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LING-6 SOUNDS AS A HEARING SCREENING TOOL

by

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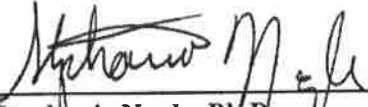
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THESIS APPROVAL PAGE


This is to certify that the thesis prepared by Kelly Burgdorf, B.A. entitled Ling-6 Sounds as a Hearing Screening Tool has been approved by the thesis committee as satisfactorily completing the thesis requirements for the degree, Doctor of Audiology (Au.D.).



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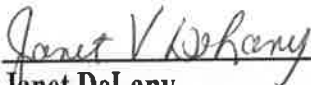
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Abstract

Ling-6 Sounds as a Hearing Screening Tool

Kelly Burgdorf

Despite its high prevalence, hearing loss often goes undetected amongst American adults. Undetected hearing loss can have several negative impacts on an individual's well being, including social withdrawal and depression. To combat the adverse effects of undetected hearing loss, a simple and effective screening measure must be developed. Many of the currently available hearing screeners are simple and cost effective, but are not very sensitive for detecting hearing loss. This is especially true for milder degrees of hearing loss. With its six speech sounds that span all of the speech frequencies, the Ling-6 Sound Test is a promising new method for screening hearing. The purpose of this study was to correlate the Ling-6 sounds to individuals' audiograms and examine its feasibility as a bedside hearing screener. Results of this study indicated that hearing loss has a negative effect on accuracy for repeating back Ling-6 sounds. A significant difference in scores for each Ling-6 sound was observed between the normal hearing participants and participants with hearing loss. A significant correlation existed between scores for each Ling-6 sound and puretone thresholds. Based on these findings, the Ling-6 Sound Test is a simple and accurate method for detecting hearing loss across the frequencies of speech.

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Chapter 1

Introduction

Hearing loss results from an insult or injury that occurs in the inner, middle, or outer portions of the ear. Of all chronic illnesses in the United States, hearing loss has the third highest prevalence in older adults (U.S. Department of Health and Human Services, 2008). Despite its high prevalence, hearing loss often goes undetected. The gradual onset of many hearing losses makes it difficult for a patient to identify and report their hearing symptoms to their physician. Formal hearing testing can more accurately identify hearing losses, but it is often a costly investment that involves expensive equipment and specially trained staff. Furthermore, many hospital-bound patients may not be well enough to travel to be formally tested.

Hearing loss that goes undetected can have several negative impacts. For instance, individuals with undetected hearing loss may experience difficulty in understanding speech. This inability to understand speech properly can lead to individuals becoming socially withdrawn, isolated, and depressed (Newman & Sandridge, 2004). In order combat these problems and identify hearing loss sooner, a simple and effective hearing screening measure must be developed.

There are very few guidelines for screening adult populations for hearing loss. The American Speech- Language, and Hearing Association (ASHA) recommends that adults be screened for hearing loss as needed, requested, or when their pre-existing health conditions or personal lifestyles placed them at risk for developing a hearing loss (American Speech-Language-Hearing Association, 1997). Current methods available for use as a hearing screener include: Calibrated Finger Rub Auditory Screening Test, tuning

fork tests, Hearing Handicap Inventory, Multimedia Hearing Handicap Inventory, and uHear (Chisolm & Abrams, 2008; Szudek et al., 2012; Torres-Russotto et al., 2009; Vento & Durrant, 2009). All of these methods are both simple and quick to administer, but they also lack either standardization or the validation to support their use. Furthermore, most screeners only identify more severe hearing losses, meaning those with lesser degrees of hearing loss could pass a hearing screen and have their hearing loss go completely undetected.

This study proposes that a new possibility for screening hearing in adult populations is the Ling-6 Sound Test (Ling, 1976). This test is a series of six phonemes (/m/, /i/, /a/, /u/, /j/, and /s/) that are spoken by a clinician at the level of normal conversational speech. These phonemes contain energy that spans the entire speech spectrum from 250 to 8000 Hz, allowing for a quick assessment of hearing sensitivity across the speech frequencies. The Ling-6 Sound test is currently being used with hearing aids and cochlear implants as a daily listening check to assess a child's ability to detect and discriminate between sounds that fall within the speech spectrum.

In summary, hearing loss has a very high prevalence amongst adults, and unidentified hearing losses have been shown to adversely affect an individual's health (e.g., Newman & Sandridge, 2004; Strawbridge, Wallhagen, Shema, & Kaplan, 2000). The first step to effectively combat the ill effects of a hearing loss is to identify that it exists. One of the easiest ways to do so is with a hearing screening. The Ling-6 test is also easy to both learn and execute, making it an ideal hearing screener for adults. Its six phonemes make it feasible to screen hearing sensitivity across the entire speech spectrum

in a matter of minutes. The current study correlates the Ling-6 sounds to individuals' audiograms and examines its feasibility as a bedside hearing screener.

Chapter 2

Literature Review

Hearing loss results from pathologies that occur along the auditory pathway. Most often these pathologies occur within the inner ear, although pathologies of the outer and middle ear can also cause a hearing loss (Agrawal, Platz, & Niparko, 2008). According to audiological testing performed on a representative sample of the United States population, approximately one in five people over the age of twelve has a hearing loss (Lin, Thorpe, Gordan-Salant, & Ferrucci, 2011). Between 2003 and 2004, 16.1% of U.S. adults aged 20 to 69 years (29 million Americans) had a bilateral hearing loss within the speech frequencies (Agrawal et al., 2008). Thirty-one percent (approximately 55 million Americans) had a high frequency hearing loss (Agrawal et al., 2008). According to the U.S. Preventative Task Force, the current population based estimates place the prevalence of hearing loss somewhere between 20% and 40% in adults older than 50 years. In adults older than eighty, the prevalence increases to 80% or more (U.S. Preventative Services Task Force, 2012). Of all chronic illnesses, hearing loss has the third highest prevalence in older Americans (U.S. Department of Health and Human Services, 2008).

