noise represents another method that can be used to shift thresholds in selected spectral regions. It has been suggested that it also simulates loudness recruitment experienced by those with sensorineural hearing loss (Stevens & Guirao, 1967); however, Fabry and VanTasell (1986) showed no altered loudness effect of simulation using masking on supra-threshold speech. Villchur (1974) used spectrally shaped noise to simulate sensorineural hearing loss for two people with unilateral sensorineural hearing loss. They reported that the masking noise impacted the presented speech stimuli in a similar way as their hearing loss. He concluded that masking noise was an accurate way to simulate sensorineural hearing loss. Humes, Espinoza-Veras and Watson (1988) suggested that masking of speech using masking noise is a combination of Lufti's spectrally separated masking model (Lufti, 1983, 1985) and Penner's temporally separated masking model (Penner, 1980; Penner & Shiffrin, 1980). Both of these previous models conclude that the combined masking effect of the two maskers is simply the sum of the masked thresholds and this follows a non-linear transform likely caused by the effects of the cochlea. As the previous studies used non-speech stimuli, Humes and colleagues (Humes, Esponoza-Veras, & Watson, 1988) described that for speech, it would be impossible to temporally or spectrally separate the intended signal from the masker. They developed a new model for masking of speech for simulating sensorineural hearing loss. Using this model, they determined that masking closely approximates sensorineural hearing loss. However, these previous models that use masking seek to simulate sensorineural hearing loss and do not separate out audibility from cochlear pathology. Additionally, the use of masking as a simulation of hearing loss has been suggested to produce questionable results with the use of speech stimuli (Milner, 1982 as cited by Fabry and VanTasell, 1986).

Fabry and VanTasell (1986) sought to compare these two methods of simulation of hearing loss. They suggested that frequency specific attenuation (filtering) is generally a good simulation of hearing loss, although it has limitations. There is some spectral smearing and the inability to reproduce all effects of hearing loss such as poor frequency and/or temporal resolution. One suggested limitation also could be seen as a positive aspect of filtering; filtering does not simulate loudness recruitment while simulation using masking does; however, this could suggest that filtering is preferred if specifically the impact of audibility is the desired focus of the research study. Additionally, Fabry and VanTasell (1986) suggested that masking does not work as effectively as frequency specific attenuation (filtering) and that filtering provided a better simulation of the hearing loss than did masking. Although simulation of hearing loss through these methods is not always an accurate representation of sensorineural hearing loss, they reported that the use of masking for simulating hearing loss was never a successful simulation when attenuation was not. Filtering is more accurate than masking and that use of frequency specific attenuation (filtering) is an effective and accurate way of simulating hearing loss. Furthermore, noise is part of the signal that should be subjected to simulated hearing loss, filtering would be the necessary choice for hearing loss simulation. A comparison of these methods is in Table 7.

Table 7: Simulation of Hearing Loss: Filtering versus Masking

Frequency specific attenuation (filtering)	
Pros	**Cons**
Closely represents error patterns of actual hearing loss	Cannot simulate abnormal loudness growth (recruitment)
Can incorporate additional noise along with stimuli	
Masking	
Pros	**Cons**
Simulates recruitment	Not always effective representation of hearing loss
	Cannot separate out cochlear pathology and audibility
	Questionable with use of speech stimuli
	Cannot incorporate additional noise into stimuli

1.3 PREDICTIONS OF SPEECH INTELLIBILITY

1.3.1 Long Term Average Speech Spectrum

Throughout the 20th and now 21st century, speech intelligibility has been the focus of many researchers as it is the foundation of communication. The long term average speech spectrum (LTASS) is the underpinning of our understanding of speech transmission and for analyzing speech signals. The first significant effort to understand the impact of various distortions on speech intelligibility was made by AT&T's Western Electric Research which was renamed Bell Telephone Laboratories (BTL or Bell Labs) in 1925. The telephone company supported a comprehensive internal research program during most of the twentieth century whose original goal was to improve the clarity of telephone speech. These experiments were intended to determine which frequencies and intensities were necessary for transmission through the phone for proper understanding.

Dunn and White (1953) asked eleven participants to read a short passage while filters were applied to the recordings. These were then analyzed and graphically represented by frequency in Hertz versus intensity in decibels (frequency on x axis and intensity on y axis). This graphical representation is still used today when analyzing speech signals, although now digital filters allow for a much quicker analysis. The graphic representation of the speech signal is used to demonstrate for which frequencies the intensity is the strongest; this may help provide clues as to the impact of noise or other interferences on the speech signal and thus the intelligibility. Other studies also were conducted to characterize the effects of noise, filtering, and channel distortion on the LTASS in order to predict their impact on intelligibility (Fletcher & Galt, 1950; French & Steinberg, 1947; Kryter, 1968). More recent literature (Byrne et al., 1994; Humes et al., 1986) provided a LTASS for multiple languages. They attempted to quantify multiple speech samples concluding the LTASS is similar across the speech samples. While the measurement of LTASS is important to understanding speech, it does not allow for a prediction of the speech understanding once the signal reaches the intended listener.

1.3.2 Audibility Index

French and Steinberg (1947) provided a review of the experiments and potential problems with speech intelligibility research up to World War II. They further identified the Audibility Index (AI), the next generation in prediction of intelligibility of speech. The AI's foundation is in LTASS, but it is able to predict understanding ability based on factors other than strictly the acoustic characteristics of the signal. The original AI was developed by Fletcher in the Bell Laboratories in the 1920s based on the initial ideas of Crandall. Nearly three decades after the initial idea, Fletcher and Galt published the Articulation Index (Fletcher & Galt, 1950). Articulation index research was discontinued when Fletcher retired from Bell Labs and consequently the Fletcher and Galt 1950 version of the *AI* was never used in practice. The first American National Standards Institute 1969 version, (American National Standards Institute, 1969), was actually derived from a simpler *AI* calculation provided by Bell Labs to the Harvard's Psycho-acoustic and Electro-acoustic Laboratories in 1942 (French, 1942) to help WWII communications research.

The ANSI S3.5-1969 AI is an index between 0 and 1 that describes the effectiveness of a speech communication channel. The frequency range is divided into twenty bands whose frequency limits are chosen based on the importance of that frequency to the LTASS (French and

Steinberg, 1946). The frequency bands range between 0.15 and 8 kHz, with the width of each band adjusted to make the bands equal in importance. These adjustments were made on the basis of intelligibility tests with low-pass and high-pass filtered speech, which revealed a maximum contribution from the frequency region around 2.5 kHz. Furthermore, the effect of masking from a lower frequency band upon a higher frequency band occurring in the hearing organ is considered. The auditory masking is accounted within each octave band within the AI.

The AI has two key assumptions. First, the contribution of any individual frequency band is independent of the contribution of other bands. Second, the contribution of each frequency band depends on the signal-to-noise ratio within that band. Under optimal conditions, each frequency band would contribute 0.05 to the AI resulting in an AI of 1.0. When conditions are not optimal, only part of the signal at each frequency would be transmitted. Thus 0.05 would be multiplied by the proportion of the signal that is transmitted in each frequency. These are then summed to get the AI for the less audible signal. To accurately calculate the AI, the speech and noise signals must be defined. An AI of 1.0 is not required for 100% understanding (Killion, Mueller, Pavlovic, & Humes, 1993). An "articulation-to-intelligibility" transfer function can be applied to convert the AI to predicted intelligibility in terms of percent correct. This assumes that the predicted intelligibility depends on the proportion of time the speech signal, especially the spectrum, exceeds the threshold of audibility or the noise.

There have been few corrections to the actual AI calculation since its inception. Many have made suggestions to make the AI easier to calculate and easier for clinicians and practitioners to use. One of these was developed by Mueller and Killion (1990). Their "count the dots" method of determining AI used 100 dots on an audiogram (see Figure 4). A clinician could overlay a patient's thresholds onto the audiogram, count the dots that were audible to the patient and approximate their AI (See Figure 4). Then using the graph presented in the 1990 article, the clinician could use the calculated AI to determine the percent intelligibility. While this method is simple for the clinician to use, the actual formula AI calculation is a more accurate predictor of understanding ability. However, for clinical use, the "count the dots" method is more practical.

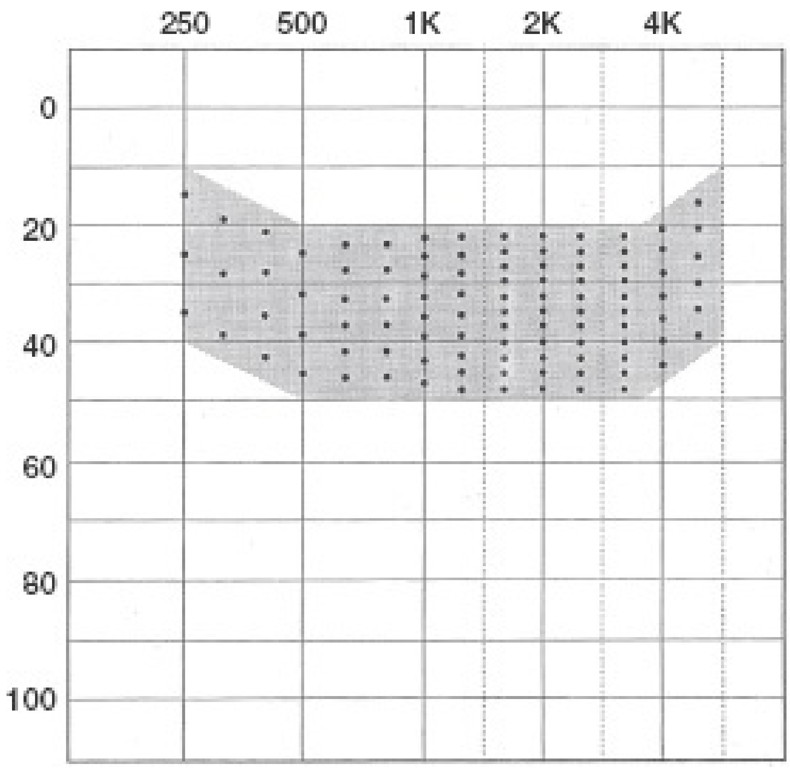


Figure 4: Count the Dots (Mueller & Killion, 1990)– reprinted with permission

The AI generates accurate predictions of average speech intelligibility over a wide range of conditions. These include broadband noises (Egan & Weiner, 1949; G. Miller, 1947), high- and low-pass filtering (Fletcher & Galt, 1950; French & Steinberg, 1947), and distortions of the communication (Beranek, 1947). It also has been used to model the loss of speech intelligibility resulting from sensorineural hearing impairments (Fletcher, 1952, 1953; Humes et al., 1986;

Ludvigsen, 1987). Most studies of the AI have found that it overestimates the performance of those with hearing loss (Egan & Weiner, 1949; Fletcher & Galt, 1950; Hulsch, 1975). The AI model is founded with the idea that speech intelligibility under adverse conditions is strongly affected by the audibility of the speech spectrum. However, the AI was designed to accommodate linear distortions and additive noises with continuous spectra. It is less effective for predicting the effects of nonlinear or time varying distortions, transmission channels with sharp peaks and valleys, and time-domain distortions, such as those created by echoes and reverberation. Some of these difficulties are overcome by reformulations of AI theory such as the speech intelligibility index (SII).

1.3.3 Speech Intelligibility Index

The primary differences between the SII and AI are that the SII provides a more general framework for making the calculations than the AI. This framework was designed to allow flexibility in defining the basic input variables (e.g., speech and noise levels, auditory threshold) needed for the calculation. The general framework also allows for flexibility in determining the reference point for your measurements (e.g., free-field or eardrum). Additionally, differences include corrections for upward spread of masking and high presentation levels. Finally, the SII is calculated using 1/3 octave bands rather than the AIs 20 bands of differing sizes. One-third octave bands were used as they are the critical bandwidth of perception. As each band is of equal width, the SII provides frequency importance functions (FIFs). These FIFs are used to determine the weighting of each frequency band on the contribution to understanding of a signal. For American Standard English, the FIF is show in Figure 5. Note that nearly 50% of speech cues for English derive from 1000 to 2000 Hz.

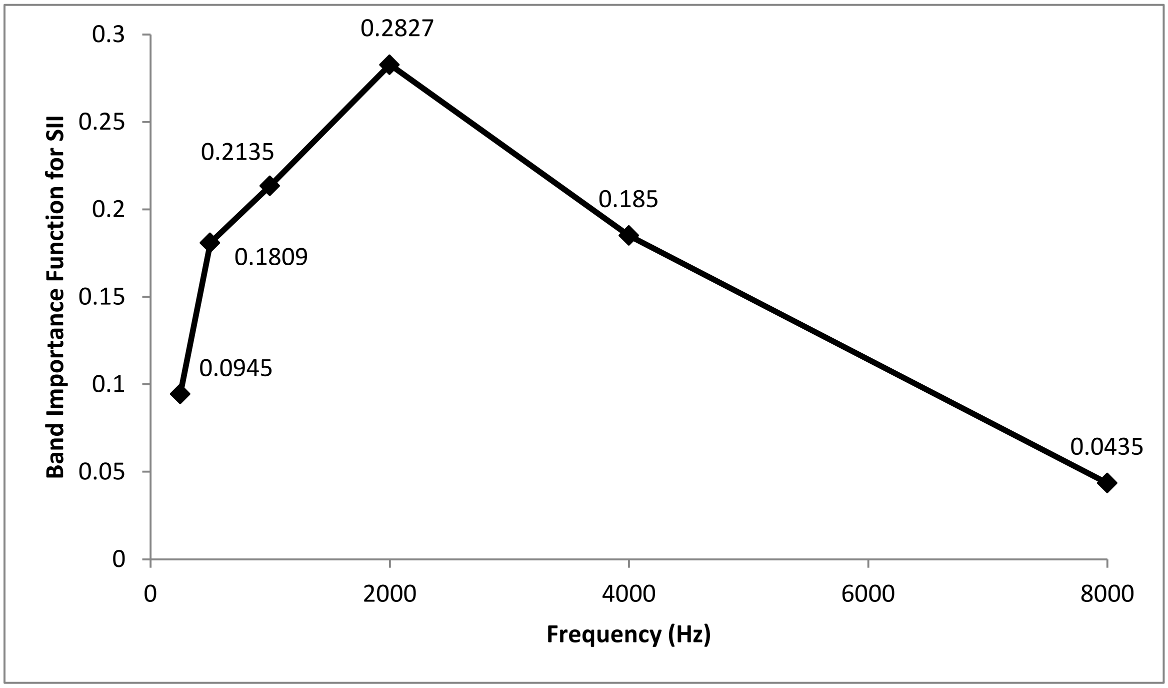


Figure 5: Frequency Importance Function (Comprised from information within ANSI, 1997 (R-2007))

The American National Standard's Methods for the Calculation of the Speech Intelligibility Index was published in 1997 (ANSI, 1997 (R-2007); Dugal et al., 1980). It defined the method for calculation of what was described as the physical measure that is highly correlated with the intelligibility of speech for a group of talkers and listeners. Like the AI, the SII is calculated from acoustical measurements of speech and noise.

The general formula for SII is:

$$\text{SII} = \sum_{i=1}^{n} \text{Ii Ai}$$

Where the *n* refers to the number of individual frequency bands used. The current SII standard (Dugal et al., 1980) is flexible in that the user can choose how specific they would like the measurements to be. This ranges from 6 bands (octave bandwidth) to 21 bands (critical bandwidth). The more frequencies used, the more accurate the calculation of the SII. The I_i refers to the importance of a given frequency band (*i*) to speech understanding. A_i is the band audibility function associated with the frequency. The values for I_i, also known as the frequency importance function (FIF), are based on specific speech stimuli, and when summed across all bands are equal to approximately 1.0 (Dugal et al., 1980).

The SII is calculated with the following assumptions: the listener is facing the speech source and the source is otherwise free field, and the speech and any noise are independent and can be independently measured. To calculate the SII, the calculation method needs to be selected. This means choosing the critical frequency band width (21 bands), one-third octave frequency band width (18 bands), equally-contributing band width (17 bands), or the octave frequency band width (8 bands). Based on the selection, the chart in ANSI 3.5 (1997) provides the frequency importance functions by frequency. To calculate the SII, the equivalent speech spectrum level, equivalent noise spectrum level and the equivalent hearing threshold level is needed. The accurate calculation of these require the equipment for measurements of the modulation transfer function for intensity (MTFI) and the combined speech noise spectrum level at the tympanic membrane (CSNSL) as well as a human head manikin such as KEMAR. The exact calculations of these are available in the ANSI 3.5 – 1997, however, current technology allows for computer calculation rather than hand calculation of the speech and noise spectrum. Once these have been calculated, the A_i, or band audibility, will be calculated. The determination of the A_i variable is based simply on the level of the speech, in a given frequency band, relative to the level of noise in that same band. If the question is actually how a person may do with a hearing loss in quiet, the ANSI 3.5 -1997 has a conversion factor that is used to convert thresholds (in dB HL) to a hypothetical internal noise that would give rise to the measured threshold in quiet. So this number is used for the noise spectrum number. When determining A_i, a dynamic range of speech of 30 dB is assumed. Using the formula for calculating A_i, $(E'_i - D_i +15)/30$, subtract the spectrum level of noise from the spectrum level of the speech (in dB) in a given band, add 15 dB (the assumed speech peaks), and divide by 30. If the results are greater than one or less than zero, the numbers one and zero are used. This value is equivalent to the proportion of the 30 dB dynamic range of speech that is audible to the listener. This value, the A_i, is finally multiplied by the FIF to determine the contribution that each frequency band provides to the signal received by the listener. Finally, summing these values across the frequency bands leads to an SII number between 0.0 and 1.0. This should not be considered the understanding function. Instead it should be interpreted as 1.0 meaning that the entire speech signal is reaching the listener, while 0.0 can be interpreted as none of the speech signal is reaching the listener.

The SII model predicts the average speech intelligibility; it does not attempt to predict the intelligibility of the utterance. For estimating speech understanding, another conversion is needed. The shape of the appropriate transfer function (Sherbecoe & Studebaker, 2002; Studebaker & Sherbecoe, 1991, 1993; Studebaker, Sherbecoe, McDaniel, & Gwaltney, 1999) depends on speech material (words/sentences) and the measurement method (word score, sentences score, up/down method, fixed levels). This transfer function can be used to predict speech intelligibility as a function of speech level in quiet or in noise or to describe observed performance. For most conversational speech stimuli an SII of 0.5 would correspond to close to 100% intelligibility.

Many researchers have used the SII to determine the impact of audibility on a signal. The predictive value of the SII can be used to determine if lack of audibility is the primary reason for lack of intelligibility. Using the SII as a measure of audibility, if hearing loss impacts performance on the orally presented test, it can be concluded that audibility is the primary feature that decreases the intelligibility of the stimuli used in the study. Hargus and Gordon-Salant (1968) used the SII with a range of speech material redundancy to determine the impact of audibility on these stimuli. If audibility impacts the participants' performance, this would mean that audibility was the primary factor in the performance on these stimuli. If it did not, then some other factor, such as cochlear pathology or central processing, also influences the speech understanding. The authors reported that audibility as demonstrated using the SII did not influence the performance of the elderly hearing-impaired participants as well as it did the young noise-masked normal hearing participants. They concluded that the speech recognition difficulties experienced by the elderly hearing-impaired individuals are not likely solely due to reduced audibility.