Although hearing loss has an increasingly high prevalence amongst adults, it is often unidentified. It is common practice in a primary care setting to have patients fill out questionnaires that identify the symptoms they are experiencing. These questionnaires, however, rely on the patient to be able to identify whether or not they have a problem (Kerr, McCullagh, Savik, & Dvorak, 2003). As most hearing losses have a gradual onset, many individuals may not identify or report their hearing related

symptoms to their primary care physician. A more accurate method for identifying hearing loss is formal audiologic testing. Formal testing, however, requires a sound-treated booth, expensive standardized test equipment, and trained clinical staff (Bagai, Thavendiranathan, & Detsky, 2006). Patients within a hospital may be too sick to be transported to an audiology test suite to be formally tested. In these cases it is necessary to test their hearing bedside (Valente, Potts, Valente, St. George, & Goebel, 1992). The most accurate bedside testing is performed using a portable audiometer. Still, even portable audiometers are not always a feasible option. A commonly used portable screening audiometer, the AudioScope, costs approximately \$450 or more (Liu, Collins, Souza, & Yueh, 2011). This equipment cost, combined with the cost of hiring trained staff member to use it, poses a costly investment that hospitals or other healthcare facilities may not be able or willing to make. Finally, ambient noise can prevent hearing screenings performed with a portable audiometer from conforming to guidelines put forth by ASHA. According to ASHA's guidelines for screening for hearing impairments in adults, ambient noise levels may exceed the American National Standard Institute's (S3.1-1991) standards for pure-tone threshold testing but cannot be loud enough to prevent accurate screening (American Speech-Language-Hearing Association, 1997). Maximum permissible ambient noise levels for ears-covered screenings are 51.5 decibel of Sound Pressure Level (dB SPL) (1000 Hz), 53.0 dB SPL (2000 Hz), and 59.5 dB SPL (4000 HZ) (American Speech-Language-Hearing Association, 1997). Noise levels within patient rooms of the intensive care unit can range between 43.5 and 88.3 dB SPL, with an average of 65.9 dB SPL for a 30-minute time interval (Cordova et al., 2013).

Regardless of how individuals are tested, the negative impacts of an unidentified hearing loss can vary greatly. Strawbridge et al. (2000) analyzed the longitudinal effects that self-reported hearing loss had on the physical health, functioning, mental health, and social functioning outcomes for 2,461 participants in the Alameda County Study. The researchers found that hearing losses of a moderate degree or more are longitudinally associated with measured Instrumental Activities of Daily Living (IADL), Activities of Daily Living (ADL), and Physical Performance disabilities (Strawbridge et al., 2000). Hearing loss can affect an individual's ability to understand speech, especially in the presence of background noise. Difficulty with speech understanding can lead to social withdrawal, isolation, and even depression. Family members and friends may become frustrated at the difficulty of interacting with someone that has a hearing loss (Newman & Sandridge, 2004). Early detection and treatment of hearing loss can help reduce social isolation, improve depressive symptoms, and improve overall quality of life (Mulrow et al., 1990; Yueh et al., 2010). To combat the adverse effects of undetected hearing loss, a simple and effective screening measure must be developed. This paper examines the shortcomings of current hearing screening and investigates the feasibility and/or accuracy of using the Ling-6 sound test as a screening measure for hearing loss.

Current Hearing Screening Guidelines

Current clinical guidelines regarding screening for hearing loss in adult populations are sparse at best. The American Speech-, Language, and Hearing Association (1997) recommends that adults be screened for hearing loss as needed, requested, or when their pre-existing health conditions or personal lifestyles place them at risk for developing a hearing loss. It is also recommended that adults be screened for

hearing loss at least once every decade until they turn 50. After age 50, it is recommended that they be screened every three years (American Speech-Language-Hearing Association, 1997). Screening protocols set forth by ASHA indicate that adults should be screened at 25 decibel of Hearing Level (dB HL) at 1000, 2000, and 4000 Hz. Screenings can be performed by either a certified audiologist or other medical personnel. In order to pass a screening, participants must respond to 1000, 2000, and 4000 Hz pure-tone air conduction stimuli presented at an intensity of 25 dB HL in both of their ears. If an adult does not respond to any test stimuli in either ear, they fail the screening (American Speech-Language-Hearing Association, 1997).

Current Hearing Screening Methods

The current hearing screening methods available include: finger rubs, whispered voices, watch ticks, tuning forks, and questionnaires. While all of these methods are both quick and easy to administer, there is an insufficient amount of either standardization or validation available to support their use. A study conducted by Boatman, Miglioretti, Eberwein, Alidoost, and Reich (2007) investigated the sensitivity, specificity and positive predictive value of several screening tests commonly used by neurologists to rule out hearing loss. Tests included the finger rub, whispered speech, watch tick, and Weber and Rinne tuning fork tests. All test results were compared against a standard reference of pure-tone audiometry (Boatman et al., 2007). Commonly used bedside screeners were found to have poor sensitivity and high rates of false positives. Sensitivity values ranged anywhere from 0.05 to 0.60. When tests were combined with one another the sensitivity increased to 0.64. In order to correctly identify individuals with hearing loss as having hearing loss, a high sensitivity value is required. Similarly, a high specificity value is

needed to correctly identify normal hearing individuals as not having a hearing loss. Hearing losses most frequently identified were moderate or greater and bilateral. It is likely that screening results may be further compounded by a lack of standardization across examiners (Boatman et al., 2007). One examiner may whisper louder than the next, or have a watch with a louder ticking sound (Boatman et al., 2007). Given that most screeners only identify the more severe ranges of hearing loss, those with a more mild hearing loss could pass the bedside screen and have their hearing loss go completely undetected.

Calibrated finger rub auditory screening test. The Calibrated Finger Rub Auditory Screening Test (or CALFRAS^T) is a screening method that involves rubbing the fingers together to identify hearing loss (Torres-Russotto et al., 2009). The test is performed when the hand is comfortably dry, by rubbing the thumb against the distal fingers (Torres-Russotto et al., 2009). The patient is seated comfortably in a chair and instructed to listen carefully with their eyes closed. The examiner positions themselves nose-to-nose at a distance of six to ten inches from the listener. With their arms extended at their sides, the examiner rubs their fingers together in a position that is the same distance from theirs and the patient's ears. The CALFRAS^T technique includes two screening procedures: CALFRAS^T-Strong 70 and CALFRAS^T-Faint 70 (Torres-Russotto et al., 2009). When performing the Strong 70 procedure, the clinician rubs their fingers as hard as possible without snapping. The Faint 70 procedure involves the softest finger rub that the examiner can hear with their arms completely outstretched. Intensity measurements have shown the average Strong 70 intensity to be 31 dBA, while the average Faint 70 intensity was 25 dBA. If a patient accurately reports hearing the strong

finger rub in each ear, they are presented with the faint finger rub. If a patient does not perceive the Strong 70 finger rub, the distance between their ear and the examiner's fingers is decreased by standard intervals (Torres-Russotto et al., 2009). These standard intervals include 35, 10, and 2 centimeters. Each patient is then assigned a CALFRASST level, which is the faintest stimulus they can perceive. The creators of the CALFRASST report that the CALFRASST-Strong 70 has a sensitivity and specificity of 61% and 100%. They report the CALFRASST Faint-70 has a sensitivity and specificity of 99% and 75% (Torres-Russotto et al., 2009). However, independent researchers have reported a sensitivity of just 27% for hearing losses greater than 25 dB HL. For hearing losses greater than 40 dB HL, they report a sensitivity that is only marginally better at 35% (Boatman et al., 2007). These discrepancies in sensitivity could be due to the differences in tester bias between the independent researchers and the creators of the CALFRASST. While the CALFRASST appears to be a straightforward screening measure, it is very hard to standardize how fast or hard someone rubs their fingers together. Despite the average reported intensities, there is no real way of knowing how intense the finger rub is each time it is performed. It is also incredibly difficult to rub your fingers together without snapping instead.

Whispered voice test. A similar screening method to the finger rub is the whispered voice test. This screening method is performed without any visual cues; the examiner stands behind the patient so that they cannot speech-read. The ear canal of the non-test ear is masked by being occluded and rubbed in a circular motion with one finger (Swan & Browning, 1985). This allows for only one ear to be tested at a time. Patients are instructed to respond when the words being spoken to them are very faint. They may

be oriented to the task by having them repeat numbers presented at a conversational level of speech. After the patient has been oriented to the task, a series of numbers and letters is whispered at an arm's length from their ear. All stimuli are presented after a full exhalation to ensure that the examiner's voice is as quiet as possible (Swan & Browning, 1985). If the patient is able to repeat back the entire combination correctly, the screener moves onto their other ear. If the patient is either unable to repeat the combination, or repeats it incorrectly, they are given a new one. Patients pass the screening if they are able to correctly repeat back at least three of a total of six possible letters and numbers (Swan & Browning, 1985). Original research reported sensitivity and specificity of 90% and 80% in individuals with hearing losses measuring greater than 30 dB HL (Eekhof et al., 1996). More recent studies report a sensitivity of 40% for hearing losses greater than 25 dB HL. For hearing losses greater than 40 dB HL its sensitivity was reported to improve marginally to 46% (Boatman et al., 2007). These discrepancies in sensitivity could be due to the differences in tester bias between the independent researchers and the original researchers of the whispered voice test. Much like the finger rub test, it is difficult to standardize a whispered voice across multiple examiners. The author of this paper was unable to standardize just her own whispered voice when attempting this screening method several times.

Tuning fork tests. Otolaryngologists often use tuning fork tests as a quick assessment of a patient's hearing sensitivity. The first of these tests is the Rinne tuning fork test (Vento & Durrant, 2009). The Rinne test is conducted using a 256 Hz tuning fork. After the tuning fork is set into motion, its tines are alternately held to the patient's mastoid and lateral to his or her pinna. As this is done, the patient is asked whether he or

she can hear the tone (Vento & Durrant, 2009). If the patient hears the tone longer by bone conduction, the test is considered “negative.” If the tone is heard longer by air conduction, the test is considered “positive.” A positive Rinne test indicates that the patient has either normal hearing or a sensorineural hearing loss. A negative test indicates that the patient has a conductive hearing loss (Vento & Durrant, 2009). The Weber tuning fork test is also uses a 256 Hz tuning fork. Instead of placing the tuning fork to the mastoid or near the pinna, the tines are struck and placed on the patient’s forehead near their hairline. The patient is then asked to identify the ear that is hearing the tone (Vento & Durrant, 2009). If the tone lateralizes it will do so to the ear with better hearing or a conductive hearing loss. Symmetrical hearing is indicated by a tone that is perceived at the midline. The Bing test is the last of the tuning fork tests. Again, a 256 Hz tuning fork is used (Vento & Durrant, 2009). During this test, the tines of the tuning fork are struck and placed against the patient’s mastoid. The ear canal is then covered and the patient is asked whether the tone now sounds louder (Vento & Durrant, 2009). The test is “positive” when the patient can hear the tone louder with the ear canal covered. It is “negative” if the patient says there is no difference in loudness with the ear canal covered or uncovered. A positive test is indicative of either normal hearing or a sensorineural hearing loss (Vento & Durrant, 2009). A negative Bing test indicates that the patient has a conductive hearing loss. The accuracy of these tests is very dependent on both the examiner’s ability to administer them properly and the patient’s ability to accurately make the required judgments (Vento & Durrant, 2009). Tuning fork tests are often incorrectly used to screen for any type of hearing loss, despite all three being designed to identify very specific types. While the Rinne test has a reported sensitivity of

84%, neither the Bing nor Weber tests have been found to be useful diagnostic tests (Miltenburg, 1994).

Hearing handicap inventory. The Hearing Handicap Inventory for the Elderly is comprised of 25 questions that aim to identify the social and emotional handicap experienced by an individual secondary to their hearing loss. Thirteen questions provide information from an emotional domain, while twelve questions provide information from a social domain. Each question is scored based on a *yes* (4 points), *sometimes* (2 points), or *no* (0 points). The entire questionnaire is scored out of 100 points, with a higher score indicating a greater degree of hearing handicap (Chisolm & Abrams, 2008). The Hearing Handicap Inventory for Adults is also a 25-question questionnaire, but includes questions related to an individual's occupation. Both questionnaires have ten question short forms called the Hearing Handicap Inventory for the Elderly Screening Version (HHIE-S) and Hearing Handicap Inventory for Adults Screening Version (HHIA-S) (Chisolm & Abrams, 2008). The screening versions are the most commonly used screeners used to identify hearing handicap (Menegotto, Soldera, Anderle, & Anhaia, 2011). Tomioka et al. (2012) reported HHIE-S sensitivity of only 43.9% in individuals with pure tone averages greater than 25 dB HL. In individuals with pure tone averages greater than 40 dB HL, the sensitivity value was 81.3% (Tomioka et al., 2012). It is likely that the sensitivity increased for individuals with pure tone averages greater than 40 dB HL because their hearing loss was causing a greater amount of handicap. While the HHIE and HHIA have the potential to identify hearing handicap, they cannot be used to detect hearing loss as a handicap is subjective and may differ even within individuals who have the same puretone thresholds (Sindhusake et al., 2001).