In the attempts to make the SII faster to calculate, Killion and Mueller (2010) updated their count the "count the dots" method. While this method adapts the SII to be more clinically applicable, like the "count the dots" method of the AI, the updated SII version is not as accurate as the true calculation of the SII, but it is clinically friendly.

1.3.4 Extended Speech Intelligibility Index

An extension of the SII was proposed by Rhenbergen and Versfeld (2005). They suggested that the SII does not take into account any fluctuation of the masking noise as the SII uses the LTASS and noise. Therefore, any fluctuations in the noise would not be accounted for in the SII. The authors created an Extended SII (ESII) in the attempt to capture modulations in the noise. This could help explain why some researchers who have used modulated noise did not find a strong correlation with the SII predicted value (Dubno, Horwitz, & Ahlstrom, 2002). They suggested a slight change in the model of the SII to create a small critical band filter to capture the modulated noise and use this as the noise factor. Their change did slightly increase the SII predictive value. Although this change was introduced in 2005, it has not been readily used in the general literature. It is likely due to the lack of real world application for the modulated noise. Other publications using the ESII are primarily from the same authors (Rhenbergen, Versfeld, de Laat, & Drescher, 2010; Rhenbergen, Versfeld, & Drescher, 2006).

1.3.5 Speech Transmission Index

A similar model to the SII, the Speech Transmission Index (STI) (Steeneken & Houtgast, 1980), is used primarily by acoustic consultants and engineers. The primary difference between the SII and the STI is that the STI is based on the generation and analysis of an artificial test signal that replaces the speech signal. In the STI concept, the intelligibility of speech is related to the preservation of the spectral differences between consecutive speech elements; the phonemes. This can be described by the envelope function. Rather than the speech signal in the SII, this envelope spectrum is used to derive the STI. Like the SII, STI has frequency importance functions. The signal is divided into octave bands, like the 8 band SII. There is then a transmission index value (TI value) applied to each band which represents the contribution of each octave band to the final STI. However, the SII algorithm is more complex than STI with respect to its mechanisms to account for the upward spread of masking and hearing acuity (van Wingaarden & Drullman, 2008). As the STI, like the SII, is primarily a monaural model there has been a proposed correction for binaural presentations (van Wingaarden & Drullman, 2008). The authors suggest their changes could likely be used for the SII.

The AI, SII, ESII and STI are the primary models used to describe speech intelligibility. These are outlined in Table 8. Other methods for calculating speech intelligibility have been proposed such as the Rectangular Passband Intelligibilities (Taub, 1977). However, these have not been widely used or verified. The reliability of these for performance prediction is limited. As the Speech Intelligibility Index is more commonly used and has been validated for judging the impact of audibility on speech intelligibility for those with normal hearing and hearing impairment, it is the suggested model. The SII may provide a useful tool for assessing whether audibility is a factor in the accurate diagnosis of dementia via a verbally/orally administered test (MMSE) and further whether audibility is the primary factor given the complex nature of the auditory system.

Table 8: Models of Speech Intelligibility

Model	Methods described by:	Primary Components
AI	French and Steinberg (1947)	Equal Bandwidths, Frequency Importance Functions
SII – 21 band	ANSI (1997)	Critical Bandwidths, Frequency Importance Functions, Noise (HL is internal noise)
SII – 18 band	ANSI (1997)	1/3 octave Bandwidths, Frequency Importance Functions, Noise (HL in internal)
SII – 17 band	ANSI (1997)	Equal Bandwidths, Frequency Importance Function, Noise (HL is internal noise)
SII – 8 band	ANSI (1997)	Octave Bandwidths, Frequency Importance Function, Noise (HL is internal noise)
ESII	Rhenbergen and Versfeld (2005)	Critical bandwidths, Frequency Importance Function, Modulated Noise
STI	Steeneken and Houtgast (1980)	Octave Bandwidths, Transmission Index Value, Noise Bands

1.4 OTHER FACTORS THAT IMPACT AUDIBILITY AND COMMUNICATION

As discussed previously, audibility is the most important factor for accurate speech perception (Humes, 1991, 2007; Kamm et al., 1978; Otto & McCandlis, 1982). However, other factors, such as background noise, reverberation, rate of speech and visual cues can have an impact on audibility and speech perception.

1.4.1 Background noise

Background noise refers to any auditory disturbance that interferes with the intended auditory signal (Crandell, Smaldino, & Flexer, 1995). The guidelines from the World Health Organization state that background noise in medical facilities should be no louder than 35 dB SPL (1998). However, many studies have reported much louder levels ranging from 45 dB to 68 dB SPL, with 45 dB being the most common (Allaouchiche, Duflo, Debon, Bergeret, & Chassard, 2002; Blomkvist, Eriksen, Theorell, Ulrich, & Rasmanis, 2005; Falk & Woods, 1973; Hilton, 1985; McLaughlin, McLaughlin, Elliott, & Campalani, 1996). Most measurements of background noise are obtained using a sound level meter with an A weighting which is designed to simulate the average human ear under conditions of low sound loudness.

A study of a variety of medical units including a geriatric internal medicine unit was conducted to determine the intensity and spectral shape of the noise in medical units (Busch-Vishniac et al., 2005). They determined a significant variability between units, rooms and times of the day the noise was recorded. In the geriatric internal medicine unit the average RMS across all frequencies for the entire 24-hour collection period was 43.51 dB SPL (Busch-Vishniac, 2011). The spectral shape is shown in Figure 6.

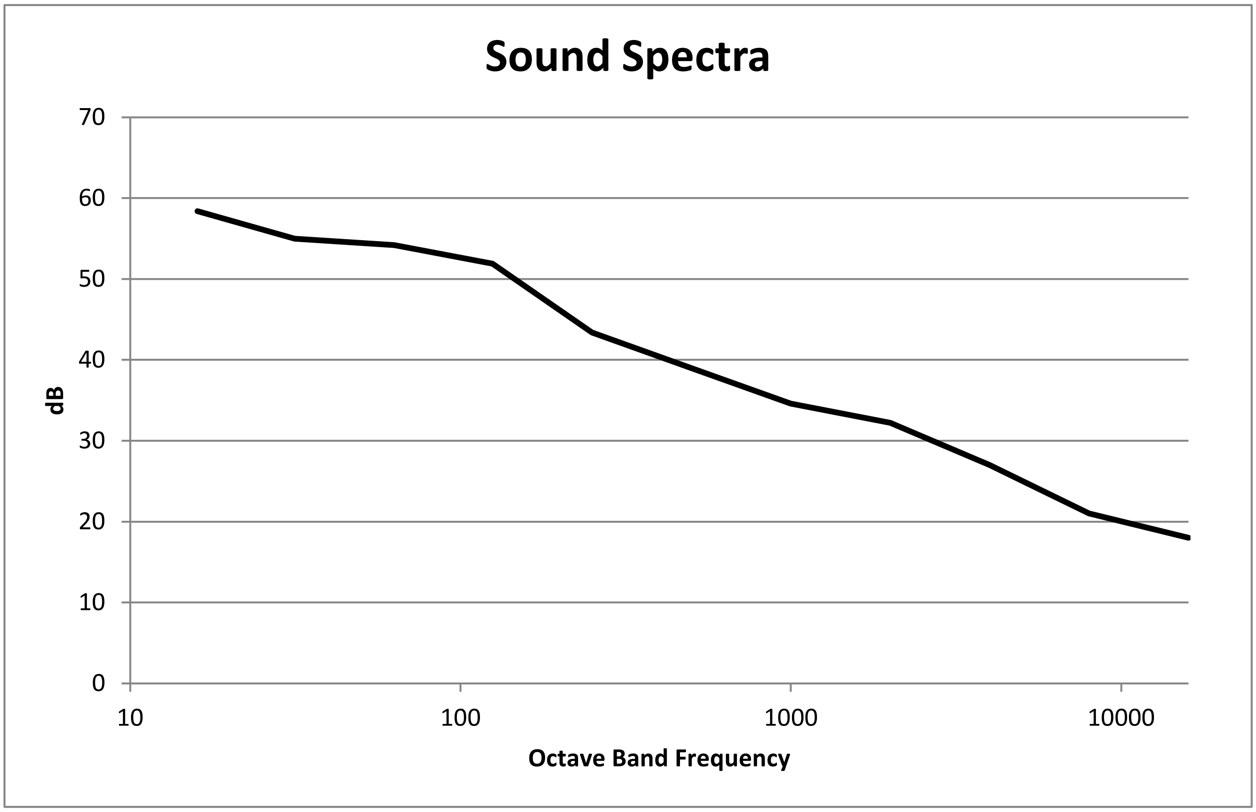


Figure 6: Sound Spectra Unit Nelson 7 - Johns Hopkins Hospital (Busch-Vishniac, 2011)

Background noise compromises an acoustic signal by masking some of the acoustic and linguistic cues. Generally background noises mask the weaker consonants more than the vowels and causes a significant reduction in speech perception because nearly 90% of the important acoustic information in speech is provided by consonants (French & Steinberg, 1947; Wang et al., 1978).

Common noises in a medical examination room would be white noise from the venting system. Noises such as air conditioning units have predominately low frequency energy and are often more effective maskers of high-frequency speech sounds due to the upward spread of masking. This phenomenon involves noise producing greater masking for signals that are higher in frequency than the noise. Continuous noises, such as those emitted by a fan, are generally more effective maskers than impulse or interrupted noises because continuous noises more effectively reduce the spectral-temporal information available in the speech signal (Crandell & Smaldino, 2002). These cues, as discussed previously, are critical to accurate speech perception.

1.4.2 Reverberation

While noise is one of the most obvious distortions of a speech signal, reverberation is also common; most listening situations have some noise and some degree of reverberation. Both of these distortions significantly alter the speech signal. While noise obscures the less intense portions of a stimulus, reverberation causes masking of adjacent phonemes, smears elements in the time domain, and smooths the temporal envelope (Houtgast & Steeneken, 1973). As discussed previously, these elements are more difficult for elderly persons to process without any distortions, with reverberation causing a distortion; this is even more detrimental to speech perception. Several studies have reported that elderly people perform more poorly on speech perception tasks when the signal is distorted with reverberation (Harris & Reitz, 1985; Nabeleck, 1988; Nabeleck & Letowski, 1985).

One of the ways reverberation of a room is determined is reverberation time (RT). RT is the time in seconds required for sound pressure at a specific frequency to decay 60 dB after the sound source has stopped (Kreisman, 2003). Long RTs reduce the clarity of the speech and thereby intelligibility. This is because the speech signals reaching a listener are a mixture of direct energy and time-delayed reflections. In addition, when RTs are too long, undesired sounds remain longer in the room and consequently, noise levels increase, which as discussed previously is detrimental to speech perception.

The critical distance of a room is the distance at which the sound pressure wave spreading out from a sound source becomes equal to the reflected sound due to reverberation (Mijic & Masovic, 2010). This distance depends greatly on the geometry and absorption materials within the space. For the most accurate perception of sound information the listener must be inside the critical distance around the sound source. Although no average critical distance measurements could be found related to medical examination rooms, information can be extrapolated from calculations of critical distances in a classroom. Although a classroom is much larger, it likely has the similar geometry and absorption. Crandell and Smaldino (1994) suggest that in an average sized room (6 x 6 x 3 meters) with a commonly measured reverberation time of 0.8 seconds, the critical distance would be approximately 3.6 meters. Based on this, it could be suggested that a medical examination room is ½ the size of an average classroom therefore the critical distance would be 1.8 meters or about 6 feet. It is likely that due to the small size of typical exam rooms, the physician and patient are within the critical distance necessary for reduced impact of reverberation.

1.4.3 Rate of speech

On a daily basis most communication is spoken in a conversational manner; this is in contrast to the deliberately slow and accurately articulated speech that occurs when material is read out loud. Picheny, Durlach and Braida (1986) reported that conversational speech is twice as fast as read speech and other authors have reported that conversational speech affects many of the cues of speech (Ferguson & Kewley-Port, 2002; Klatt, 1975; Krause & Braida, 2004). With fast conversational speech, as the rate increases the cues of speech are lost. Acoustic information, such as intensity, spectral and temporal cues, are distorted and often lost in conversational speech (Picheny et al., 1986).

Alternatively, read speech, also known as clear speech, is much slower and articulation is much clearer. This slower speaking rate is something that many talkers adopt in difficult communication situations. Picheny et al (1985) suggested that clear speech is significantly more intelligible than conversational speech for both normal-hearing and hearing-impaired listeners, nearly 17% more intelligible. Read speech is typically spoken more slowly than conversational speech (Picheny et al., 1986), it has more acoustic energy at the high frequencies (Krause & Braida, 2004; Picheny et al., 1986) and typically it has larger temporal envelope modulations (Krause & Braida, 2004). All of these acoustic differences factor into the increased intelligibility of the intended signal when clear speech is used.

There is likely a third category that has not been studied. It is likely somewhere between conversational speech and read speech. It is more like the rate of speech an instructor would use. It is slow enough to foster auditory processing, but as the material is familiar to the lecturer, it is delivered faster than read speech. As physicians are using the same questionnaires over and over again, this rated of instructed speech is likely the rate that they would use.

1.4.4 Visual Cues

Under ideal listening situations, a person with normal hearing does not require any visual information for mostly accurate speech perception. However, in the presence of background noise, reverberation or for those with hearing loss, there is substantial improvement in speech perception when the person is able to see the talker's face (MacLeod & Summerfield, 1987). MacLeod and Summerfield (1987) suggested that in the presence of hearing loss or background noise, adding a visual cue to speech as compared to auditory alone improved the signal-to-noise ratio by as much as 11 dB. This is not insignificant as recent evidence suggests that improving the signal-to-noise ratio decreases listener effort (Fraser, Gagne, Alepins, & Dubois, 2010).

However, as a person ages, their ability to use these speech cues significantly decreases. Beginning at 65 – 70 years, older adults with normal, or corrected normal vision, are unable to use visual cues as effectively as younger adults on tasks involving visual recognition of words and sentences (Cienkowski & Carney, 2002; Lyxell & Ronnberg, 1991; Middleweerd & Plomp, 1987).

1.5 IMPACT OF HEARING LOSS ON DIAGNOSIS OF DEMENTIA

Little research has been conducted on the relationship between reduced hearing acuity and assessment of cognitive functioning. There are, however, a few studies that suggest a degree of association between hearing loss and dementia. These studies are primarily field studies not laboratory or controlled studies. There are several studies that have reported that hearing loss is generally twice as likely in individuals with dementia or other mental disorders as those with normally aging cognitive function (Hodkinson, 1973; Kay, Beamish, & Roth, 1964; Uhlmann, Larson, Rees, Koepsell, & Duckert, 1989). There are examples of instances where the behavior of hearing-impaired individuals who appeared "confused" and were labeled as "senile" improved after the use of hearing aids (Ronholt, 1986). Palmer et al (1998) showed that the difficult behaviors associated with Alzheimer Dementia were reduced after treatment with amplification. These studies have focused on the population diagnosed with dementia and the rate of hearing loss. While this and other studies provide evidence that hearing loss can impact those with dementia, research on the effects of undiagnosed hearing loss on the diagnosis of dementia is sparse. Currently, there are three articles that discuss the association between hearing loss and the diagnosis of dementia; these are summarized in Table 9.

Uhlmann et al. (1989) reported that patients with mild to moderate hearing losses have a diminished performance on the verbally presented MMSE. Their justification for including participants with mild to moderate hearing was that more significant hearing losses would be clinically obvious and that mild to moderate hearing losses are frequently unrecognized. Their description of hearing loss was based on average hearing loss and did not define configuration or type of hearing loss. The conclusions were based on auditory sensitivity as measured by soundfield audiometry, not frequency specific threshold information. However, Durrant, et al. (1991) reported that accurate frequency-specific audiometric information can be obtained, even in those with advancing Alzheimer Disease; this was replicated by Palmer, et al (1998).

Uhlmann et al. (1989) participants were given the MMSE after completing a medical evaluation; they did not provide a description of how the MMSE was administered other than it was completed in the clinic. As this test does not have a standardized administration, it is unknown who conducted the MMSE testing and/or if it was one of the investigators; this could have confounded their results if the testing was completed by an unblinded investigator. Study participants were people who had a diagnosis of dementia. They reported that those with mild to moderate hearing loss did not do as well on the MMSE as those with normal hearing. While this answered their question of whether hearing loss would worsen the cognitive scores, they were unable to accurately report the effects of the different components of hearing loss or auditory processing on the diagnosis of dementia. The study concluded that hearing loss did not confound the results of the verbally administered MMSE. They based this conclusion on the fact that there was not a significantly different result on the verbally administered MMSE and the written MMSE they were trying to develop. These results are in question because of the potentially unblinded nature of the study and the inclusion of a non-standardized measure that was under development. It is difficult to draw conclusions based on a measure that was being developed. It could be that the visually administered test was more difficult as visual information has been shown to be more difficult to process than verbal information in the elderly population (Cummings, Benson, Hill, & Read, 1985). If the verbal administration actually produced poorer results than agreement with the orally derived scores does not mean hearing loss had no impact, it would mean that the hearing loss had an equal impact to the difficulty produced by a written test. Given the details provided by the study, it is impossible to draw conclusions about the impact of untreated hearing loss on this measure. The authors noted that these were preliminary findings, but no follow-up publications were produced.

Weinstein and Amsel (1986) attempted to quantify the prevalence of hearing impairment for those diagnosed with dementia and to determine the effect of amplification on performance on the Mental Status Questionnaire (MSQ) (Kahn, Goldfarb, Pollack, & Peck, 1960). The MSQ is a brief 10 item questionnaire asking about recent memory and orientation to person, place, and time (Verwoerdt, 1976). Weinstin and Amsel (1986) recruited a study group of 30 individuals with a clinical diagnosis of dementia from a Veteran's Affairs physician. Participants with a negative history of functional hearing loss or previous hearing aid use were given an audiologic evaluation; a majority, 83%, had a significant hearing loss. They did not report how the diagnosis was determined by the physician. They were then given the MSQ under both unamplified and amplified conditions. They concluded that hearing loss is more prevalent in the population diagnosed with dementia, 83% as compared to 70% of a random sample of institutionalized non-demented persons. They also determined that there was a significant decline in the MSQ score for the unamplified condition, suggesting that the person would appear to be more demented if a physician were to use the MSQ as their primary measure for diagnosing dementia without ensuring audibility. These results suggest that there could be a significant effect of hearing loss on mental status testing. However, this study used the MSQ, a test which is not used often in current protocols for diagnosing dementia (Jorgensen et al., 2012 - submitted; Shulman et al., 2006).

Raiha et al. (2001) attempted to quantify false diagnoses using the MMSE. They stated that the most common causes for difficulty on the test performance of the MMSE was likely related to hearing loss or poor vision. They stated that out of the total participants, 1196 participants, that testing results were confounded by other factors with the most common being vision and hearing impairment. They reported that 36 were likely affected by vision impairment and 20 were affected by hearing loss. This is significantly lower than previous estimations of people with hearing loss in this population. The study reported that hearing was examined, but did not state how this was completed. A research nurse conducted the MMSE screening; if a participant was unable to complete a portion of the MMSE, the examining nurse recorded what they felt was the cause that had interfered with performance. This study was conducted in a clinic and has a great deal of possible researcher bias. In the discussion of the study results, the researchers conceded that the criteria for poor performance were not agreed upon in advance of the study and the research nurse had to use his/her own experience to determine a participant's difficulty on the testing. While the results support that there is a likely connection between undiagnosed hearing loss and the diagnosis of dementia, the foundation for these statements is weak.

Table 9: Hearing Loss and Diagnosis of Dementia

Citation	Study Question	Population	Materials	Findings	Problems
Raiha, et al 2001	The extent to which causes other than dementia will contribute to poor performance on MMSE	People born before 1926 residing in Lieto, Finland - 408 men and 708 women interviewed	MMSE administered by nurse; when participant missed item nurse recorded reason (ex: vision, hearing, functional, cognition) Nurse rated whether performance on MMSE was due to other factors	10% of those tested did not do well on MMSE but were contributed to other factors; Most common causes for difficulty were vision and hearing; most had problems on writing of sentence or drawing pentagons	Subjective ratings of nurses; use of just MMSE; did not test other things that were reported as cause (ex: hearing, vision, etc) just took word of nurse or participant self-report; not blinded; criteria not agreed upon prior to completion of the study
Uhlmann, et al, 1989	1 – does mild to moderate hearing loss artificially lower the MMSE 2 – to develop a comparable version of a written form of the MMSE	71 patients enrolled in AD research with: >14 on MMSE, diagnosis of AD, English speaking, 20/200 vision, audiometric reliability	MMSE	Those with mild to moderate hearing loss did worse on the MMSE than those with normal hearing, written version of the MMSE was not significantly higher than the verbally administered MMSE for either group	Done in clinic – not blinded; made conclusions based on written version of MMSE that was not validated, used just the MMSE, used those with prior dx of dementia – influence of central processing

Table 9 (continued): Hearing Loss and Diagnosis of Dementia

Citation	Study Question	Population	Materials	Findings	Problems
Weinstein & Amsel, 1986	1 – determine the prevalence of hearing impairment in dementia 2 – determine association of hearing loss to MSQ 3 – determine performance of MSQ amplified and unamplified	30 VA long term residents with diagnosis of dementia; control group of no diagnosis of dementia	MSQ without amplification and with auditory trainer to most comfortable loudness level of participant	1 – higher incidence of HL in dementia population 2 – those with poorer MSQ (more dementia) had higher PTA 3 – when amplified, the distribution of amount of HL equalized across MSQ score (not statistically significant) Able to reclassify 10/30 participants to less severe dementia	No power analysis as to why 30 participants; used those with diagnosis of dementia; did not take in consideration normal cognitive aging; used PTA for hearing loss

While there is some evidence that hearing loss correlates with diminished performance on verbally administered cognitive tests for dementia, it is unclear what component of the aging hearing loss may be the significant contributor to their findings. Most studies, such as previously discussed Uhlmann et al. (1989) and Weistein and Amsel (1986), focused on patients already diagnosed with dementia. Studies also were conducted in the clinic and were not controlled or blinded. Furthermore, the criteria for dementia diagnosis are unclear.

Hearing loss is often under diagnosed in the general population and this is even more evident in the population with memory impairment (Yueh et al., 2003). Neurologists and primary care doctors conduct unreliable hearing tests with a bedside type hearing test such as finger rub, whispered speech, watch tick, and the Rinne and Weber tuning fork tests or assessing their abilities when speaking to the patient. Patient self-identification of hearing loss is also unreliable, 1-51% correct (Boatman et al., 2007). Lack of accurate diagnosis and treatment of hearing loss may contribute to the misdiagnosis of people with dementia. Many of the symptoms of dementia and hearing loss are similar. Similarities between the symptoms of hearing loss and dementia are described in Table 10. Patients are often brought to their primary care doctor or neurologist with concerns of dementia by their caregivers, usually family.

Table 10: Similarities between Dementia & Untreated Hearing Loss (Jorgensen, et al 2012)

Dementia	Untreated Hearing loss
Social Isolation (Holmen, Ericsson, & Winblad, 2000)	Social Isolation (Weinstein & Ventry, 1982)
Decreased Comprehension (Pogacar & Williams, 1984)	Decreased Understanding/Discrimination (Dubno et al., 1984)
Repeating Questions (Nyatsanza et al., 2003)	Repeating Questions (Katz, 2002)
Short-term memory problem (E. Miller, 1973)	Working memory problem (Salthouse, 1996)
Stereotyped/inappropriate word use (Nyatsanza et al., 2003)	Stereotyped/inappropriate word use (Tesch-Romer, 1997)
Difficulty following conversation (Bozat, Gregory, Lambon Ralph, & Hodges, 2000)	Difficulty following conversation (Dalton et al., 2003)

The question remains as to whether hearing loss alone can make someone with normal cognitive function appear to be demented or make someone appear to have a more advanced stage of dementia then they truly have. Lopes, Magaldi, Gandara, Reis and Jacob-Filho (2007) investigated two groups of people who had mild cognitive impairment. These two groups performed similarly on tests of cognitive function. They questioned the participants about their cognitive status and two groups immerged – those that reported normal cognitive function and those that reported cognitive impairment. The authors assessed the hearing status of these two groups and determined that those that reported cognitive impairment had significantly worse hearing than those who reported normal cognitive function. These results put further into question the protocols used to diagnose dementia as they generally rely on self-report of cognitive impairment.

1.5.1 Possible Negative Consequences of Inaccurate Diagnosis

Implications of proper diagnosis are broad for both people with and without dementia. The diagnosis of dementia could affect the person's autonomy, independence and the way others view this person. It is also a question of disclosure of the diagnosis. It could lead to difficulty obtaining insurance or being accepted into assisted living facilities. Holroyd, Snustad and Chalifoux (1996) reported 79.5% of patients stated they would prefer to know of the diagnosis of Alzheimer Disease. That is significantly lower than the percent that would like to know if they had terminal cancer, which was 91.7%. Furthermore, 65.7% of people reported they would want their spouse to know of the diagnosis of dementia whereas 80.2% said they would want their family to know if they had cancer. There are several case studies that report incidents of suicide in patients newly diagnosed with Alzheimer Disease; however, the extent of this concern is unknown in the more general dementia population (Conwell & Caine, 1991; Rohde, Peskind, & Raskind, 1995). The implications of a false diagnosis are broad and, while speculative, could affect a person's lifestyle and have detrimental effects on the rest of their life and on their family.

1.6 SUMMARY

Dementia and hearing loss have very similar presentations in a clinical setting. Depending on the person that they present to, audiologist or geriatrician, the clinical course could be very different. It is of concern that someone who has an undiagnosed hearing loss could be diagnosed with dementia. While there are many different types of dementia, most physicians report using only the MMSE when diagnosing dementia; although the authors of the MMSE suggest not using solely this method for diagnosis.

Hearing loss has many different components in the aging population. The most important aspect of hearing is that the sound is audible although the sound then has to be coded effectively by the cochlea, an organ that is often damaged by sensorineural hearing loss. Additionally, the signal has to be processed by the central auditory system; which in aging adults may be compromised. Additionally, other factors, such as background noise, reverberation, access to visual cues and rate of speech can make speech more difficult to effectively decode for an aging adult.

In summary, there are several unanswered questions about the effects of the aging auditory system on verbally given tests for dementia like the MMSE.

(1) Does decreased audibility caused by hearing loss, such as presbycusis, have an effect on the intended auditory signal of the MMSE subsequently impacting the outcome of the assessment?

(2) Does cochlear pathology caused by sensorineural hearing loss, such as presbycusis, have an effect on the intended auditory signal of the MMSE subsequently impacting the outcome of the assessment?

(3) Do aging listeners have increased problem processing the MMSE due to changes in their auditory processing system subsequently impacting the outcome of the assessment?

(4) Does age related decline in the ability to process speech in difficult listening situations, such as speech in clinic and hospital-related noise, have an effect on the MMSE evaluation?

(5) Are there interactions of any/all of these factors?

Any or all of these processes in the auditory system, could affect the diagnosis of dementia as determined by an orally presented evaluation. As the auditory system compounds as it travels to the cortex, to effectively test these hypotheses, the initial step is to answer the question on the effect of audibility on a test such as the MMSE. Would lack of audibility make someone who is not demented appear demented or someone who is demented to appear to have more difficulties? The Speech Intelligibility Index is a model that could be used to demonstrate whether audibility impacts performance on the MMSE by being able to determine what proportion of poor performance on the MMSE is due strictly to audibility.

2.0 REARCH METHODS

2.1 RESEARCH PROBLEM AND OBJECTIVES

This study investigated whether audibility impacts the score obtained on an orally presented test such as the Mini-Mental State Exam (MMSE). As noted by Humes and Roberts (1990) audibility is the primary predictor in performance on spoken communication. The MMSE evaluation was presented at different levels of audibility, as calculated by the SII, to a group of participants. Based on the gaps in the literature and lack of our understanding of the impact of hearing loss on orally presented tests, the following research questions were addressed: Does audibility as represented by differing SII's influence performance on the MMSE? Further, does decreasing audibility produce significantly worse scores on the MMSE or is this evaluation immune to the impact of audibility?

H_0: Audibility does not have an impact on the orally presented MMSE.

H_1: Audibility does have an impact on the orally presented MMSE and furthermore incremental decreases in audibility will have a greater impact on the performance.

2.2 STUDY METHODS

2.2.1 General Research Design

This study used an across-group design. Participants were randomly assigned to one of five groups; participants were blinded as to group assigned. To protect from researcher bias, participant responses were recorded and scored by an independent, blinded researcher. These were compared to the primary researcher's transcriptions of responses. If there was disagreement between the first two reviewers, a third reviewer was elicited to review these responses and a consensus was reached between the three reviewers. Data were collected for each group and comparisons were made across groups.

2.2.2 Stimuli

2.2.2.1 MMSE Recording

The study sought to determine the impact of audibility on the score obtained on the MMSE while controlling other presentation variables. As discussed previously, there is not a uniform or directed method of administering the MMSE to patients. Therefore, an observation was conducted in a representative Internal Medicine Clinic to determine how physicians administer the test. Information was collected about how physicians speak when administering the evaluation and observations were made about the environmental conditions in which the evaluation is conducted. The factors that were observed and the methods for controlling these factors are described in Table 11.

Table 11: Factors for Consideration for Simulation of Real World Environment

Factor	Observation	Simulation Control	Justification/Citation
Hearing Loss	Physicians generally do not take hearing loss into account when assessing dementia	Simulating 4 hearing losses	These 5 hearing conditions will represent progressively decreasing audibility and thus progressively decreasing access to the acoustic information. (Humes & Roberts, 1990; Jorgensen, et al 2012)
Loudness Level	Loud conversational level	70 dB SPL	(Olsen, 1998)
Background noise	45-83 dB SPL A white noise from fan using sound level meter phone application measured at position of patient	45 dB RMS white noise (average per published research) using published spectral shaping combined with original stimuli	(Allaouchiche et al., 2002; Blomkvist et al., 2005; Busch-Vishniac, 2011; Falk & Woods, 1973; Hilton, 1985; McLaughlin et al., 1996)
Reverberation	The rooms were small and thus it is likely that the physician was within the critical distance	No reverberation will be added	(Crandell & Smaldino, 1994; Mijic & Masovic, 2010)

Table 11 (Continued): Factors for Consideration for Simulation of Real World Environment

Factor	Observation	Simulation Control	Justification/Citation
Rate of speech	Not as fast as conversational speech, not as slow as read speech – instructional rate	Recording of experienced physician giving/instructing on MMSE	This rate most closely simulates 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 will be given	Audibility only is the desired task to be evaluated. Additionally, want to err on the side of difficulty.

In an attempt to control for the manner in which the MMSE is administered, one recording was obtained and manipulated for this experiment. In geriatrics, more physicians are male than female, therefore in order to be most realistic, a male voice was used (Tu & O'Malley, 2007). As discussed before, physicians are very familiar with the MMSE and present it to their patients often. As observed clinically, the physicians do not speak as slowly as read speech or as quickly as conversational speech, it is more like instructional speech. A recording of a male physician giving the MMSE was used as the material for this test; this was obtained from online teaching recordings (Internet Archives, 2012). Conversational speech ranges between 160 and 200 words per minute while the speaking rate for read speech decreases by an average of 50-100 words per minute (Picheny et al., 1986). The recording of the physician’s speech was 123 words per minute. As loud normal conversation is 70 dB (Olsen, 1998) the stimuli were analyzed and RMS was increased to 70 dB SPL to simulate loud normal conversational level as was observed in clinical settings.

2.2.2.2 Simulation of hearing loss

Simulations of five hearing conditions were used in the study along with stimuli that were not modified and represented normal hearing. Together, these created five hearing conditions. The five hearing condition groups were as follows: 1) Normal hearing (NH) 2) mild to moderately-severe sloping hearing loss (MI-MS) 3) mild to severe sloping hearing loss (MI-S) 4) moderate to severe sloping hearing loss (MO-S) 5) severe to profound sloping hearing loss (S-P). Group 1 used the persons’ normal hearing sensitivity and no modifications were made to the recorded MMSE. Groups 2, 3, 4 and 5 were based on Cruikshanks et al. (1998) data and are described below.

Cruickshanks et al (1998) described hearing loss by age and reported in dB HL. They grouped their participants into 4 age categories: 48-59, 60-69, 70-79, 80-92 years of age. As discussed previously, people are not typically diagnosed with dementia until the age of 65. As half of the people in the study in the 60-69 group were under the age of 65, only 70-79 and 80-92 were considered. The two audiograms for ages 70-79 and 80-92 are not clinically or statistically significantly different. Cruikshanks et al (1998) also separated hearing loss by gender. As the hearing loss for males is worse than females, the average for males was the average used. It is of interest to use the "worst case scenario" to see if audibility has an impact on the MMSE evaluation. Therefore, the 80-92 year old male hearing loss was chosen as this group has more variability than the 70-79 group for mild to moderately-severe hearing loss (Group 2). One-half, one and two standard deviation decreases in threshold were used to create mild to severe simulated hearing loss (Group 3), moderate to severe simulated hearing loss (Group 4) and severe to profound simulated hearing loss (Group 5) groups, respectively. This led to four different hearing loss simulations. The hearing losses have been plotted below on an audiogram, rounded to the nearest 5 dB, (see Figure 7) and listed in the table below in dB HL (see Table 12) and dB SPL as converted using ANSI S3.6 (1996) (see Table 13).

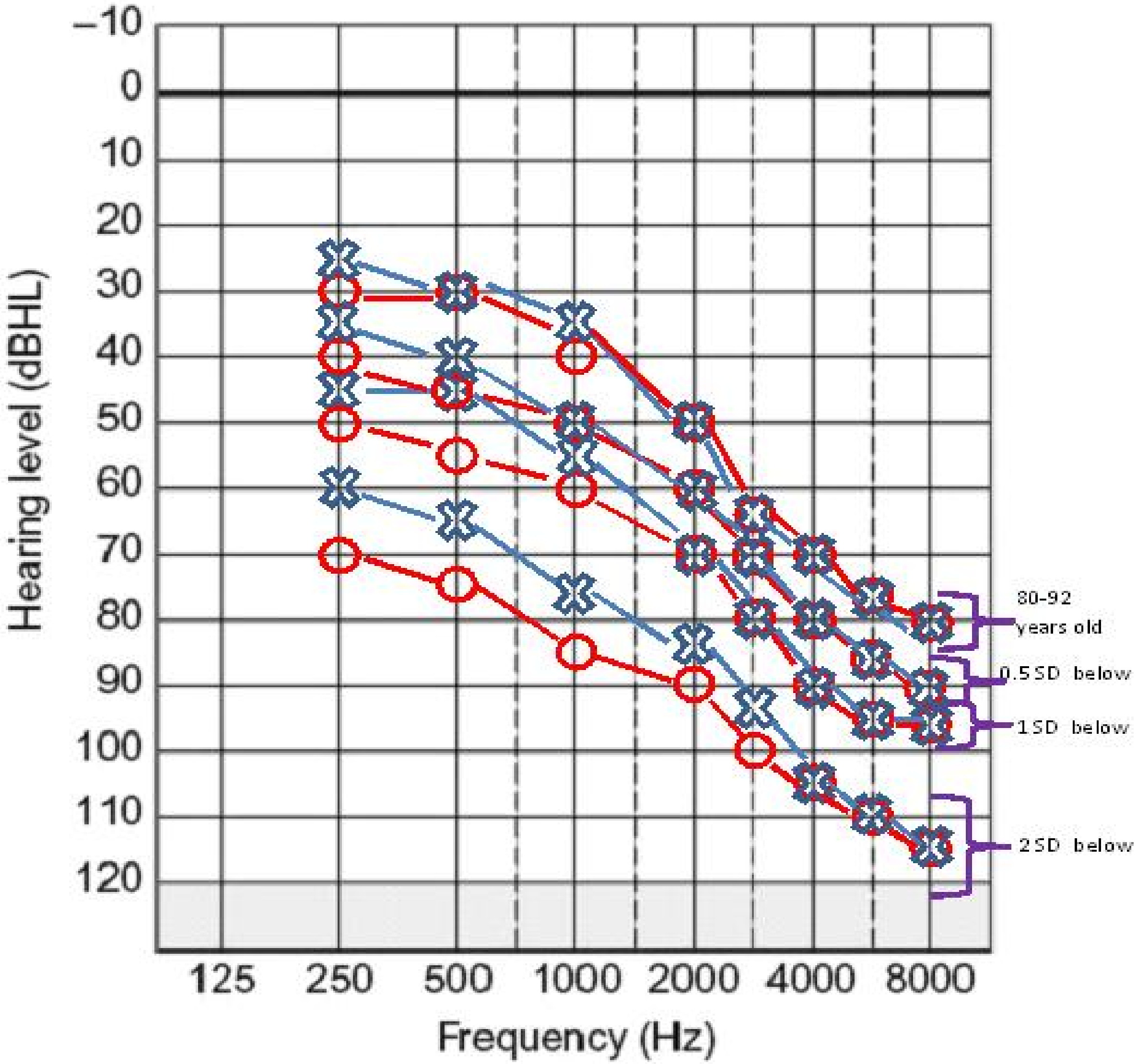


Figure 7: Simulated Hearing Losses

Table 12: Simulated Hearing Loss (dB HL)

		250 Hz	500 Hz	1000 Hz	2000 Hz	3000 Hz	4000 Hz	6000 Hz	8000 Hz
80-92	R	30.6	31.8	38.2	52.3	63.5	70.5	77	81.3
	L	27.4	27.8	34.8	50.4	63.4	71.3	77	79.7
0.5 SD	R	38.3	43.3	49.6	62.3	72.1	79.2	85.5	89.1
	L	35.8	41.3	47.9	61.3	72	77.6	85.5	88.3
1 SD	R	45.9	54.7	60.9	72.2	80.6	87.8	93.9	96.8
	L	44.2	45.9	54.3	68.1	79.8	88.1	94.3	95.2
2SD	R	71.2	77.6	83.6	92.1	97.7	105.1	110.8	112.3
	L	61	64	73.8	85.8	96.2	104.9	111.6	110.7

Table 13: Simulated Hearing Loss (dB SPL)

		250 Hz	500 Hz	1000 Hz	2000 Hz	3000 Hz	4000 Hz	6000 Hz	8000 Hz
80-92	R	65.1	45.3	45.7	61.3	75	82.5	93	96.8
	L	54.4	41.3	42.3	59.4	74.9	83.3	93	95.2
0.5 SD	R	65.3	56.8	57.1	71.3	83.6	91.2	101.5	104.6
	L	62.8	54.8	55.4	70.3	83.5	89.6	101.5	103.8
1 SD	R	72.9	68.2	68.4	81.2	92.1	99.8	109.9	112.3
	L	71.2	59.4	61.8	77.1	91.3	100.1	110.3	110.7
2SD	R	98.2	91.1	91.1	101.1	109.2	117.1	126.8	127.8
	L	88	77.5	81.3	94.8	107.7	116.9	127.6	126.2

Hearing losses were simulated using Adobe Audition 3 graphic equalizer (10 bands). Information below 250 Hz and above 8000 Hz was not manipulated. When listening in the soundfield, a person hears with their better hearing ear; therefore, the better threshold at each frequency was used to simulate hearing loss. Hearing losses (from audiogram dB HL) were converted for each frequency and ear in dB SPL (ANSI, 1996) and were subtracted from the sound file previously recorded using frequency specific attenuation. The use of frequency specific attenuation (filtering) was necessary as the impact of audibility was desired as well as the use of filtering allowed for the addition of white noise along with the MMSE recording. It should be noted that although the 80-92 age range hearing loss was used to simulate hearing loss, once the results were obtained, the impact of audibility can be generalized to all ages as it demonstrates the impact of audibility and has no association with age.