Multimedia hearing handicap inventory. A multimedia version of the Hearing Handicap Inventories has also been developed in recent years. Called the Multimedia Hearing Handicap Inventory (MHHI), it encompasses both the HHIA-S and HHIE-S. The program was created by Michigan State University and is an interactive CD-ROM run on the Microsoft Windows 95/98 operating system (Holcomb & Punch, 2006). The long MHHI program includes an educational portion and includes either the HHIA-S or HHIE-S, depending on the age of the participant (Holcomb & Punch, 2006). The educational portion of the long program includes information such as factors that affect speech understanding or common problems people with hearing loss experience. The questionnaire portion includes ten questions that the participant answers by clicking either *yes* (4 points), *sometimes* (2 points), or *no* (0 points) basis. The computer automatically calculates social-situational, emotional, and total scores (Holcomb & Punch, 2006). The long program takes approximately 15 to 20 minutes to complete. The short program, which only takes about two minutes to complete, includes only the MMHI without an educational portion. Depending on the age range selected, either the HHIE-S or HHIA-S version is administered. Again, the participant answers ten questions that the computer automatically scores. The short version of the MHHI was intended for use during mass hearing screenings (Holcomb & Punch, 2006).

uHear. With the advent of smartphone technology, a hearing screening application was recently developed for use on the Apple iOS platforms. The director of Audiology at Unitron, a major hearing aid company, developed the uHear application. It can be run on any product that runs iOS and can be downloaded for free from iTunes. The application tests pure-tone air conduction sensitivity and speech-in-noise (Szudek et

al., 2012). Test frequencies for the hearing sensitivity portion include: 250, 500, 1000, 2000, 4000, and 6000 Hz. Participants are instructed to take the test in a very quiet room with either earbuds or headphones. They are also instructed to complete the test with their device set to 50% volume and asked to indicate what type of transducer they are using. The application uses a 267 millisecond pulsed stimulus and a down 10 dB, up 5 dB threshold seeking method. Participants respond to the stimuli by pressing a button on the touch screen of their device (Szudek et al., 2012). Thresholds are considered to be the lowest intensity at which the participant responds two out of three times. When the test is over, the application provides results in a standard audiogram format. It has been noted that the application is more accurate in ears that already have a recognized hearing loss (Szudek et al., 2012). It often overestimates pure-tone thresholds in individuals that have normal hearing (Szudek et al., 2012). In fact, the application reported an asymmetrical mild to moderately-severe hearing loss when the (normal hearing) author of this paper screened her hearing. These overestimations in pure-tone thresholds may be partly due to the fact that the screening is performed using non-calibrated earbuds or headphones.

From the descriptions above, one can tell that there are a great number of screening measures currently available for use. Yet none of the previously existing screening methods have a good sensitivity for hearing loss. In fact, the most sensitive screening method has a sensitivity of only 46% for hearing losses of a moderate degree or worse. The self-report questionnaires are not even capable of providing information about the presence of a hearing loss, but instead provide information about hearing

handicap. To address these deficiencies, there is a promising new screening technique that involves screening hearing using the six phonemes of the Ling-6 sound test.

The Ling-6 Sound Test

The Ling-6 Sound Test is a series of six phonemes that are spoken by a clinician at the level of normal conversational speech. The phonemes included in the test are /m/, /i/, /a/, /u/, /ŋ/, and /s/ (Tenhaaf & Scollie, 2005). The Ling Sound Test was originally developed by Daniel Ling as a quick method for verifying hearing aid fittings in children (Ling, 1976). The test originally had five sounds and was referred to as the Ling-5 Sounds. The original five sounds included in the test were /ŋ/, /s/, /i/, /u/, and /a/ (Ling, 1976). The addition of the low frequency /m/ sound created what is now known as the Ling-6 Sound Test. The phonemes included in the test contain energy that spans the entire speech spectrum from 250 to 8000 Hz, allowing for a quick assessment of hearing sensitivity across the speech frequencies. The individual phonemes are low, middle, and high frequency in nature (Smiley, 2004).

The Ling-6 sound test includes three corner vowels (/i/, /a/, and /u/). Vowel perception is dependent on a listener's ability to hear both the first and second formants (F1 and F2) of a vowel. The vowel /i/ is a high front unrounded sound. A speaker produces it by fronting the tongue against the alveolar ridge and making the oral cavity small (Raphael, Borden, & Harris, 2007). It has an average first formant of 270 Hz and second formant of 2290 Hz in men (Raphael et al., 2007). When spoken by women, the average first formant is 310 Hz and second formant is 2790 Hz (Raphael et al., 2007). The vowel /a/ is a low back vowel. It is produced with a large oral cavity and small pharyngeal cavity. The oral cavity is made smaller by either lowering the jaw or

depressing the tongue. It has an average first formant of 730 Hz and second formant of 1090 Hz in men. In women, the average first formant is 850 Hz and second formant is 1220 Hz (Raphael et al., 2007). It is used to determine whether central vowels are audible (Agung, Purdy, & Kitamura, 2005). The vowel /u/ is a high back rounded vowel. To produce it, the speaker rounds their lips and presses the dorsum of their tongue against the roof of the mouth. It has an average first formant of 300 Hz and second formant of 870 Hz in men (Raphael et al., 2007). The average first formant is 370 Hz and second formant is 950 Hz in women (Raphael et al., 2007). It can be used to assess a person's ability to detect whether the lower end of the vowel formant range is audible (Agung et al., 2005).

The sound test also contains the three consonants /m/, /s/, and /ʃ/. The consonant /m/ is a nasal consonant and produced through nasal resonance. This nasal resonance is achieved by occluding the oral cavity while the velum is lowered to allow access to the nasal tract (Agung et al., 2005). The specific nasal consonant /m/ is produced by pressing the lips together to occlude the oral cavity. The /m/ sound has nasal formants at 250, 1200, and 2400 Hz. Its peak energy occurs at approximately 250-350 Hz, making it suitable for assessing low frequency sensitivity (Agung et al., 2005). The consonants /s/ and /ʃ/ are fricative sounds. Fricatives have an aperiodic sound that is created by obstructions formed within the vocal tract (Raphael et al., 2007). The /s/ sound is a voiceless fricative, meaning the vocal folds do not vibrate while it is produced. The speaker forms a constriction between the tongue and the alveolar ridge while saying /s/. The sound /ʃ/ is also a voiceless fricative, with the constriction in airflow occurring in the post alveolar area (Raphael et al., 2007). Both /s/ and /ʃ/ have energy located in the high

frequencies, with dominant energies of 5000 and 3000 Hz respectively (Agung et al., 2005).