2.2.2.3 Simulated Noise

As discussed previously, white noise is common in the rooms where the MMSE is given. The range of noise in an examination room is 45 dB SPL to 68 dB SPL, with 45 dB SPL being most common. Previous research demonstrated the spectral shape of the noise in hospital rooms (Busch-Vishniac et al., 2005). Personal communication with the lead author allowed for acquisition of recorded values from this publication (see Table 14 and Figure 8). In the attempt to replicate the actual environment, white noise was spectrally shaped and RMS was adjusted to 45 dB SPL. This was then added to the original sound file prior to creation of the hearing loss. This is because the noise also would have been "heard" through the person's hearing loss.

A calibration tone was created at original stimuli RMS. This was to ensure that the original stimuli would have been at 70 dB SPL at the participant's ear.

Table 14: Room Sound Spectra

Frequency (Hz)	16	31.5	63	125	250	500	1000	2000	4000	8000	16000
Intensity (dB SPL)	57.44	57.58	54.07	51.76	46.03	43.34	39.02	36.08	29.11	23.65	19.57

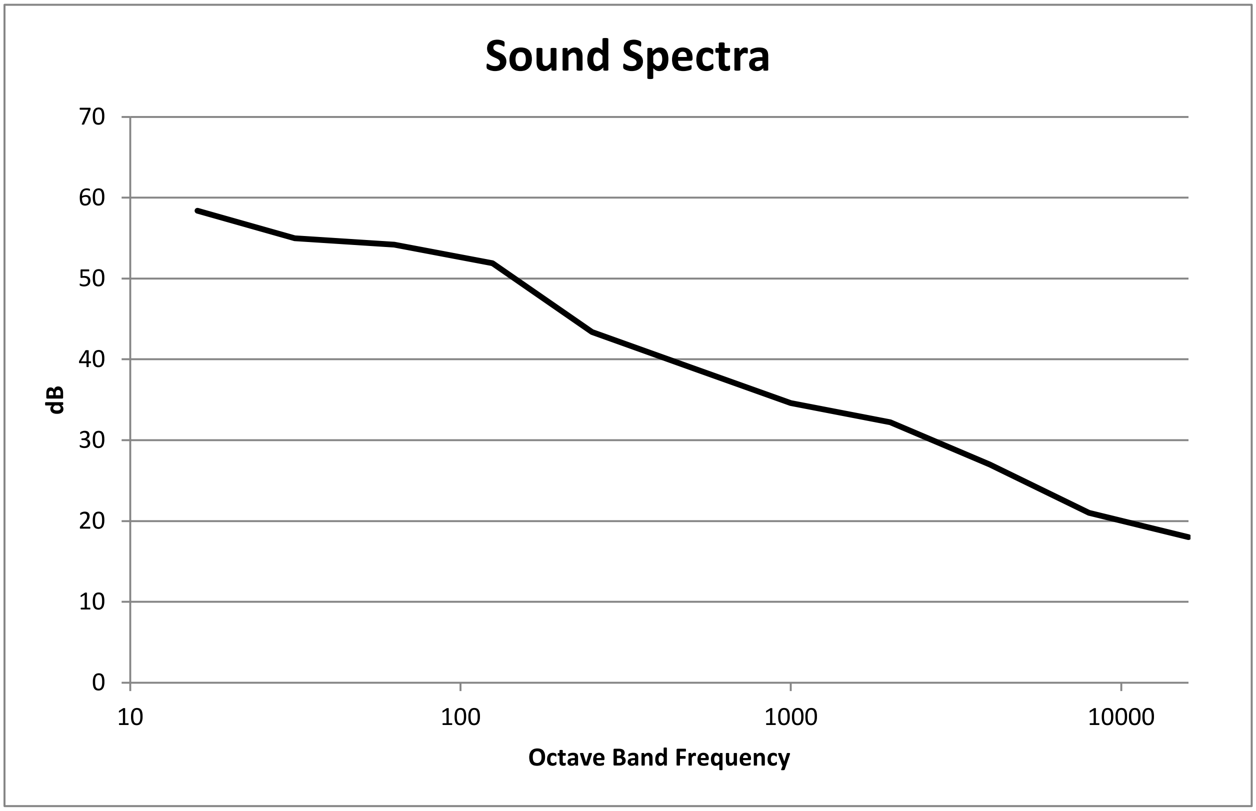


Figure 8: Room Sound Spectra

2.2.2.4 Stimuli Creation

MMSE Stimuli Creation

Using the methods described above, the MMSE recording at 70 dB SPL and the 45 dB SPL noise combination were attenuated. This created five (one unaltered and four altered) recordings of the MMSE. See Figure 9 for flowchart of stimuli creation.

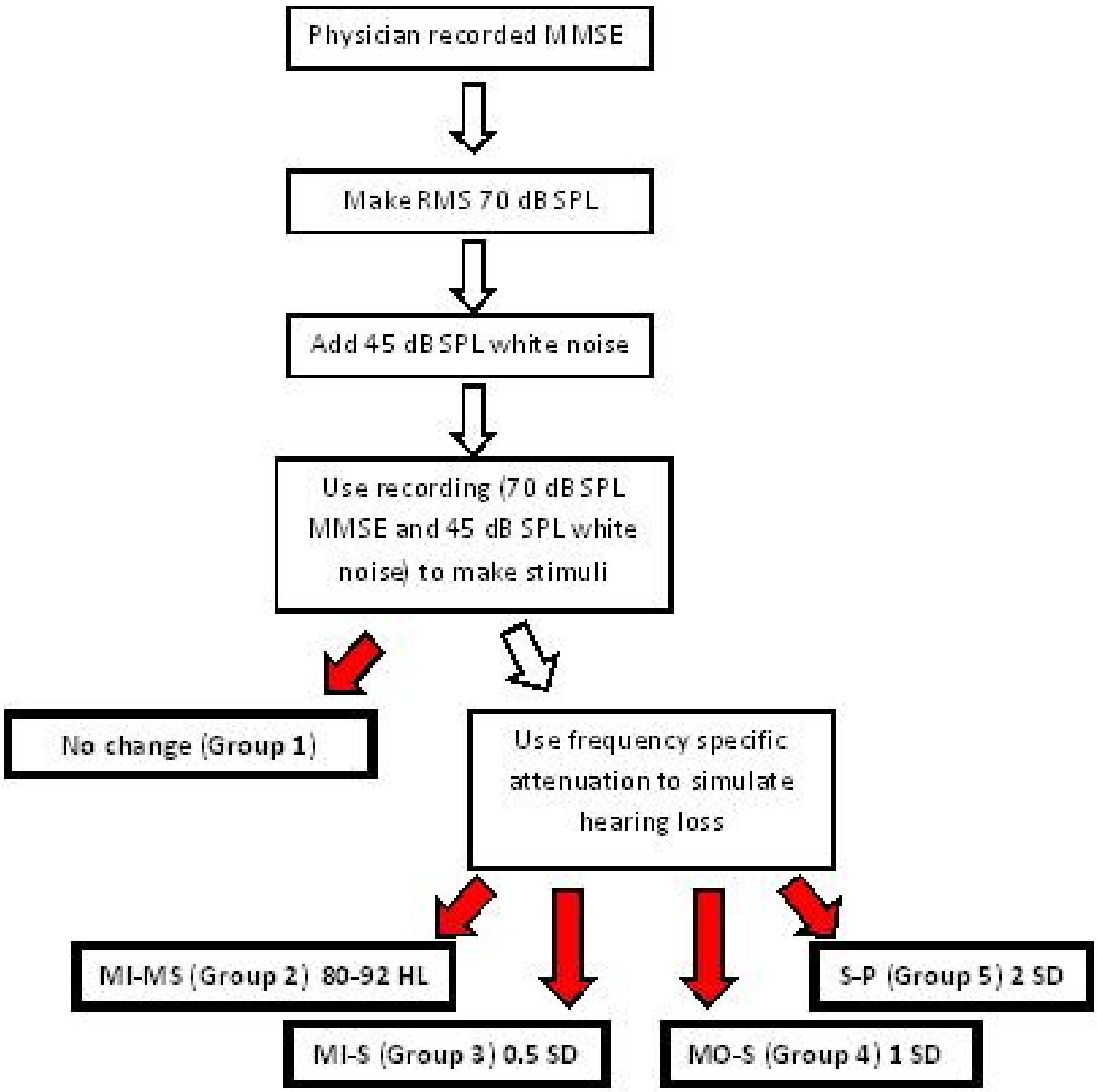


Figure 9: Flowchart of Stimuli Creation

Northwestern University Test Number 6 Stimuli Creation

Additionally, the *Northwestern University Word Recognition Test Number 6* (NU-6, Northwestern University; Tillman & Carhart, 1966) male voice 50-word lists were attenuated with the same four hearing losses listed above. The purpose of including the NU-6 recording was to ensure that the attenuation was impacting audibility and to replicate previously published data on the impact of audibility on these tests. The male speaker 50 words version of the NU-6 test was used. As the lists are phonetically balanced, two lists were chosen. This resulted in ten recordings of the NU-6 test – two 50 word lists for each of the five listening conditions. The NU-6 test was chosen because of its known sensitivity to changes in audibility and its wide clinical use. Using the same hearing condition group as the MMSE, one 50 word list was presented to each ear for each participant.

2.2.3 Participants

2.2.3.1 Power Analysis

Using G-power (Faul, Erdfelder, Lang, & Buchner, 2011), a power analysis was conducted to calculate the number of participants needed. The power analysis was based on one-way, fixed effects, omnibus ANOVA with a power of 0.80 and alpha of 0.05. As no previous studies were available where the MMSE was given to young normal hearing participants, an effect size was unknown. Therefore, a large effect size for an ANOVA was assumed (0.40, Cohen, 1988, 1992) as this would be most clinically significant. A total of 125 participants were needed with 25 participants in each of the 5 groups.

2.2.3.2 Inclusion criteria

In the attempt to control for audibility, cochlear pathology and central processing, this study included young adults with normal hearing. This was needed to control for factors (i.e., cochlear pathology and central processing and cognitive status) not being investigated in this study. Participants must have met all of the inclusion criteria to be considered a research study participant. The inclusion criteria are listed in Table 15.

Table 15: Participant Inclusion Criteria

Test	**Inclusion Criteria**
Age	18 – 39 years of age
Language	English as first language
Pure Tone Audiometry	Normal hearing sensitivity (thresholds less than 20 dB) No more than 10 dB difference between ears
Word Recognition Ability	Miss no more than 1 word of the 10 hardest words presented at 40 dB SL
Tympanometry	Ear canal volume: 0.8 – 2.1 cm^3 Peak Pressure: 0.2 – 1.8 mmhos
Random Dichotic Digits	Within 95% confidence interval – See table 15
Familiarity with MMSE	Not high knowledge of the MMSE

After obtaining informed consent, as approved by the University of Pittsburgh Institutional Review Board (IRB), participants were asked a series of case history questions and an inclusion screening followed to ensure eligibility. Please see Appendix B for the screening forms.

In order to remove the impact of aging central processing, young adult participant were recruited for this study; this included people aged 18 – 39. Several studies, (Humes & Christopherson, 1991; Humes & Roberts, 1990) have noted age-related changes in central processing for those over the age of 60. Koningsmark and Murphy (1974) noted anatomical changes in the central auditory system for participants over the age of 50. They further noted that as organ systems do not age uniformly within or across people, this study included participants younger than 40 to control for any aging effects on the central auditory system.

To control for the effects of cochlear pathology, participants had normal hearing. Normal hearing was defined as air conduction thresholds better than 20 dB HL at all audiometric octave frequencies (250, 500, 1000, 2000, 4000, 8000 Hz) (Katz, 2002). The NU-6 word recognition score screening was completed at 40 dB SL using the 10 hardest words procedure (Hurley & Sells, 2003). Participants were only included if they missed no more than 1 word of the 10 hardest words in each ear. This combination of testing ensured that cochlear pathology did not distort the signal presented to the participants.

Additionally, participants did not have evidence of middle ear disease as defined by normal tympanometry using 226 Hz probe tone. Normal tympanometry was defined as: Peak pressure (mmhos) 0.2-1.8 and ear canal volume (cm^3) 0.8-2.1 (Roup, Wiley, Safady, & Stoppenbach, 1998; Wiley et al., 1996). A screening tympanometer was used for this study.

Accurate central auditory processing was necessary to ensure that central effects did not impact the proposed study. Participants were assessed using the Randomized Dichotic Digits Test (Strouse & Wilson, 1999). Participants were presented a ½ list in the directed mode (Moncrieff, 2011) at 40 dB SL. To be included, participants were able to perform within normal limits for their age as described by Strouse and Wilson (1999). See Table 16 for normative values.

Table 16: Random Dichotic Digits Normative Values (Strouse & Wilson, 1999)

Age	Ear	One Pair	Two Pairs	Three Pairs
18-29	Right	99%	96%	87%
18-29	Left	99%	95%	87%
30-39	Right	96%	93%	82%
30-39	Left	93%	81%	70%

As the testing used the MMSE, it was imperative that the participants not have intimate knowledge of the test. In an attempt to control for this, a list of five cognitive tests were given to the participants for them to rate their familiarity with these tests (Appendix C). Four of these five were tests that are not in existence, only the MMSE was a real test. The purpose of this was to determine participant's familiarity with the MMSE without cueing them as to this being part of the examination. Participants that rated their familiarity with the MMSE as high familiarity were excluded from participation – none of the participants recruited were highly familiar with the MMSE.

Additionally, as understanding English is imperative to the understanding of the MMSE, only participants whose first language was English were included in this study.

2.2.4 Procedure

Once participants qualified for the study based on the previously described inclusion criteria, they were randomly assigned to one of the five hearing condition groups: no alteration (normal hearing – Group 1), mild to moderately-severe simulated hearing loss (Group 2), mild to severe simulated hearing loss (Group 3), moderate to severe simulated hearing loss (Group 4) and severe to profound simulated hearing loss (Group 5). Participants were not informed as to the hearing condition to which they were assigned – See Appendix E for instructions. Participants were seated in a single-walled sound treated booth at the University of Pittsburgh, Forbes Tower room 5057.

To ensure that the frequency specific attenuation impacted audibility and therefore speech perception, group specific NU-6 (Northwestern University) monosyllabic materials were presented to each participant via insert earphones (ER3). Participants were randomly assigned 1 list of 50 words presented into each ear. The recording states "say the word ___" and asks for repetition of the word. The results were recorded and percent correct was scored.

Listening condition specific MMSE recordings were routed through the single left speaker with the research participant facing the speaker at 0^{o} azimuth as if the person were facing the practitioner.

To ensure appropriate bandwidth, speaker response was measured using a pure tone sweep of 100-10100 Hz at a rate of 25 Hz per second. Dayton Audio ½ inch EMM-6 Measurement Microphone (omnidirectional, bandwidth 18Hz -20 kHz) was used to record the frequency response in the booth; equipment specific technical data can be viewed in Appendix D. The microphone was routed to a Marantz digital recorder with settings for a mono recording at a 44.1 kHz sampling rate and 16 bit depth. Results demonstrate that the speaker response was flat out to 9000 Hz which should ensure important speech sounds were not lost (see Figure 10). Additionally, as some of the MMSE instructions require visual cues, the researcher was seated in the test booth with the participant. The response of the test booth as well as the test booth with the researcher seated in the booth is in Figure 10; there was little impact to the acoustic response when the researcher was seated in the booth to the right of the speaker. See Figure 11 for a schematic of the set-up.