Current applications. The Ling-6 Sound test can be used as a daily listening check to assess a child's ability to detect and discriminate between sounds that fall within the speech spectrum. While the Ling-6 Sound Test does not encompass every speech sound in the English language, it includes a sampling from the entire speech range. For example, the /m/ sound is very low frequency while the /s/ sound is very high. The sound test is used with both cochlear implant and hearing aid users to determine their ability to both detect and discriminate between different sounds (Dickson, 2010). The sounds are randomly presented individually in close proximity to the child's microphone. The child is not allowed any visual cues, to ensure that they are hearing the speech sounds and not simply speech-reading. As the child correctly identifies the speech sounds, the distance between the speaker and their microphone is increased (Dickson, 2010). By increasing the distance between the speaker and the child's microphone, the child's distance hearing can be informally assessed. This gives both their parents and teachers an idea of how far away the child is able to detect speech. Such information is vitally important in the classroom, where most classroom instruction is conveyed through spoken language (Meehan, 2012). Having a child sit further away than they are capable of hearing could have potentially devastating educational ramifications (Meehan, 2012). After a child has mastered the detection phase, the sound test can be used to assess their discrimination abilities. During the discrimination phase, the child is asked to either point to a picture or repeat the sound when they've heard it. Sounds are still presented in random order, but

now silence is introduced as a foil. Sounds may also be embedded within words to increase the difficulty of the task (North & Sindrey, 2007).

Current Project

Hearing loss has a very high prevalence amongst adults, and unidentified hearing losses have been shown to adversely affect an individual's health. One way to effectively combat the potentially ill effects of an unidentified hearing loss is to identify that it exists. One of the easiest ways to do so is with a hearing screening. While there are many screening methods available for use in the adult population, most pale in comparison to the gold standard of a portable audiometer. However, with price tags of hundreds of dollars or more, portable audiometers are often too costly of an investment. Screening methods such as the CALFRAST or whispered voice are free but suffer from a lack of standardization and poor sensitivity for lesser degrees of hearing loss. In contrast, the Ling-6 Sound test has been used successfully to quickly assess hearing aid functionality and a child's ability to discriminate between speech sounds. The Ling-6 sounds are easy to administer and, regardless of examiner, represent the different frequencies found in speech. Its simplicity and ease of use makes it an ideal candidate for use as a screening measure in adults. The Ling-6 test is both easy to learn and easy to implement. Its six phonemes make it feasible to screen hearing sensitivity across the entire speech spectrum in a matter of minutes. The current project used male and female recordings to correlate the sounds of the Ling-6 sound test to an individual's audiogram and determine its feasibility as a hearing screener.

Chapter 3

Methods

Participants

Twenty-five participants aged 24 to 76, average age 46 (17.37) years, were recruited to participate. Participants were recruited through word of mouth, local church groups, local libraries, and the graduate audiology program at Towson University. Twelve of the participants had pure-tone thresholds within the normal range of hearing. The other thirteen participants had hearing thresholds within the mild to profound hearing loss range. Exclusion criteria included: impacted cerumen, non-Type A tympanograms, reported history of head injury or neurological deficits, history of attention deficit disorder or attention deficit hyperactivity disorder (ADD/ADHD), and the use of hearing aids with frequency transposition turned on. Impacted cerumen was defined as cerumen preventing visualization of the tympanic membrane. Type A tympanograms were defined as tympanograms with a peak pressure between -150 and +100 daPa, peak compliance between 0.3 and 1.4 ml and ear canal volume between 0.6 and 1.5 ml. Histories of head injury, neurological deficits, or ADD/ADHD were ascertained through a case history. Listening checks were used to determine whether hearing aids had frequency transposition turned on. No participants had a history of head injury, neurological deficits, ADD/ADHD, or use of hearing aids with frequency transposition turned on. All participants signed a consent form prior to participating in the study. This study was approved by the Towson University Institutional Review Board (See Appendix A).

Materials and Methods

Audiologic exam. Participants underwent a comprehensive audiology exam prior to being tested. This exam included otoscopy, tympanometry, and pure-tone air and bone conduction. Otoscopy was performed using a Welch Allyn 3.5V diagnostic otoscope. Tympanometry was performed using a GSI TympStar immittance bridge set to screening mode. An immittance probe tip was used to obtain a hermetic seal in the patient's ear. After a hermetic seal was obtained, a screening tympanogram was obtained. Pure-tone testing was performed using a GSI-61 clinical audiometer. Participants were tested while seated in a sound-treated booth. Transducers included ER-3A insert earphones and a B71 bone oscillator coupled to a metal headband. Pure tone air and bone conduction testing was performed in two dB steps using a descending technique. Tones were initially presented at an intensity of 30 dB. If the participant responded, the intensity was lowered in 4 dB steps until no response is obtained. If the participant did not respond, the intensity was raised in 4 dB steps until a response was obtained. Threshold was then bracketed using a down 4 dB, up 2 dB procedure. Threshold was considered the lowest intensity where the participant responded on an ascending run two-out-of-three times.

Ling-6 screening test.

Acquisition of speech stimuli. Stimuli for the screening portion included voice samples taken from two male and two female participants. The participants were seated in a sound-treated booth centered two feet in front of a recording microphone (Audio-Technica ATR30 low impedance cardioid) on a table. The recording microphone was located under a calibrated spot within the booth. A 50 dB HL, 1000 Hz pure tone and a 50 dB HL narrow-band-noise burst were each played through a GSI-61 clinical

audiometer in the sound field (through sound field speakers) at the beginning of the recording, prior to obtaining speech samples. The pure tone and noise burst served as reference tones when the recorded speech sounds were later presented through a GSI-61 clinical audiometer and Sony CD player. Each male and female participant was instructed to produce each of the six speech sounds a total of four times. A sheet containing four lists with examples of each of the six sounds within a word was provided to the participant to clarify the sound that they were expected to make. Participants were instructed to use their clearest voice at a normal speaking volume to read each of the four lists provided. Their speech productions were recorded using the recording microphone and an acoustic analysis software program (Adobe Audition 6.0) that was loaded onto a Dell laptop computer.

The eight best exemplars of each Ling-6 sound (two exemplars of each Ling-6 sound from each participant) were then chosen as the final speech samples. The best exemplars were the speech samples contained within the second and third set of Ling-6 sounds produced by each participant. The final exemplars of the Ling-6 sounds produced by each speaker were analyzed for average intensity by using the Adobe Audition 6.0 amplitude statistics function. To do this, first the total duration of each exemplar was measured by highlighting from the beginning to the end of each waveform. Next, average intensity was analyzed at the highlighted midpoint (± 50 milliseconds) of the exemplar. The final exemplar speech samples of the Ling-6 sounds were also analyzed, using WaveSurfer 1.8.8, for peak frequency (consonants) and frequencies of formants 1 and 2 (vowels). Again, the total duration of each exemplar was measured. Total duration was considered to be the total portion of the speech sound that was dark grey or black.