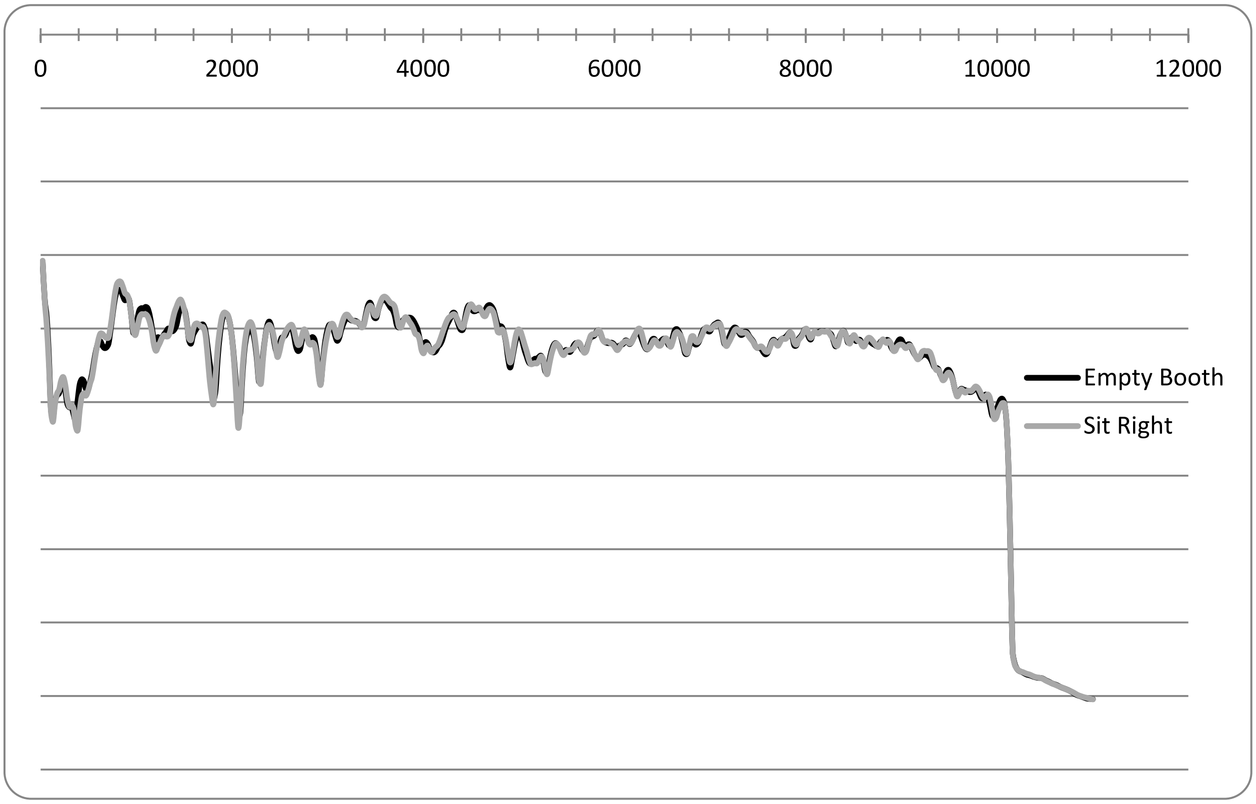


Figure 10: Booth Response

The black line represents the booth when the booth is empty. The grey line is when the researcher was seated the right of the speaker. Each vertical line represents 10 dB SPL.

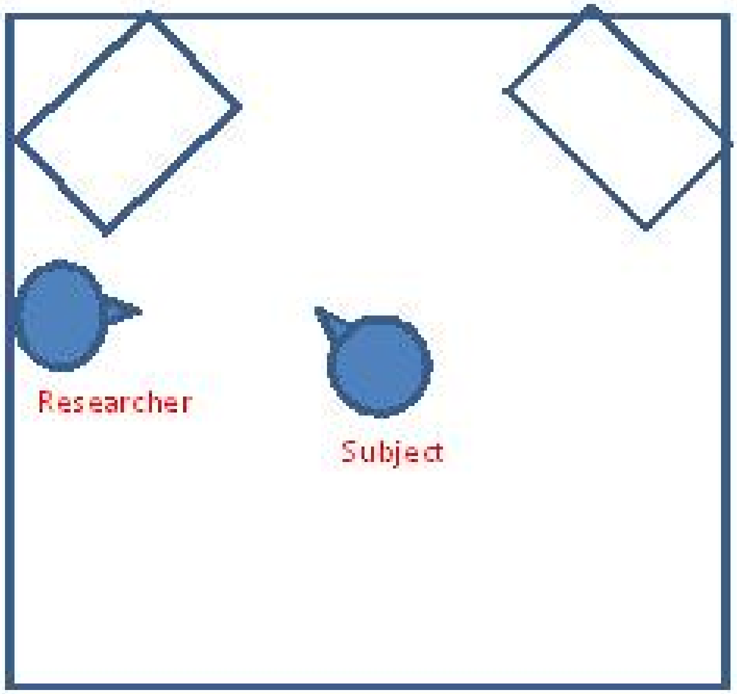


Figure 11: Schematic of Booth Set-up

With the participant facing the left speaker, a calibration tone was played to ensure that 70 dB SPL reached the participant's ear. This was measured using a hand-held sound level meter set to A weighting. Participants were instructed to keep their back against the chair so that they did not change the SPL at ear level.

The hearing condition group specific recorded MMSE was played via the speaker with the participant listening in the soundfield. Recordings were played only once and were not repeated as per instructions on the MMSE with the exception of the initial repetition of the three items asked in the Repetition Section (Folstein et al., 1975). Recordings were paused between each item to give participants adequate time to respond. Responses to the MMSE questions were recorded by the researcher.

To ensure accuracy and to protect for researcher bias, participant responses on the NU-6 and the MMSE were digitally recorded. These recordings were reviewed by a researcher blinded to the participant groups. The second researcher documented responses. The participant responses documented by both researchers were compared for accuracy. If any discrepancies existed, these recordings were reviewed by a third researcher and a consensus was reached as to the participant response.

2.3 SPEECH INTELLIGIBILITY INDEX CALCULATION

The Speech Intelligibility Index (SII) was calculated for each of the five hearing condition groups listed above (normal hearing – Group 1, mild to moderately-severe simulated hearing loss – Group 2, mild to severe simulated hearing loss – Group 3, moderate to severe simulated hearing loss – Group 4, and severe to profound simulated hearing loss – Group 5). As described previously, the SII can be calculated with 6 bands (octave bandwidth) to 21 bands (critical bandwidth). The 21 band method was selected for the most possible accuracy. The original sound files were analyzed using Adobe Audition 3 in order to input the sound energy for 70 dB SPL output at each of the critical bands. This information was then entered into the software available for calculating the SII from the Acoustical Society of America Workgroup S3-79 (2010). The hearing loss was then entered along with information about the background noise (45 dB SPL spectrally shaped white noise). Using this, the SII was calculated for each of the five hearing conditions. The SII calculation results in a number between 0.0 and 1.0. This resulted in four SII audibility scores (see Table 17). The group with no changes to audibility had an SII of close to 1.0; although it is nearly 100% audible, due the addition of the 45 dB SPL noise, some audibility was reduced. The other four hearing condition groups had a less audible signal and, therefore, received a significantly lower SII.

Table 17: SII Calculations by Group

Group	SII Calculation
Normal hearing (G1)	0.998
MI-MS (G2)	0.3868
MI-S (G3)	0.2351
MO-S (G4)	0.1088
S-P (G5)	0.022

Previous researchers have used the SII to determine speech intelligibility for syllables, words and sentences. These researchers suggest that for sentences, such as those presented in the SII, near 100% intelligibility is reached by an SII of 0.40 (see figure 12). This illustrates that the chosen levels of audibility as represented by the SII should result in different MMSE scores because they are known to result in different speech intelligibility scores in similar types of material. However, there are two distinct differences between the data presented here and those previously published data – (1) previous data used the same participants over and over to determine the impact of audibility whereas this study used five distinct groups at varying levels of audibility and (2) the previously published data are repetition tasks but the MMSE includes "answer the question" or "follow the instruction" tasks.

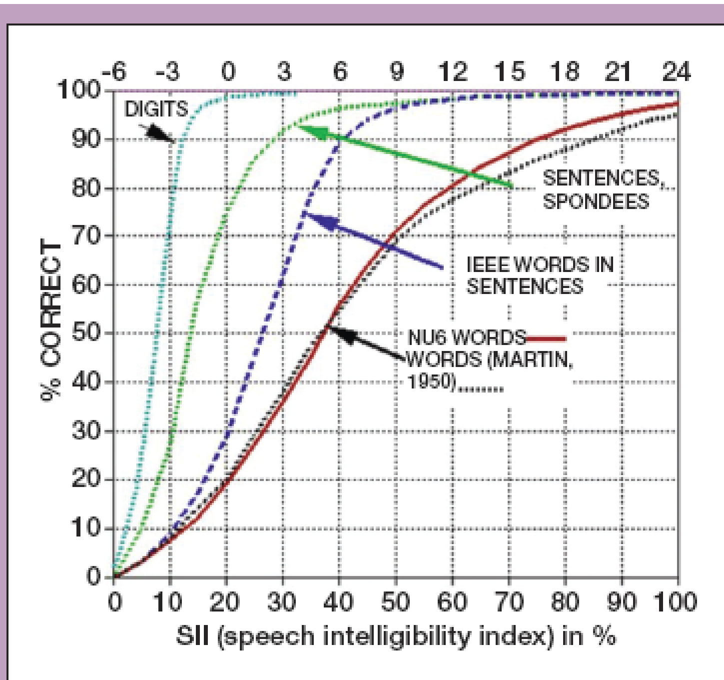


Figure 3. *Approximate relationship between AI or SII and intelligibility of digits, spondees, sentences, words in sentences, and isolated words. The Y-axis is predicted percent correct, the lower X-axis is the AI or SII percentage, and the upper X-axis is the signal-to-noise ratio (SNR), normalized by QuickSin 50% words correct at 2 dB SNR: adjusted to 50% correct IEEE words in sentences at 2 dB SNR re: four-talker babble.*

Figure 12: SII related to Speech Intelligibility for Different Stimuli (Killion, & Mueller, 2010) – reprinted with permission

3.0 RESULTS

3.1 STATISTICAL ANALYSIS

After all participant data were collected, the following analyses were conducted to evaluate the two research questions.

1) Does audibility as represented by differing SII's influence performance on the MMSE?

2) Further, does decreasing audibility produce significantly worse scores on the MMSE or is this evaluation immune to the impact of audibility?

An ANOVA was used to answer the initial question as to whether audibility impacts the MMSE. Post-hoc multiple t-tests were conducted to investigate significant differences. Each group was compared to each other (G1 to G2, G1 to G3, G1 to G4, G1 to G5, G2 to G3, G2 to G4, G2 to G5, G3 to G4, G3 to G5, and G4 to G5).

The ANOVA was calculated without use of the traditional correction of alpha. It may be of concern that by doing this there was an inflation of the Type I error rate and that a correction method, such as Bonferoni, should be used. This method without correction is justified in two ways. Each group is independent thereby reducing the error associated with multiple comparisons. Additionally, methods which hold the alpha constant for family wise comparisons are most often done to decrease the chance of a Type I error; however, by decreasing the Type I error rate, the Type II error rate is increased. It is necessary to look at which error, Type I or Type II, is more detrimental to determine if adjustment is necessary (see table 18).

Table 18: Type I and Type II error analysis

Error Type	What it means in this study
Type I error	Conclusion is that hearing loss **does** impact the diagnosis of dementia and therefore needs to be considered when the diagnosis is given; however hearing loss does not, in fact, impact the diagnosis.
Type II error	Conclusion is that hearing loss **does not** impact the diagnosis of dementia and therefore does not need to be considered; however hearing loss does, in fact, impact the diagnosis of dementia.

In the case of this study, a Type II error would be more detrimental. A Type I error would cause a physician to be more careful when they do not need to be. This would mean that they may check for hearing loss before diagnosing dementia; however, it does not have an impact on their diagnosis. This would not be detrimental to the care of people as having a hearing test should be part of their routine care. A Type II error would cause the physician to potentially ignore hearing loss when diagnosing dementia, when, in fact, they should consider it. This would be a much more serious error. Therefore, a correction was not made.

3.2 RESULTS

3.2.1 Descriptive

Average age of the participants was 18.83 (+/- 1.46) years of age. All participants had symmetrical normal hearing sensitivity across all frequencies as shown in Figure 13 with error bars to show 1 standard deviation.

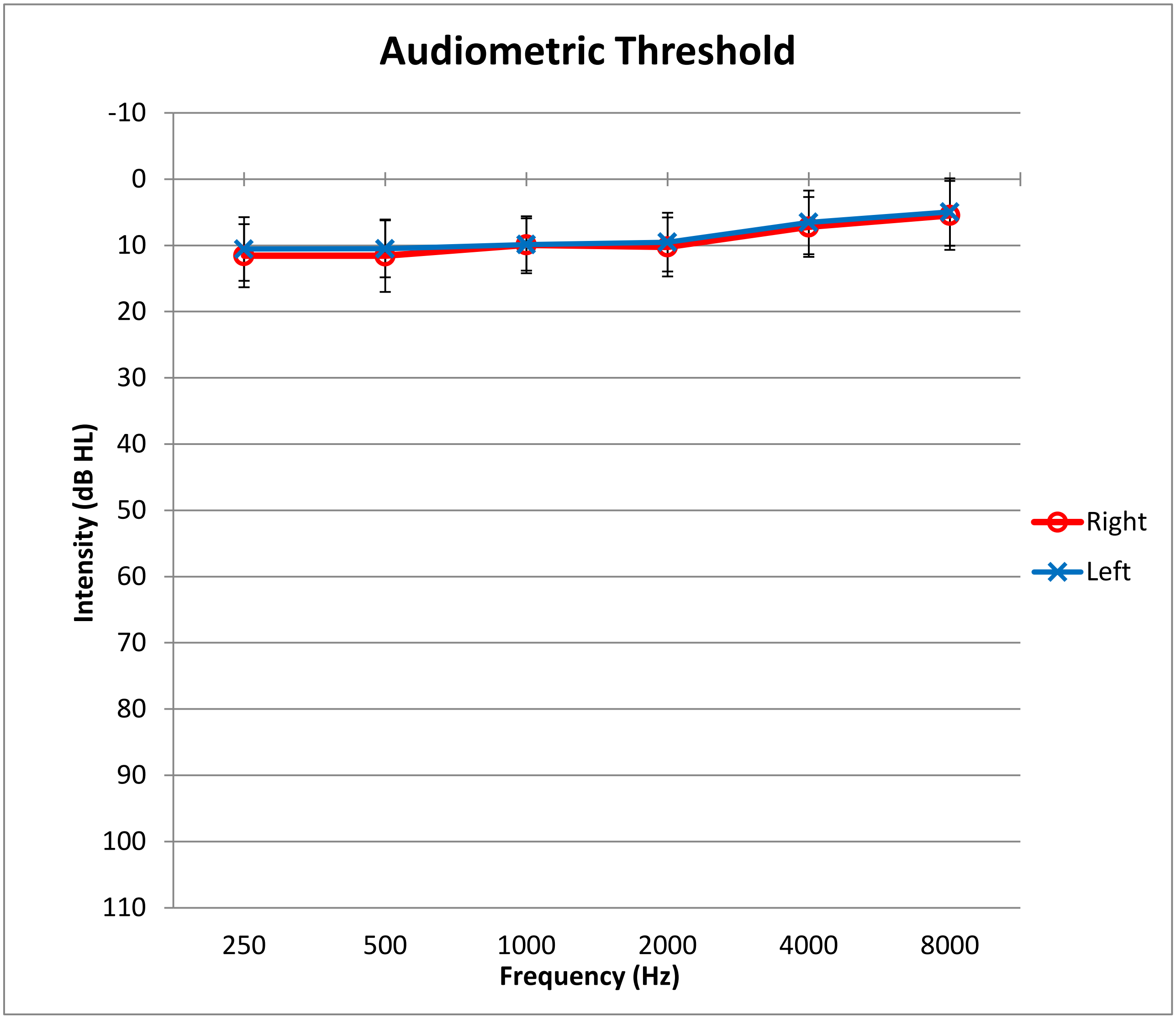


Figure 13: Participant Audiometric Data

3.2.2 Northwestern University Test 6 (NU-6)

The SII was calculated for each of the five hearing condition groups for the NU-6. As the stimuli are different than the MMSE, the SII numbers are slightly different. Comparisons were made for the NU-6 Scores by varying audibility. As expected, decreasing audibility significantly impacts the percent correct score – see Table 19 and Figure 14 for average data and one standard deviation. Although the right and left ear scores were statistically significant from each other in a pairwise comparison (*t=-3.506, df = 124, p = .001)*, they were not clinically significantly different for any participant (Thorton & Raffin, 1978).

Table 19: Impact of Audibility on NU-6

SII	Right ear	Right SD	Left ear	Left SD
0.988 (G1)	100%	1.2%	99%	2.1%
0.4262 (G2)	89%	7%	93%	3.8%
0.2735 (G3)	67%	13.1%	70%	12%
0.158 (G4)	33%	15.2%	39%	14%
0.022 (G5)	10%	6.3%	13%	7%

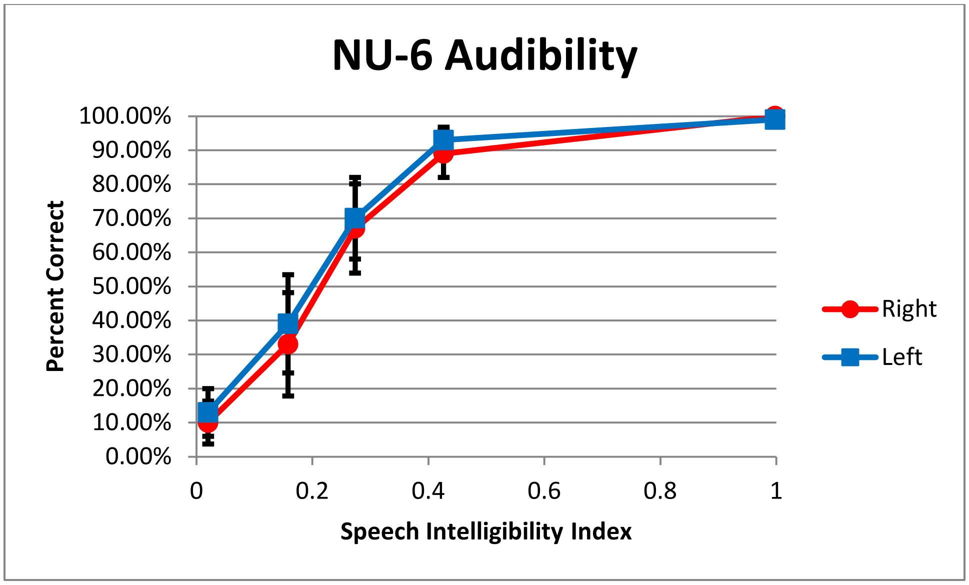


Figure 14: Impact of Audibility on NU-6

3.2.3 Mini Mental State Exam (MMSE) Total Score

An ANOVA revealed a significant difference between groups with respect to audibility on the total score of the MMSE – out of 30 possible points *($F = 19.0849$, $df = 4$, $p < .001$, $\eta^2 = .864$).* The mean and standard deviation for each group is in Table 20.

Table 20: MMSE performance by Audibility

SII (Audibility)	Mean	Standard Deviation
0.998	28.72	1.37
0.3868	27.64	2.885
0.2351	16.84	4.888
0.1088	10.36	5.715
0.022	4.20	2.843

Comparisons were made between each group and as described above, this was conducted without an alpha correction. Group 1 (normal hearing) and Group 2 (mild to moderately-severe simulated hearing loss) were not significantly different from each other, but all other groups were significantly different from one another as denoted by asterisk (*) in Table 21.

Table 21: MMSE Total Group Comparisons

Comparison	t	df	p
Group 1 vs. Group 2	1.691	48	.097
Group 1 vs. Group 3	11.702	48	< .001*
Group 1 vs. Group 4	15.622	48	< .001*
Group 1 vs. Group 5	38.847	48	< .001*
Group 2 vs. Group 3	9.514	48	< .001*
Group 2 vs. Group 4	13.497	48	< .001*
Group 2 vs. Group 5	28.935	48	< .001*
Group 3 vs. Group 4	4.309	48	< .001*
Group 3 vs. Group 5	11.177	48	< .001*
Group 4 vs. Group 5	4.825	48	< .001*

To visually demonstrate the impact of audibility (as represented by SII) and its predictive value on the MMSE a line graph was constructed to illustrate the data (see Figure 15).