Frequency measurements for formants 1 and 2 were made by placing the cursor in the middle of the formant at the midpoint of the exemplar. Peak frequency measurements were made using the long-term average spectrum function. Peak frequency was measured by placing the cursor at the top of the highest peak within this spectrum. The measured speech stimuli data is presented in Table 1 and Table 2.

Table 1

Speech Stimuli Measurements from Male Speakers

Ling-6 Sound	Intensity (dB HL)	Peak Frequency (Hz)	Formant 1 (Hz)	Formant 2 (Hz)
/a/	75.62		681	1191
/i/	72.43		398	2165
/u/	73.27		329	804
/j/	71.44	2784		
/s/	70.67	5987		
/m/	71.75	278		

Note. Reported measurements are averages for speech stimuli from two male speakers.

Table 2

Speech Stimuli Measurements from Female Speakers

Ling-6 Sound	Intensity (dB HL)	Peak Frequency (Hz)	Formant 1 (Hz)	Formant 2 (Hz)
/a/	76.80		601	1583
/i/	67.67		414	2835
/u/	70.57		374	868
/j/	69.83	2924		
/s/	65.15	6316		
/m/	69.18	253		

Note. Reported measurements are averages for speech stimuli from two female speakers.

After intensity and frequency analysis were performed, the sound quality of final speech samples was improved using the noise and hiss reduction features in Adobe Audition 6.0. Noise reduction was set to 80% and hiss reduction was set to 75%. This removed background noise picked up by the microphone and made the speech sounds easier to hear. Post reduction frequency analysis, using WaveSurfer 1.8.8, revealed that the frequency content of each Ling-6 sound remained unchanged. The speech samples were then saved as a .wav file and burned onto a compact disc using Audacity 2.0.5. The compact disc consisted of four tracks, each containing twelve randomized speech sounds.

The first track contained a calibration tone that was followed by the twelve randomized speech sounds. Speech sounds were spaced four seconds apart from each other, to allow each participant enough time to respond. Each track also contained random silent foils to confirm that the participants were not simply guessing which speech sounds they were hearing. These silent foils sounded like small silent gaps in the sound.

Speech sound repetition. Participants were again seated in a sound-treated booth for the Ling-6 screening portion of the study. Participants were positioned in the center of the booth, in front of two speakers positioned 45 degrees to the left and right. One ear was tested at a time, while the opposite ear was occluded using an ER-3A insert earphone connected to the insert earphone transducer. Participants who wore hearing aids were tested in an unaided condition. All four tracks of the stimuli CD were presented at 50 dB HL in the sound field (through sound field speakers) using a signal sent from a Sony CD player through the GSI-61 clinical audiometer. Each participant was instructed to listen to each speech sound and repeat back what he or she heard. Speech sounds were presented one at a time in isolation. The participants' responses were recorded on a data sheet containing the correct order of speech sounds for each track (See Appendix B).

Statistical Analysis

A percentage score was derived for each Ling-6 sound for each participant. This score was calculated by dividing the number of correct repetitions of each Ling-6 sound by the total number of the sound presented. These percentage scores were then input into Excel (version 12.3.6) and a statistical software program (IBM SPSS Statistics version 21) and analyzed to answer the following questions:

1. Does the hearing loss group have more errors in repeating Ling-6 sounds?

2. What is the relationship between puretone thresholds and accuracy for repeating back Ling-6 sounds?

A mixed design analysis of variance (ANOVA) was performed to determine whether there was a significant difference in accuracy for repeating Ling-6 sounds between the normal hearing and hearing loss groups. Percentage scores were designated as the outcome variable and group (normal hearing or hearing loss) was designated as the between subjects factor. A p-value of $< .05$ was considered significant.

A pearson product-moment correlation analyses was performed to determine what type of relationship existed between each individual Ling-6 phoneme percentage score and pure-tone thresholds at various frequencies. Scores for the consonant sounds (/f/, /s/, and /m/) were correlated with the two puretone thresholds closest to each sound's peak frequency. Scores for the vowel sounds (/a/, /i/, and /u/) were correlated with the puretone threshold closest to each sound's formant 1 and 2. A p-value of $< .05$ was considered significant.

Chapter 4

Results

Comparison of Percentage Scores

Mean percentage scores and standard deviations for each Ling-6 sound were calculated for the hearing loss and normal hearing groups. Initial analysis looking at effect of ear showed no main effect for ear and no interaction between ear and any other factor. As such, scores were collapsed across ears. Means and standard deviations for each group are presented in Table 3.

Table 3

Average Percentage Scores from Normal Hearing and Hearing Loss Participants

Ling-6 Sound	Hearing Loss		Normal Hearing	
	n	M (SE)	n	M (SE)
/a/	26.00	76.92 (7.33)	24.00	95.83 (4.08)
/i/	26.00	67.79 (8.83)	24.00	99.48 (0.51)
/u/	26.00	62.98 (8.23)	24.00	92.19 (2.06)
/j/	26.00	75.48 (8.48)	24.00	99.48 (0.51)
/s/	26.00	35.10 (7.92)	24.00	92.71 (2.54)
/m/	26.00	50.48 (8.13)	24.00	93.75 (1.81)

Note. Scores were obtained from twenty-four ears with normal hearing and twenty-six ears with hearing loss ranging from mild to profound.

A mixed design analysis of variance was used to compare percentage scores obtained from normal hearing and hearing loss participants for each Ling-6 sound. Percentage score was designated as the outcome variable and group (normal hearing or

hearing loss) as the between subjects factor. The three main effects investigated were Ling-6 sound, ear, and hearing loss. The mixed ANOVA indicated there was a significant main effect of Ling-6 sound, $F(5, 115) = 8.88, p < .001$, indicating that scores for different Ling-6 sounds were in general different. There was no significant main effect for ear, $F(1, 23) = .584, p = .452$. There was a significant effect of hearing loss, indicating that percentage scores obtained from participants with and without hearing loss were in general different, $F(1, 23) = 13.57, p = .001$. The only significant interaction effect was between Ling-6 sound and hearing loss, $F(5) = 4.35, p = .001$. This significant interaction refers to differences between groups being much more substantial for some Ling-6 sounds than others. The differences were greatest for the /s/ and /m/ sounds. (There was no significant interaction effect between ear and Ling-6 sound, $F(5, 115) = .259, p = .935$. There was no significant interaction effect between ear and hearing loss, $F(1) = .780, p = .386$. Also, there was no significant interaction effect between Ling-6 sound, ear, and hearing loss, $F(5) = .259, p = .935$). The interaction between Ling-6 sound and hearing loss, as well as a comparison of mean percentage scores from normal hearing and hearing loss participants, is presented in Figure 1.