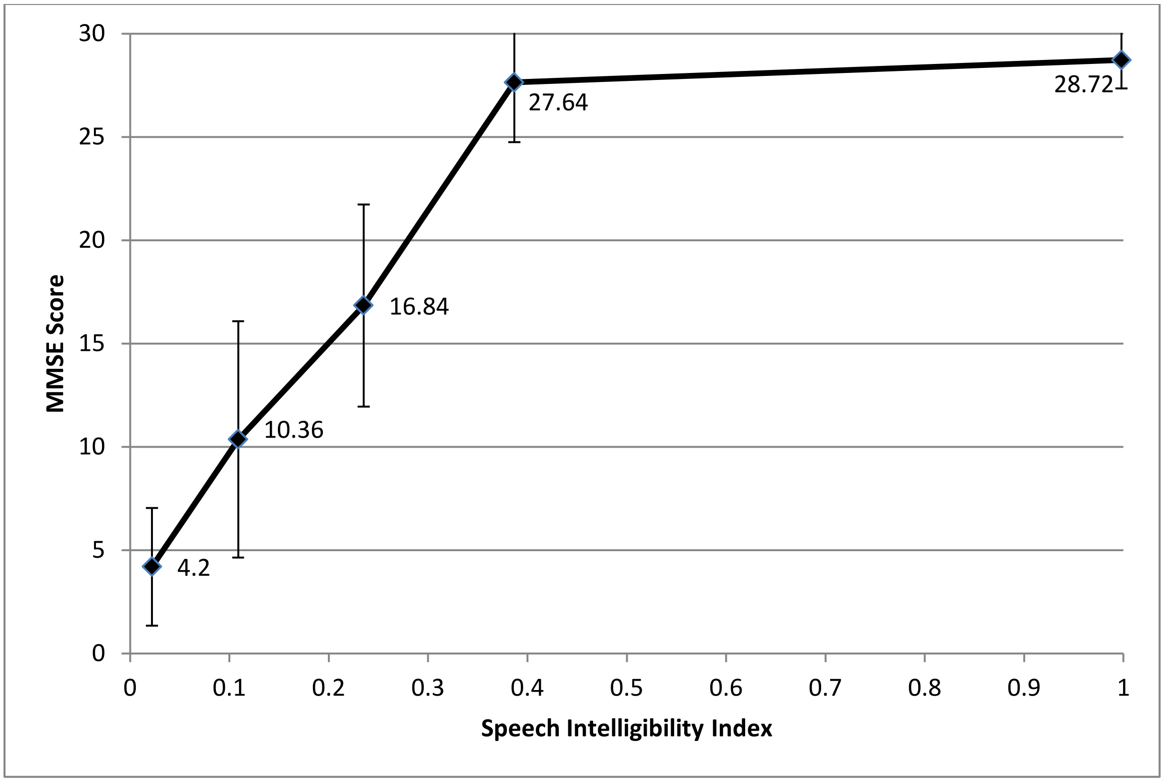


Figure 15: Impact of Audibility on Overall MMSE Score with standard deviation

A linear regression line can be used to predict points between the given data. It was determined that a linear regression line was appropriate for these data ($p < .001$ for line of best fit). After inspecting the data and using the regression analysis that provided the best prediction of the data ($r^2 = 0.806$), the linear regression line fit the most appropriately if Group 1 was removed. As Group 1 was not significantly different from Group 2, this was appropriate. This yielded a formula of $\hat{w} = 3.146 + 0.62537(\text{Audibility} - \text{SII})$, where 1 unit was equal to 1% SII. This was consistent with a 3 point decrease in MMSE score for every 5% decrease below 40% audibility or 0.4 on the SII. The plot of observed versus expected probability much more closely represented a linear function with Group 1 removed (See Figure 16).

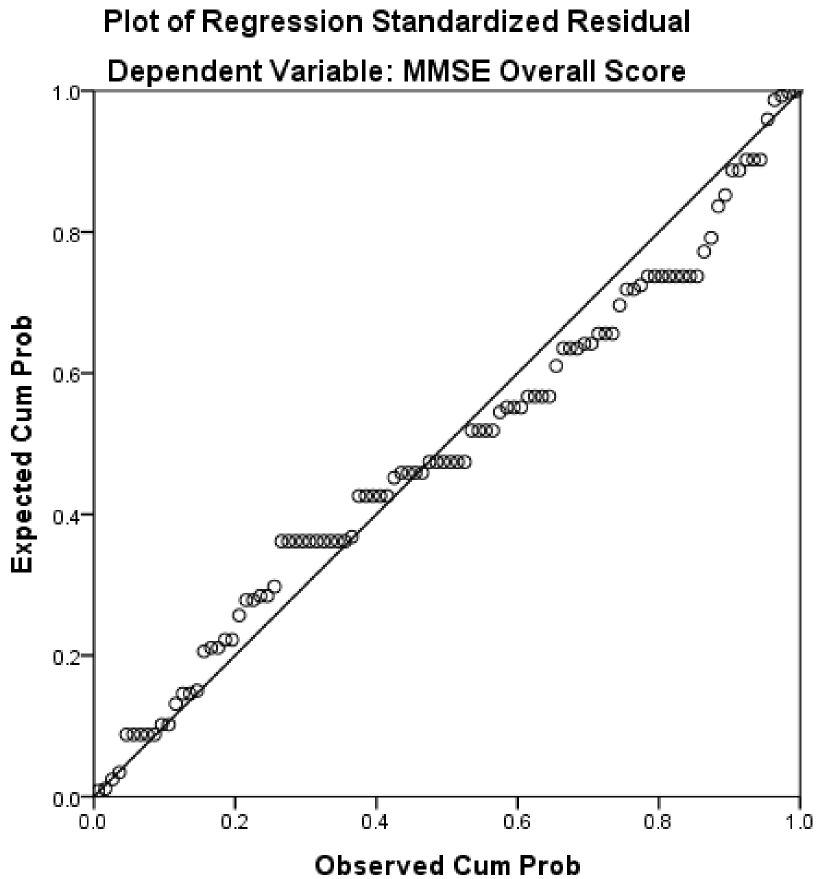


Figure 16: Observed vs. Expected Regression Plot

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, Anthony, Bassett, & Folstein, 1993); if a lower education level was used, the MMSE would need to be adjusted for age, however Crum et al (1993) found no significant difference across all ages with this level of education. See Table 22 for classification of dementia.

Table 22: Dementia Classification for Persons with College Experience or Higher

Dementia Classification	**MMSE Score**
Normal Cognitive Function	25-30
Mild Dementia	21-24
Moderate Dementia	10-20
Severe Dementia	0-9

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, severe dementia (Mungas, 1991). This directly demonstrates the impact of hearing loss on the cognitive status diagnosis. This information about the diagnosis of dementia was graphed on a bar graph for each participant group and shown in Figure 17.

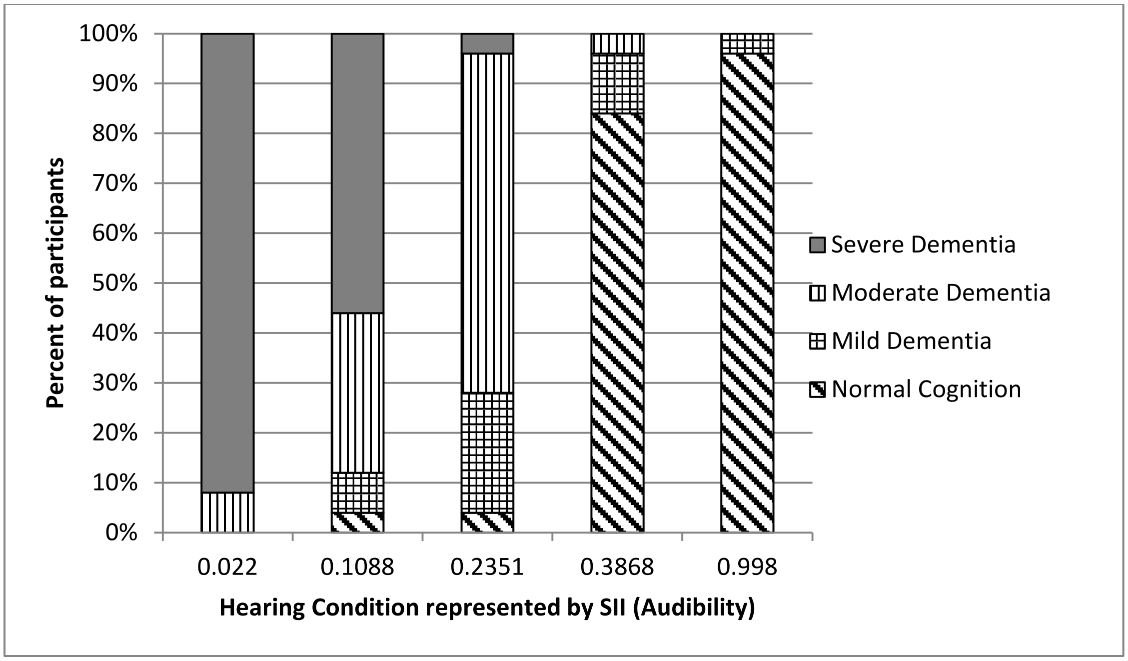


Figure 17: Diagnosis of Dementia Based on MMSE Score

3.3 ADDITIONAL ANALYSES

3.3.1 Item Analysis

Each group's data were compiled for each item on the MMSE to determine difficulty of each item. Item difficulty is a measure of the proportion of participants who have answered an item correctly and is most commonly referred to as the *p-value* (note: this is different from the p-value discussed in parametric statistics). Values are reported on a scale of 0% to 100%. P-values near 100% demonstrate that a greater proportion of participants within that group responded to the item correctly (easier items) and p-values near 0.0 demonstrate a greater proportion of participants responded to the item incorrectly (more difficult items). The items were then put into order by difficulty across all items – see Table 23.

Table 23: MMSE Items by Difficulty (Most Difficult to Easiest)

Rank	Item	Correct	Rank	Item	Correct
1	Tree (2nd)	32%	16	Dog (1st)	59.2%
2	Tree (1st)	33.6%	17/18	Month	60%
3/4	R	39.2%	17/18	Fold Paper	60%
3/4	O	39.2%	19/20	Day of Week	63.2%
5	L	43.2%	19/20	State	63.2%
6/7	D	44%	21	Write Sentence	68%
6/7	W	44%	22	City	68.8%
8	Baseball (2nd)	44.8%	23	Copy Picture	73.6%
9	County	45.6%	24	Repeat Phrase	76%
10	Dog (2nd)	46.4%	25	Season	76.8%
11	Floor (place)	47.2%	26	Year	77.6%
12	Hospital	51.2%	27	Take Paper	81.6%
13/14	Baseball (1st)	54.4%	28	Name Pencil	82.4%
13/14	Floor (action)	54.4%	29	Name Watch	84%
15	Date	56.8%	30	Close eyes (written)	84.8%

Item difficulty was determined for each item at each of the five audibility levels (Table 24). This was to determine the impact of audibility on each item. Items that are more resistant to hearing loss reach maximum performance with less audibility. These items were separated into 6 graphs by item difficulty – see Figures 18-23.

Table 24: MMSE Item Difficulty by Audibility (in same order as previous table)

	Item	0.022	0.1088	0.2351	0.3868	0.998
1	Tree (2nd)	0	8	8	60	84
2	Tree (1st)	0	8	4	68	100
3	R	0	4	16	84	100
4	O	0	4	16	84	100
5	L	0	4	20	92	100
6	D	0	4	20	96	88
7	W	0	4	20	96	92
8	Baseball (2nd)	0	12	36	84	92
9	County	0	20	60	76	72
10	Dog (2nd)	4	12	28	92	96
11	Floor (action)	4	24	44	100	100
12	Hospital	0	32	56	80	72
13	Baseball (1st)	4	24	56	88	88
14	Floor	0	20	20	96	100
15	Date	4	32	72	96	80
16	Dog (1st)	16	28	56	96	100
17	Month	0	32	68	100	100
18	Fold Paper	12	32	56	100	100
19	Day of the Week	0	44	76	100	96
20	State	4	48	68	100	96
21	Write Sentence	12	40	88	100	100
22	City	0	60	84	100	100
23	Copy Picture	20	68	80	100	100
24	Repeat Phrase	24	72	88	96	100
25	Season	16	72	96	100	100
26	Year	20	76	92	100	100
27	Take Paper	25	64	92	100	100
28	Pencil	76	60	88	88	100
29	Watch	76	64	92	92	96
30	Close eyes (written)	76	64	84	100	100

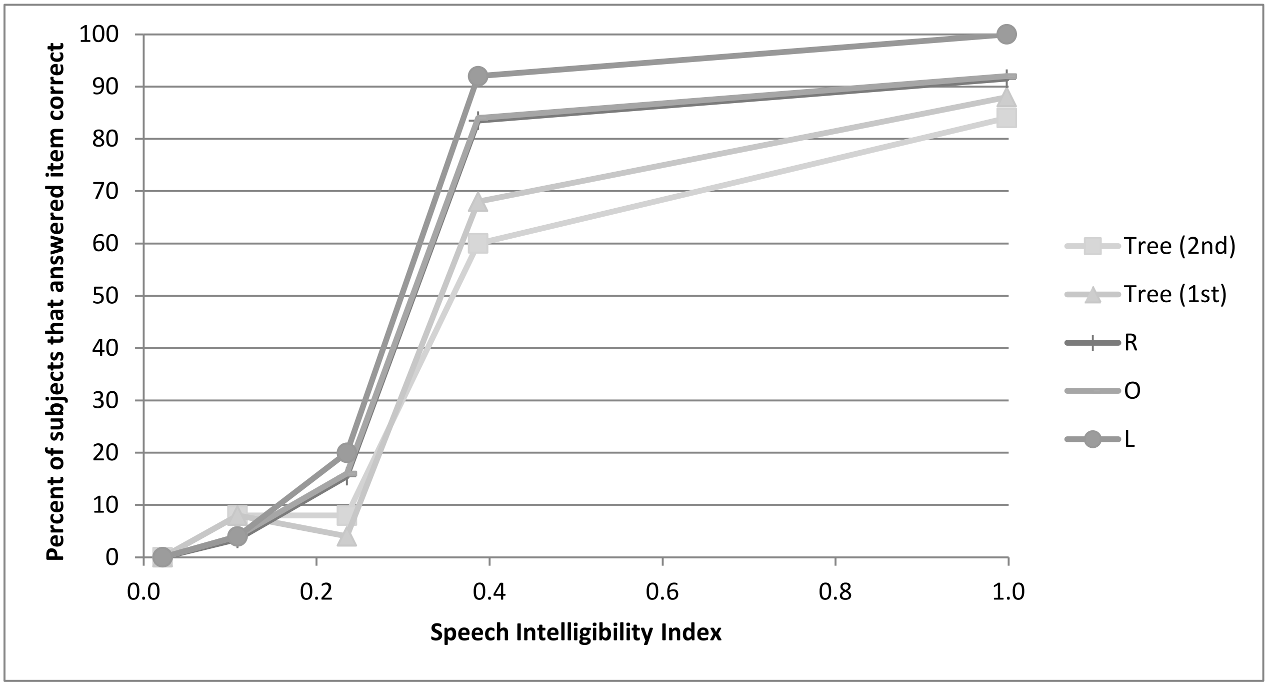


Figure 18: Item Difficulty 1-5

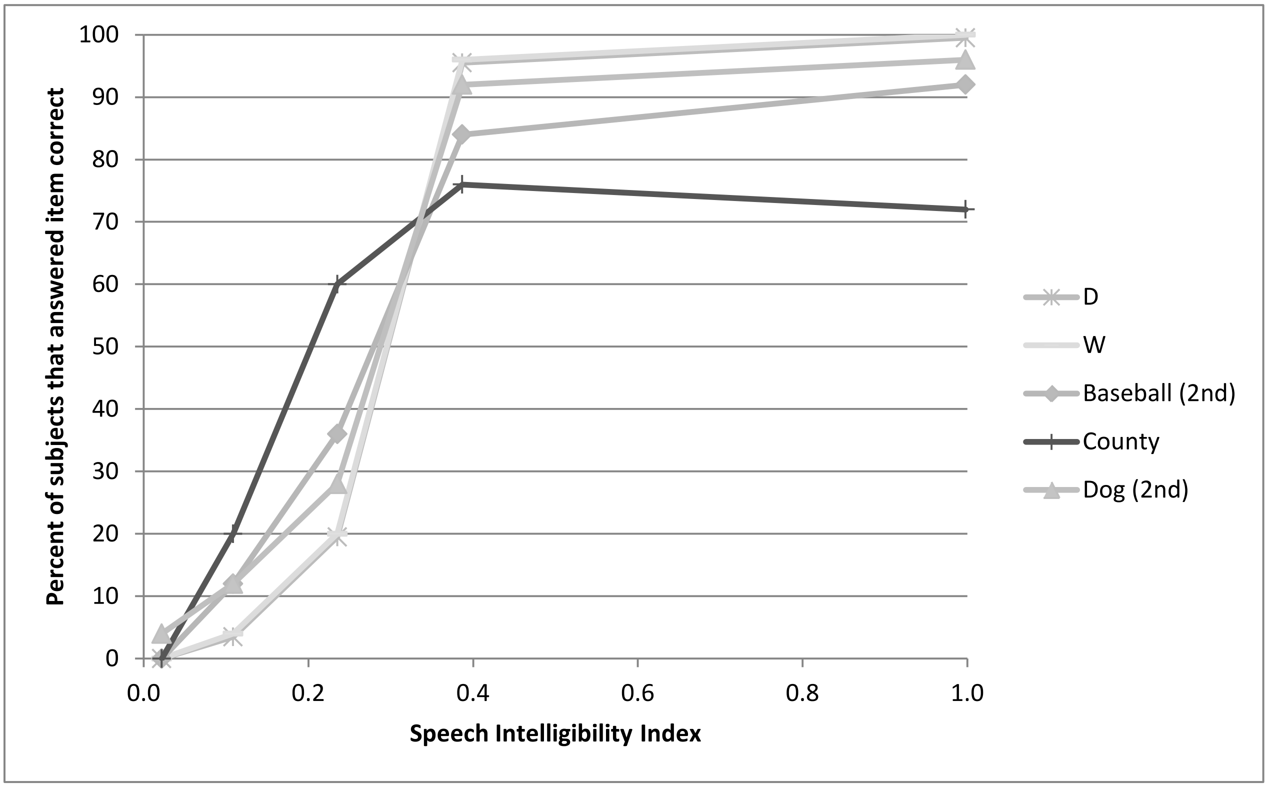


Figure 19: Item Difficulty 6-10

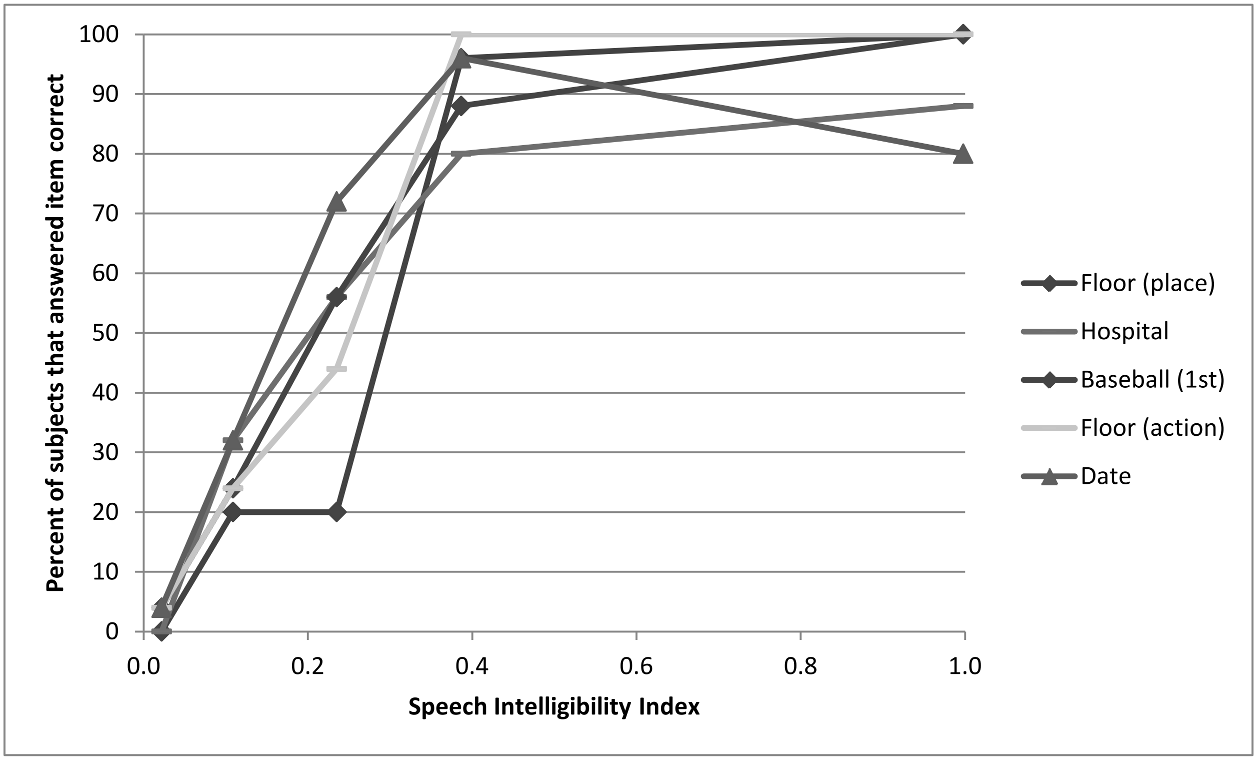


Figure 20: Item Difficulty 11-15

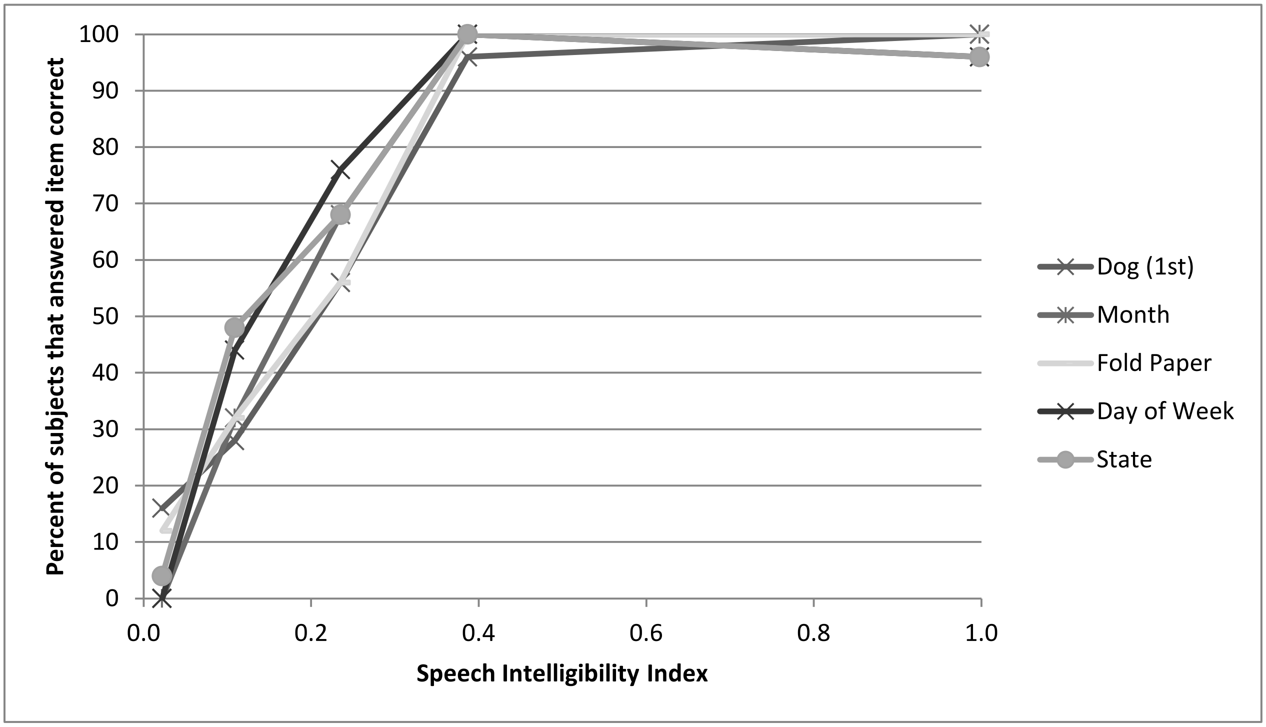


Figure 21: Item Difficulty 16-20

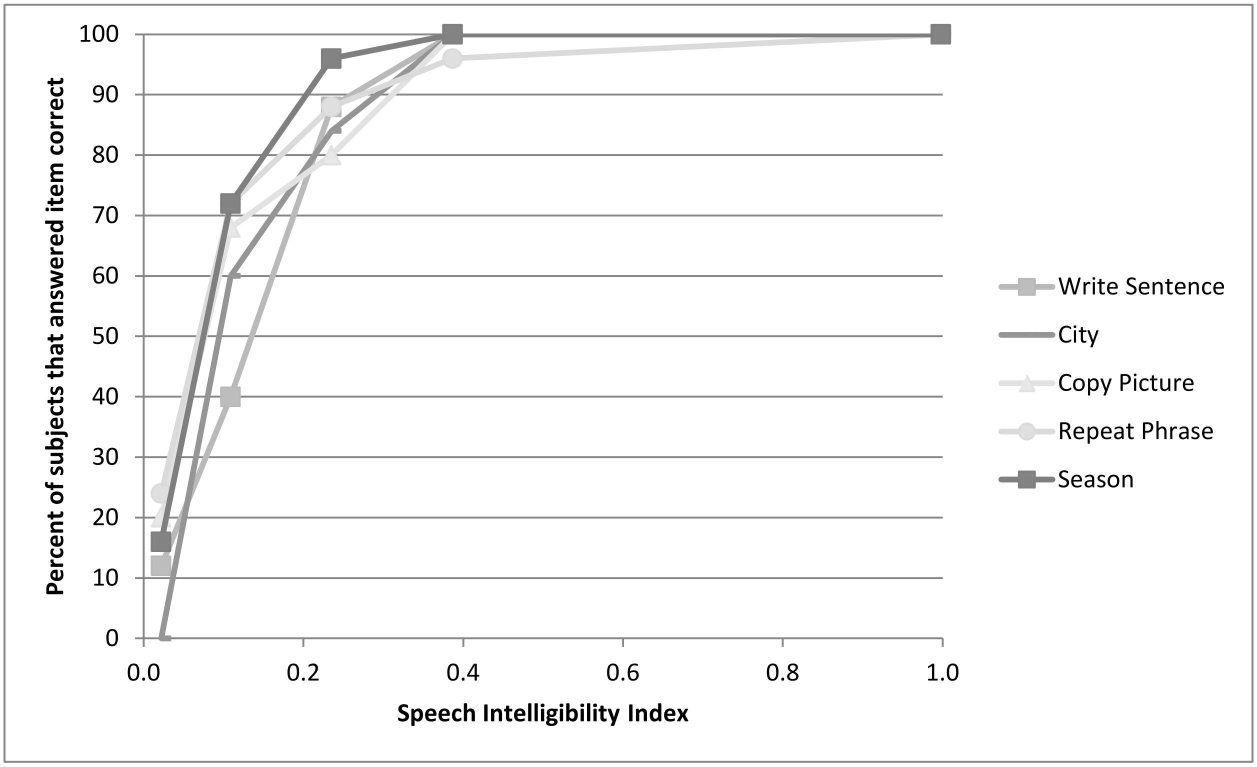


Figure 22: Item Difficulty 21-25

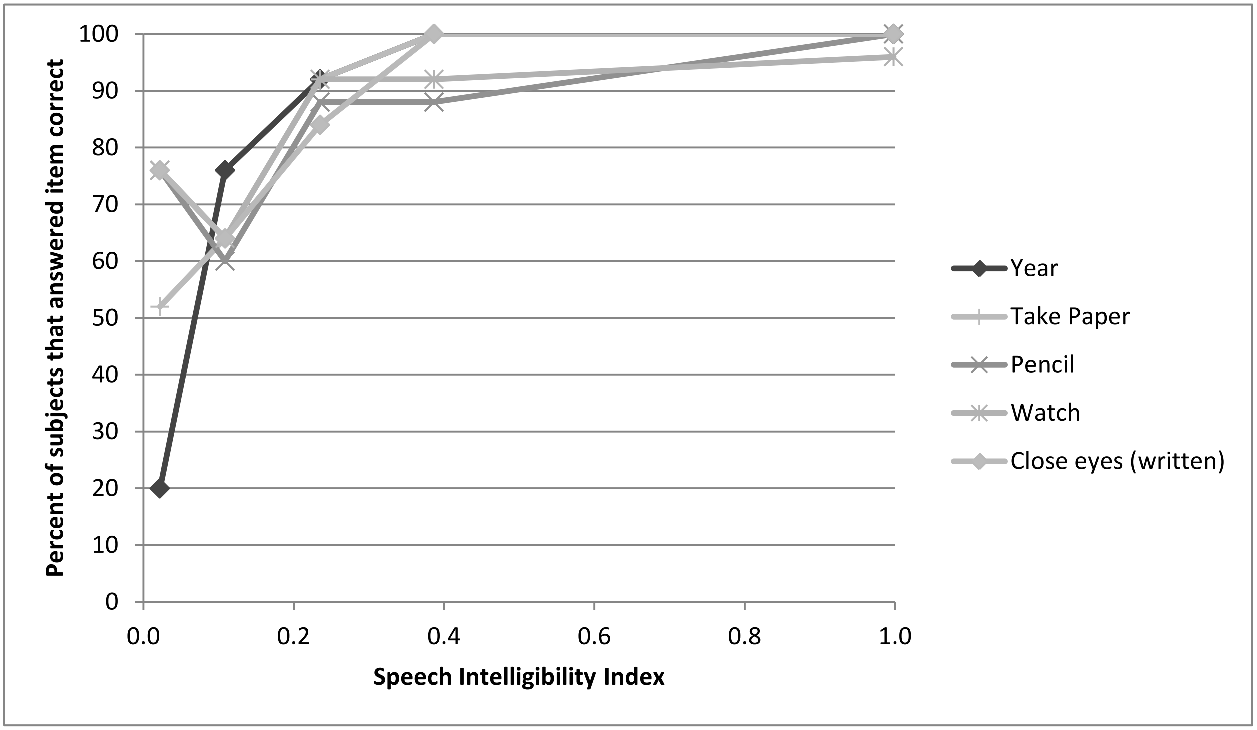


Figure 23: Item Difficulty 26-30

To determine which items were most impacted by audibility, the slope was calculated using linear regression between Group 2 (mild to moderately-severe simulated hearing loss – SII 0.3868) and Group 3 (mild to severe simulated hearing loss – SII 0.2351). This is because Group 3 was highly variable between the items and by Group 2 most items reach peak performance (see Table 25). The mean and standard deviation of the slopes were then calculated (mean: 2.3686, standard deviation: 1.691). Those numbers that are greater than one standard deviation above the mean are considered to be most impacted by audibility as those would be the most steeply sloping between Group 2 and Group 3; these items are denoted with an asterisk in Table 25.

Table 25: Item Analysis - Slope between Group 2 and 3 (steepest to least steep)

Rank	Item	Slope G2-G3
1	W	5.101*
2	Floor (place)	5.01*
3	D	5.01*
4	L	4.746*
5	R	4.483*
6	O	4.486*
7	Tree (1st)	4.219*
8	Dog (2nd)	4.291*
9	Floor (action)	3.391
10	Tree (2nd)	3.428
11	Baseball (2nd)	3.164
12	Fold Paper	2.9
13	Dog (1st)	2.637
14	Month	2.109
15	State	2.109
16	Baseball (1st)	2.109
17	Date	1.582
18	Day of the Week	1.582
19	Hospital	1.582
20	Draw Picture	1.318

Table 25 (continued): Item Analysis - Slope Between Group 2 and 3 (steepest to least steep)

21	County	1.055
22	City	1.055
23	Close Eyes (written)	1.055
24	Write Sentence	0.791
25	Year	0.527
26	Repeat Phrase	0.527
27	Take Paper	0.527
28	Season	0.264
29	Name Pencil	0
30	Name Watch	0

3.3.2 Comparison to Known Speech Intelligibility Data

Each participant's score was converted to percent correct using a linear conversion where the 30-point scale was converted to percent correct. It is assumed that percent correct is correlated with percent intelligibility; this statement is guarded, however, as it is not necessary to hear the entire sentence to be able to correctly answer the question/follow the command in the MMSE. However, as the participants were young normal hearing participants without dementia, it can be assumed if the items are intelligible they would have gotten the item correct. Using this, the data were superimposed onto previously known data about speech intelligibility by audibility. The data from this study are different from these data on two points: 1) these data are question/answer and the published data are repetition and 2) the data that comprises the lines in the published data are from the same participants at varying degrees of audibility while the current data are from five different groups with varying audibility between groups. However, this transform allows inferences to be made about the impact of audibility on the MMSE and to determine how similar the current data are to known/published data (See Figure 24).

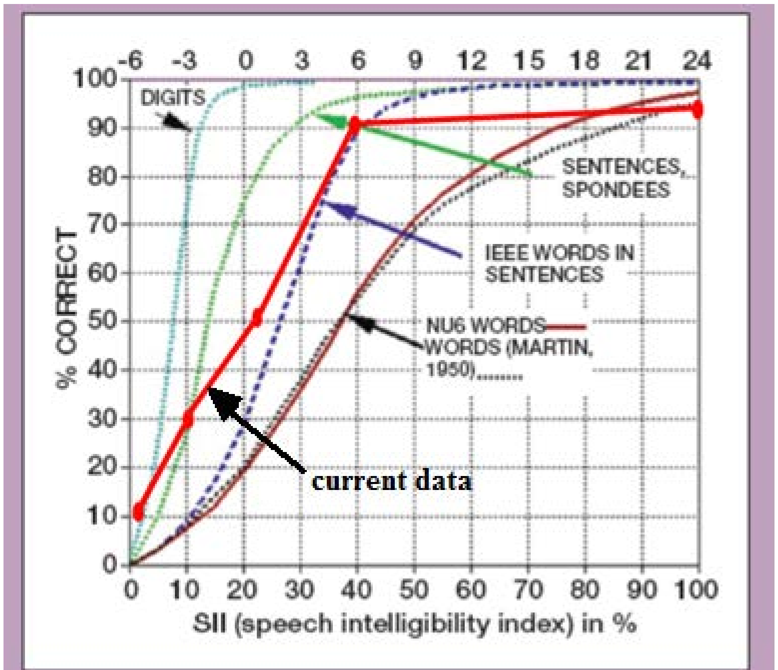


Figure 3. *Approximate relationship between AI or SII and intelligibility of digits, spondees, sentences, words in sentences, and isolated words. The Y-axis is predicted percent correct, the lower X-axis is the AI or SII percentage, and the upper X-axis is the signal-to-noise ratio (SNR), normalized by QuickSin 50% words correct at 2 dB SNR: adjusted to 50% correct IEEE words in sentences at 2 dB SNR re: four-talker babble.*

Figure 24: SII Related to Percent Intelligibility (adapted from Killion & Mueller, 2010)

4.0 DISCUSSION

This study sought to determine the impact of audibility on the diagnosis of dementia when the Mini Mental State Exam (MMSE) is used for diagnosis. As demonstrated previously, the MMSE is the most commonly used test to diagnose dementia. The results of this study suggest that audibility does impact the score obtained on this test and therefore could impact the diagnosis of dementia. Although the participants in this study were young normal hearing participants with normal cognitive status, based on their MMSE score, many of them would have been falsely diagnosed with dementia based on this test alone.

4.1 NORTHWESTERN UNIVERSITY TEST 6 (NU-6) SCORE

The replication of the NU-6 with impaired audibility fell in line with previously published data on the impact of audibility on the NU-6 words (Martin, 1950). This demonstrates that the simulated hearing losses did, in fact, impact audibility as expected. Additionally, in his dissertation, Ryan McCreery (2011) proposed a non-linear regression model to predict the impact of audibility on many different speech tests including the NU-6 word recognition test. His stated formula is $S = \left(1 - 10^{-SII/Q}\right)^{N}$ where S is the proportion of correct speech recognition scores; and Q and N are fitting constants that are defined in his dissertation by age. Using

McCreery's (2011) formula and data for adults, Q = .352 and N = -1.83, the predicted speech recognition scores were calculated. These were compared to the observed scores from this study (see Table 26). This illustrates that the simulated hearing conditions chosen impact audibility accurately and is consistent with previously published audibility research.

Table 26: NU-6 Predicted Score vs. Observed Score

SII	**Predicted based on McCreery (2011)**	**Observed (Right/Left)**
0.988	100%	100% / 99%
0.4262	88%	89% / 93%
0.2735	60%	67% / 70%
0.158	24%	33% / 39%
0.022	4%	10% / 13%

4.2 MINI MENTAL STATE EXAM (MMSE) TOTAL SCORE

The data presented for the impact of audibility on the MMSE overall score also agree with currently published data on the impact of audibility on speech perception tests as was shown in Figure 15. This test is different from the published data on three factors – 1) the published data use stimuli that are repetition tasks while this study used a comprehension task; 2) the published studies used the same participants for each of the groups of altered audibility while this study used different populations for each of the five data points; and 3) this test is comprised of 30 different points while published data are acoustically and linguistically similar items. While these differences are significant, the results are similar in the pattern of the impact of audibility which demonstrate that for a young normal hearing person, about 40% audibility is necessary for accurate speech perception. Below this 40% cut-off, top-down processing is necessary to accurately understand the stimuli; the amount of acoustically available information determines the slope of the curve. In this study, this is demonstrated by Groups 1 and 2 not being different from one another but that all other groups were different from one another forming a steep slope below 38% audibility. A steeper sloping transfer function and asymptote at a lower SII value is consistent with a person's ability to use linguistic and contextual information to fill in the missing or limited acoustic cues (Akeroyd, 2008; Lunner, 2003; Pavlovic, 1987; M. K. Pichora-Fuller & G. Singh, 2006). This means that the listener is able to fill in some, but not all, of the information using top-down processing. The more linguistic information provided, such as in sentences, the less acoustic information is needed as the adult listener uses their knowledge of linguistic structure and other information to parse the acoustic cues into meaningful utterances. In this study, the MMSE scores are consistent with with previously published data regarding steepness of the slope and decrement in performance below approximately 40% audibility (Killion & Mueller, 2010). This is consistent with the prediction that the participants were able to fill in some, but not all, of the missing information and the more information that was missing, the worse the overall score.