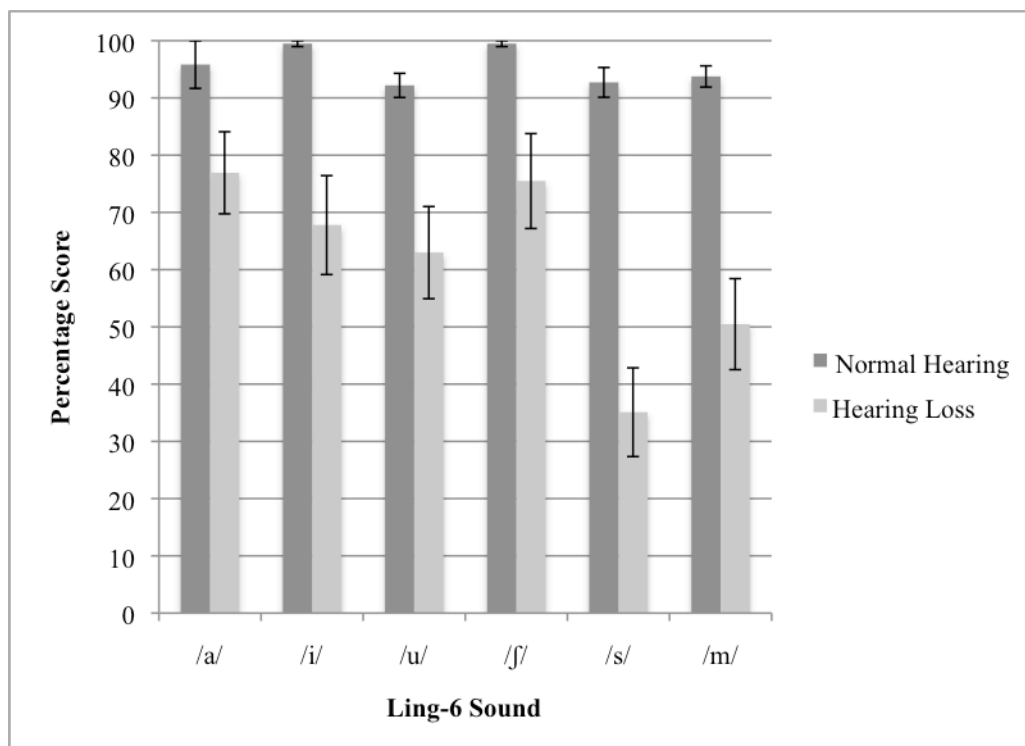


Figure 1. Comparison of percentage scores from participants with normal hearing and hearing loss. All differences between scores for each Ling-6 sound were significant, and a significant interaction existed between hearing loss and Ling-6 sound. Error bars represent one standard deviation of the sample mean.

Significant differences existed between the normal hearing and hearing loss groups for every Ling-6 sound. Information regarding independent *t*-test and *p*-value information for each Ling-6 sound is presented in Table 4.

Table 4

Independent t-test and p-value Information for Ling-6 Sounds

Ling-6 Sound	<i>t</i> (48)	<i>p</i> -value
/a/	2.27	.004
/i/	3.59	>.001
/u/	3.45	>.001
/j/	2.83	>.001
/s/	6.94	>.001
/m/	5.21	>.001

Correlations Between Percentage Scores and Threshold

A Pearson product-moment correlation was computed to assess the relationship between the percentage scores for each Ling-6 sound and select puretone thresholds across both groups. Scores for the consonant sounds (/j/, /s/, and /m/) were correlated with the two puretone thresholds closest to each sound's peak frequency. Scores for the vowel sounds (/a/, /i/, and /u/) were correlated with the puretone threshold closest to each sound's formant 1 and 2. There was a significant correlation between every Ling-6 sound percentage score and the selected puretone thresholds. Correlation coefficients for each Ling-6 sound percentage score are presented in Table 5. Scatter plots summarize the results for each Ling-6 sound (Figures 2-7).

Table 5

Correlations Between Ling-6 Sounds and Pure-tone Thresholds

Ling-6 Sound	Correlation Coefficient						
	250 Hz	500 Hz	1000 Hz	2000 Hz	3000 Hz	4000 Hz	6000 Hz
/a/		-.336**		-.395**			
/i/	-.769**				-.867**		
/u/	-.853**		-.878**				
/ɨ/				-.816**	-.829**		
/s/						-.750**	-.791**
/m/	-.765**	-.792**					

** . Correlation is significant at the 0.01 level (two-tailed).

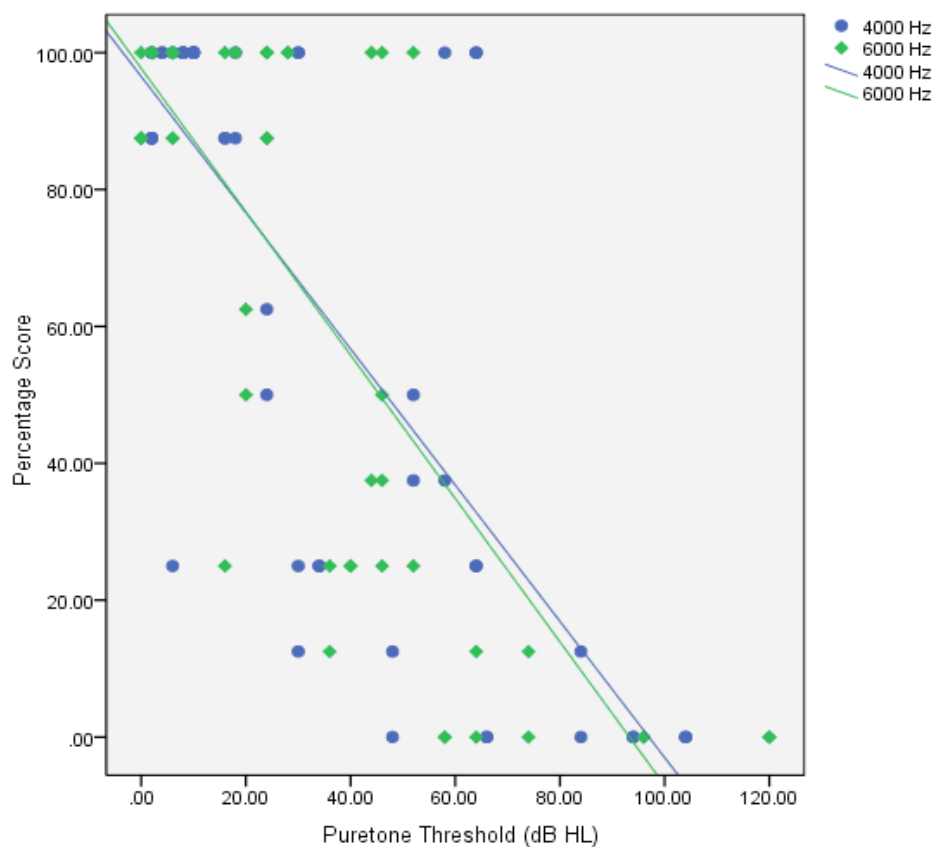


Figure 2. Comparison of pure tone thresholds at 4000- and 6000 Hz and scores obtained for the phoneme /s/. As the pure tone thresholds increased at 4000- and 6000 Hz, the scores for /s/ decreased. Lines represent line of best fit.