There are a significant number of older people with a mild to moderate hearing loss as described above and these mild to moderately-severe hearing losses are commonly overlooked without an audiologic evaluation (Corbin et al., 1984; Powers & Powers, 1978; Williamson et al., 1964). The results of this study suggest that 16% of participants with a mild to moderately-severe simulated hearing loss (Group 2) were misdiagnosed as having dementia. Below this level of audibility the rate of misdiagnosis of dementia only becomes higher and more concerning.

4.3 MMSE ITEM ANALYSIS

The MMSE overall score is comprised of different items to determine the overall score. The test items were plotted by percent of correct within each SII group (number of people who got the item correct divided by the 25 within each group). This resulted in functions which are able to be compared for the impact of audibility by item. Items such as labeling a watch and identifying the year are easier items as they reach high performance at lower audibility. Items such as repeating the word tree and naming the county are more difficult items. When comparing two functions, such as those in Figure 20, identifying the date is less impacted by audibility than putting the paper on the floor as it reaches maximum performance at a lower audibility. Those items that rely on visual stimuli, closing your eyes and naming watch/pencil, are the most resistant to hearing loss as they provide additional information beyond acoustic information. Using these results, physicians could identify if a hearing loss is masking as dementia if the MMSE score is lowered by a patient only missing those items most impacted by audibility.

Ranking of difficulty of items on the MMSE were compared to previously published data on item difficulty. Jones and Gallo (2002) analyzed items of the MMSE comparing the effects of age and sex on performance of the MMSE for those who were involved in the National Institute of Mental Health Epidemiologic Catchment Area study. This large multi-site study had 20,861 participants who were residential and community dwelling adults. For this study, Jones and Gallo selected the 8,556 participants who were over the age of 50 with complete reported data.

Table 27 is the rank order item difficulty as described in their publication as well as the current study ranking. An additional note to consider that they used the words apple, penny and table rather than baseball, tree and dog for the immediate and delayed word recall and they had the person put the paper on their lap rather than the floor so these items were marked as not applicable (N/A).

Table 27: Item-Level Ranking (Most Difficult to Easiest) - adapted from Jones & Gallo, 2002

Rank	Item	Current Study Rank	Rank	Item	Current Study Rank
1	Copy picture	23	16	Fold paper	17/18
2	R	3/4	17	Year	26
3	O	3/4	18	Season	25
4	L	5	19/20	County	9
5	D	6	19/20	Day of week	19/20
6	W	7	21	Year	26
7	Penny #2	N/A	22	Month	17/18
8	Table #2	N/A	23/24	State	19/20
9	No ifs, ands or buts	24	23/24	Table	N/A
10	Write sentence	21	25	Penny	N/A
11	Date	15	26	City	22
12	Take paper	27	27	Watch	29
13	Apple #2	N/A	28	Pencil	28
14	Lap (action)	N/A	29	Floor	13/14
15	Close Eyes (written)	30	30	Apple	N/A

The item analysis conducted in the Jones and Gallo study (Jones & Gallo, 2002) is similar to the analysis presented in this study. Currently, there are corrections for the MMSE for age and education, this suggests that similar items also are impacted by audibility and thus audibility should be considered in the scoring for this test or the test should not have be used with older adults most of which have a hearing loss.

4.4 POTENTIAL MIS-DIAGNOSIS OF DEMENTIA

In this study, participants were young adults with normal hearing. This was done to control for hearing loss and aging effects on the auditory system. Results from this study suggest that audibility impacts 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 use more top-down central processing to fill in the missing auditory information – information that the research study participants were not able to use. Adults who have experience with the language are able to fill in missing information using their linguistic knowledge. If they have had a hearing loss for a long time, they have more consistently used this skill to fill in the acoustic information they miss. Additionally, they may use visual cues to help with missing acoustic information; visual cues were not provided to the research participants.

The accuracy of tests of dementia is imperative to accurate diagnosis. This study demonstrates that the most commonly used test to diagnose dementia, the MMSE, is highly impacted by changes in audibility. This can significantly impact the diagnosis of dementia as many older patients have undiagnosed hearing loss. The data from this study support the need for identification and remediation of hearing loss prior to the evaluation of dementia.

4.5 FUTURE QUESTIONS

1. Does cochlear pathology impact the diagnosis of dementia beyond the impact of audibility?
2. Does central auditory processing associated with aging impact the diagnosis of dementia beyond the impact of audibility and cochlear pathology?
3. How does rate at which the test is presented impact the individual's score on the MMSE and subsequent diagnosis?
4. Do these findings hold true for other orally presented tests?

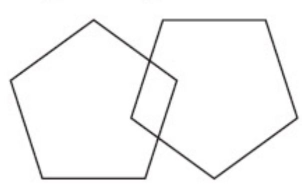
APPENDIX A

MMSE

The Mini-Mental State Exam

Patient________________________________ Examiner _________________________ Date___________

Maximum	Score	
		Orientation
5	( )	What is the (year) (season) (date) (day) (month)?
5	( )	Where are we (state) (country) (town) (hospital) (floor)?
		Registration
3	( )	Name 3 objects: 1 second to say each. Then ask the patient all 3 after you have said them. Give 1 point for each correct answer. Then repeat them until he/she learns all 3. Count trials and record. Trials ___________
		Attention and Calculation
5	( )	Serial 7's. 1 point for each correct answer. Stop after 5 answers. Alternatively spell "world" backward.
		Recall
3	( )	Ask for the 3 objects repeated above. Give 1 point for each correct answer.
		Language
2	( )	Name a pencil and watch.
1	( )	Repeat the following "No ifs, ands, or buts"
3	( )	Follow a 3-stage command: "Take a paper in your hand, fold it in half, and put it on the floor."
1	( )	Read and obey the following: CLOSE YOUR EYES
1	( )	Write a sentence.
1	( )	Copy the design shown.



_____ Total Score

ASSESS level of consciousness along a continuum ___________

Alert Drowsy Stupor Coma

APPENDIX B

DATA COLLECTION FORM

Participant Number: ___________________ Date: ____________

Case History

1.	What is your age?	_________	
2.	Do you have hearing loss?	Yes	No
3.	Do you feel one ear is better than the other?	Yes	No
4.	Within the past 3 months, any ear infections?	Yes	No
5.	Is English your first language?	Yes	No

Inclusion: 18-40, no hearing loss, no middle ear disease

Pure Tone (Air conduction)

	250	500	1000	2000	4000	8000
Right	___	___	____	____	____	____
Left	___	___	____	____	____	____

Inclusion Criteria: must be better than 20 dB in both ears, no more than 10 dB difference

NU-6 Testing – at 40 dB SL (10 hardest words)

Ear	Death	Knock	Laud	Puff	Keen	Burn	Take	Third	Met	Pool
__	___	___	____	___	____	___	____	___	___	____

Ear	Gin	Pike	Keg	Pick	Keep	Turn	Dab	Gaze	Learn	Ton
___	___	___	____	___	____	___	____	___	____	____

Inclusion Criteria: must not miss more than 1/10

Tympanometry

Right ear: Ear canal volume: ______ Peak Pressure: ______ Gradient: ______

Left ear: Ear canal volume: ______ Peak Pressure: ______ Gradient: ______

Inclusion criteria: Ear canal volume: 0.8 – 2.1 cm^3 Peak Pressure: 0.2 – 1.8 mmhos

Randomized Dichotic Digits at 40 dB SL: only give List 1 or List 2

List 1:

	One Pair		Two Pairs		Three Pairs		
#	L R	L R	L R	L R	L R	L R	**Response**
1			1,3	4,9			
2	8	6					
3	3	9					
4					6,1,3	5,10,2	
5					5,9,4	6,8,1	
6			2,8	10,3			
7	3	1					
8					2,6,1	5,10,8	
9					9,4,1	6,3,10	
10	4	1					
11			3,5	2,8			
12			1,3	6,5			
13					8,10,6	3,2,1	
14			6,1	5,10			
15	9	6					
16					1,9,4	3,2,5	
17			9,4	6,3			
18					6,9,8	4,5,10	
19			8,3	10,4			
20					9,4,6	3,2,5	
21	8	4					
22			9,1	10,2			
23			5,9	8,10			
24					1,5,8	10,9,6	
25	4	9					
26	9	2					
27	9	5					
	L R	L R	L R	L R	L R	L R	

List 2:

	One Pair		Two Pairs		Three Pairs		Response
	L R	L R	L R	L R	L R	L R	
28					8,2,1	5,10,9	
29			2,1	6,3			
30	4	8					
31	6	2					
32			2,5	8,3			
33					1,3,8	4,9,5	
34			10,2	1,9			
35	9	10					
36					3,1,9	6,5,10	
37	10	8					
38			5,2	10,3			
39					6,8,2	10,1,4	
40	9	3					
41			3,5	4,10			
42					10,6,8	3,4,9	
43	5	3					
44					1,9,3	2,6,5	
45			6,8	10,1			
46	6	9					
47	1	4					
48			10,2	5,1			
49					10,3,6	9,8,2	
50					8,1,5	6,9,2	
51			5,2	4,6			
52	8	1					
53			3,4	9,8			
54					2,10,1	3,9,6	
	L R	L R	L R	L R	L R	L R	

TOTALS	One Pair	Two Pairs	Three Pairs
Right Ear	________	________	________
Left Ear	________	________	________

Inclusion criteria: minimum of 95% confidence interval (Strouse & Wilson, 1999):

Age	Ear	One Pair	Two Pair	Three Pair
18-29:	Right	99%	96%	90%
	Left	99%	95%	87%
30-39:	Right	96%	93%	82%
	Left	93%	81%	70%

APPENDIX C

FAMILIARITY QUESTIONNAIRE

How familiar are you with the following Tests:

Arizona Test of Cognitive Status

Not Familiar Heard of it, but not able to describe Highly Familiar

Brief Exam of Mental Health

Not Familiar Heard of it, but not able to describe Highly Familiar

Mental Acuity and Dexterity

Not Familiar Heard of it, but not able to describe Highly Familiar

Mini Mental State Exam

Not Familiar Heard of it, but not able to describe Highly Familiar

Test of Cognitive Ability

Not Familiar Heard of it, but not able to describe Highly Familiar

APPENDIX D

MICROPHONE SPECIFICATIONS

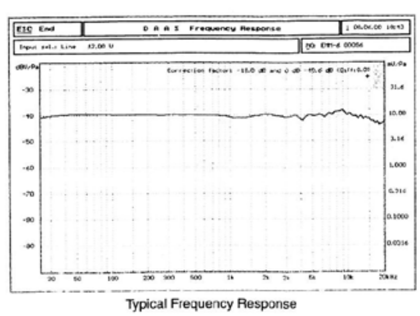
DAYTON® AUDIO

EMM-6 Measurement Microphone

- Precision condenser microphone for measurement and critical recording applications
- Perfect for use with room acoustic analyzers and audio measurement systems
- Extremely flat frequency response with very high resolution
- True omnidirectional pattern
- Works with phantom power from +15 V to +48 V
- Low noise FET input reduces low-frequency distortion
- Gold-plated XLR output connector for accurate signal transfer
- High-quality components and rugged construction
- Includes stand mount, foam windscreen, and transport case
- Each microphone includes its own unique calibration response graph
- Calibration data file unique to each microphone available via daytonaudio.com

Technical Specifications:

- Capsule type: 6 mm electret condenser
- Polar pattern: omnidirectional
- Frequency response: 18 Hz - 20 kHz
- Impedance: 200 ohms between pins 2 and 3
- Sensitivity at 1 KHz into 1K ohm: 10mV/Pa (-40dBV, re. 0dB = 1V/Pa)
- Max. SPL for 1% THD @ 1000Hz: 127dB
- S/N ratio: 70 dB A-weighted
- Connector: gold plated XLR
- Phantom power: +15 V to +48 V
- Weight: 144 grams



Typical Frequency Response

Download your calibration data text file at daytonaudio.com/emm6 (serial number required)

This calibration data is based on the On Axis (Ø) measurement

www.daytonaudio.com

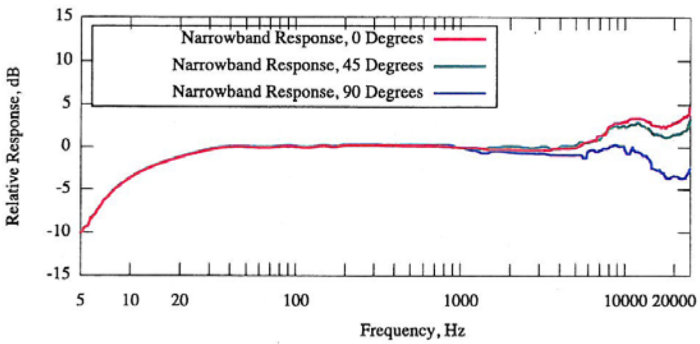
P.O. Box 52 • Springboro, OH • 45066-052 • Phone: (937) 743-8248

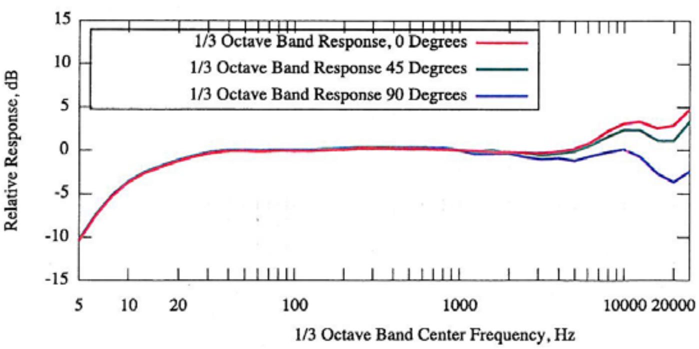
Cross·Spectrum Labs

Microphone Frequency Response Measurement Report

Microphone Manufacturer: Dayton Audio **Model Number:** EMM-6
Serial Number: 1181/CSL E404 **Phantom Power:** 48V

Measurement Date: January 22, 2010 **Temperature:** 67°F/19°C
Engineer: H. Singleton **Humidity:** 23%

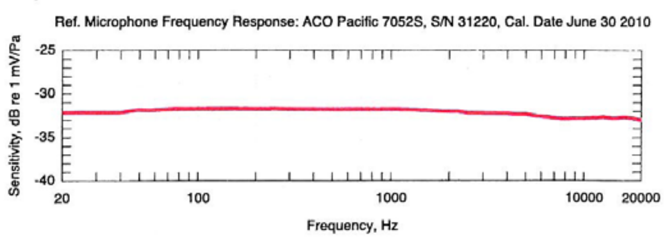




1/3 OB Results	
Freq.	Resp. (dB)
5	-10.40
6.3	-7.54
8	-5.27
10	-3.72
12.5	-2.64
16	-1.86
20	-1.24
25	-0.72
31.5	-0.30
40	-0.06
50	-0.05
63	-0.12
80	-0.03
100	-0.04
125	-0.06
160	0.04
200	0.10
250	0.23
315	0.23
400	0.21
500	0.18
630	0.16
800	0.11
1000	0.00
1250	-0.07
1600	-0.20
2000	-0.21
2500	-0.29
3150	-0.33
4000	-0.14
5000	0.16
6300	0.87
8000	2.23
10000	3.11
12500	3.35
16000	2.58
20000	2.89
25000	4.73

This frequency response measurement is not a NIST-traceable calibration.

Reference Microphone



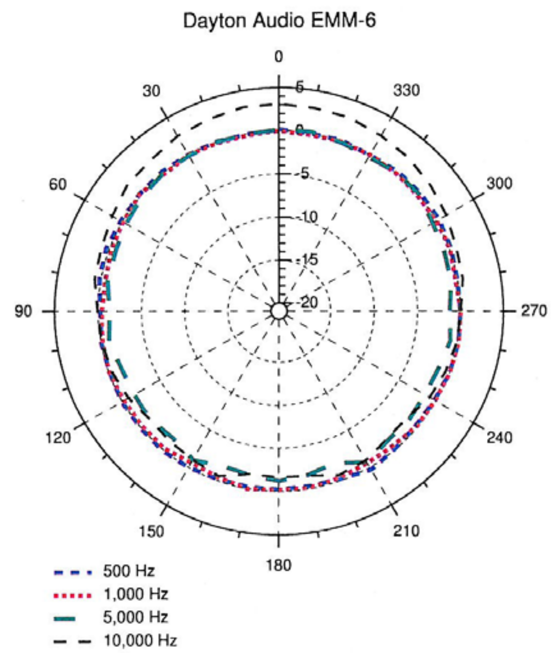
P. O. Box 90842 | Springfield, MA 01139 | Phone: (413) 747-2290/Fax: (413) 747-2295 | www.cross-spectrum.com

Cross·Spectrum Labs

Microphone Frequency Response Measurement Report

Supplemental Information

Microphone Manufacturer:	Dayton Audio	**Model Number:**	EMM-6
Serial Number:	1181/CSL E404	**Phantom Power:**	48V
Measurement Date:	January 22, 2010	**Temperature:**	67°F/19°C
Engineer:	H. Singleton	**Humidity:**	23%
Ref. Calibrator:	GenRad 1986		
Serial Number:	00242		
Microphone Sensitivity: (re 1000Hz, 94 dB)	-39.9 dB (10 mV/Pa)	**Noise Floor:**	32 dBA



APPENDIX E

PARTICIPANT INSTRUCTIONS

Tympanometry: You will feel some pressure going into and out of your ear. Please sit quietly for this test; it should not hurt.

Pure-tone Audiometry: You will hear a series of beeps, please raise your hand when you hear the beeps, even if they are very soft.

Word Recognition: You will now hear a woman talking. She will say something like “say the word boy” or “say the word match”. Please say the last word of each phrase.

Random Dichotic Digits: You will now hear a series of numbers. They will be different numbers into each ear. Please repeat back as many of the numbers as you can. Try to repeat all of the numbers.

Experimental Stimuli: (NU-6) You will now hear a man talking he will instruct you to say a word, please say the word that you hear. It may be difficult for you to hear the word, do the best you can. (MMSE) You will now hear a series of questions and instructions. They may be very difficult to hear. Please answer the questions or follow the instructions as best as you can. Please do not ask for repetitions, you may not get all the questions correct

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