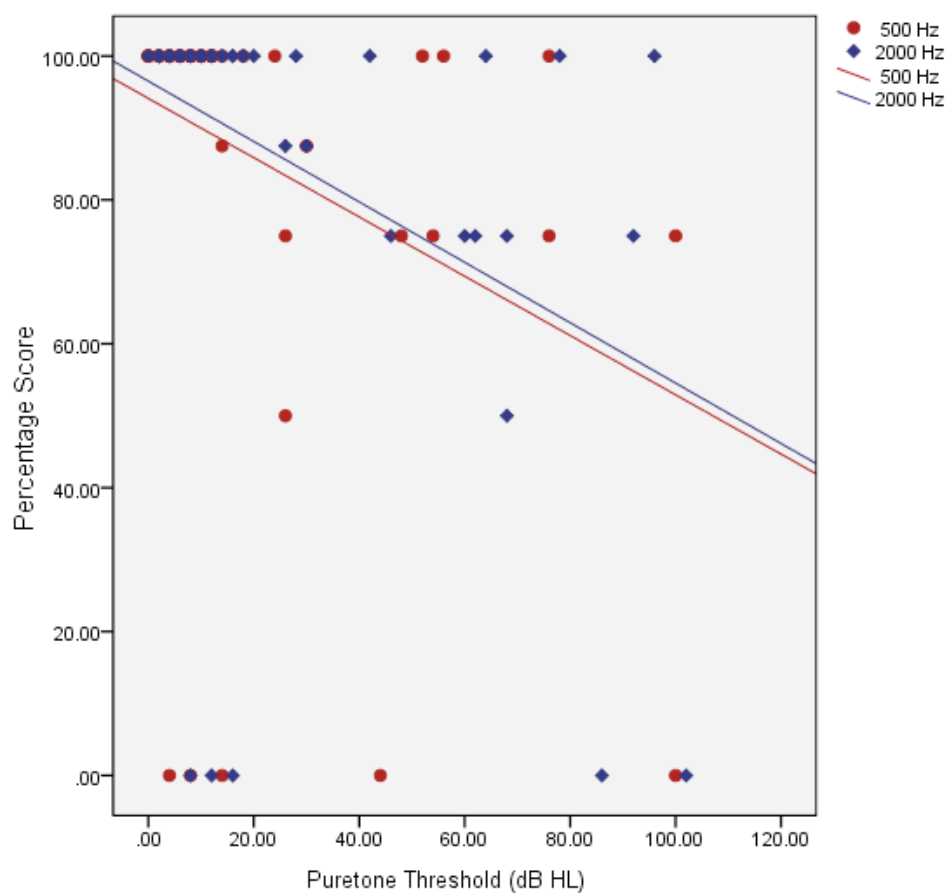


Figure 3. Comparison of pure tone thresholds at 500- and 2000 Hz and percentage scores obtained for the phoneme /a/. As the pure tone thresholds increased at 500- and 2000 Hz, the scores for /a/ decreased. Lines represent line of best fit.

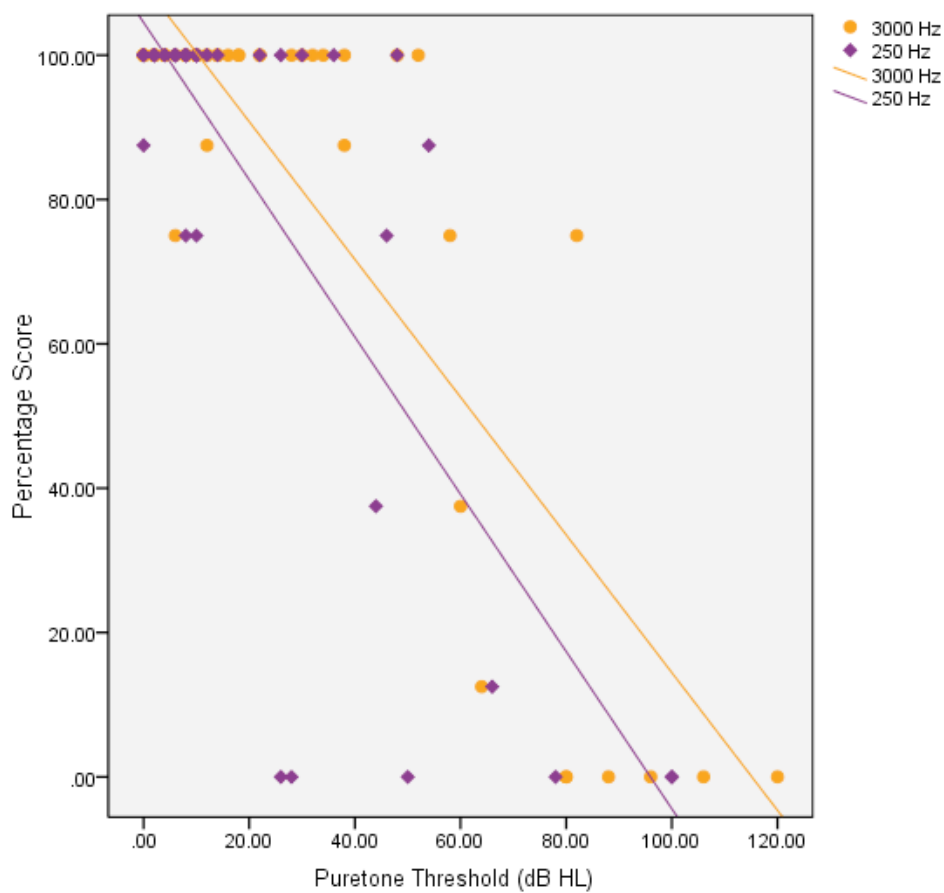


Figure 4. Comparison of pure tone thresholds at 250- and 3000 Hz and percentage scores obtained for the phoneme /i/. As the pure tone thresholds increased at 250- and 3000 Hz, the scores for /i/ decreased. Lines represent line of best fit.

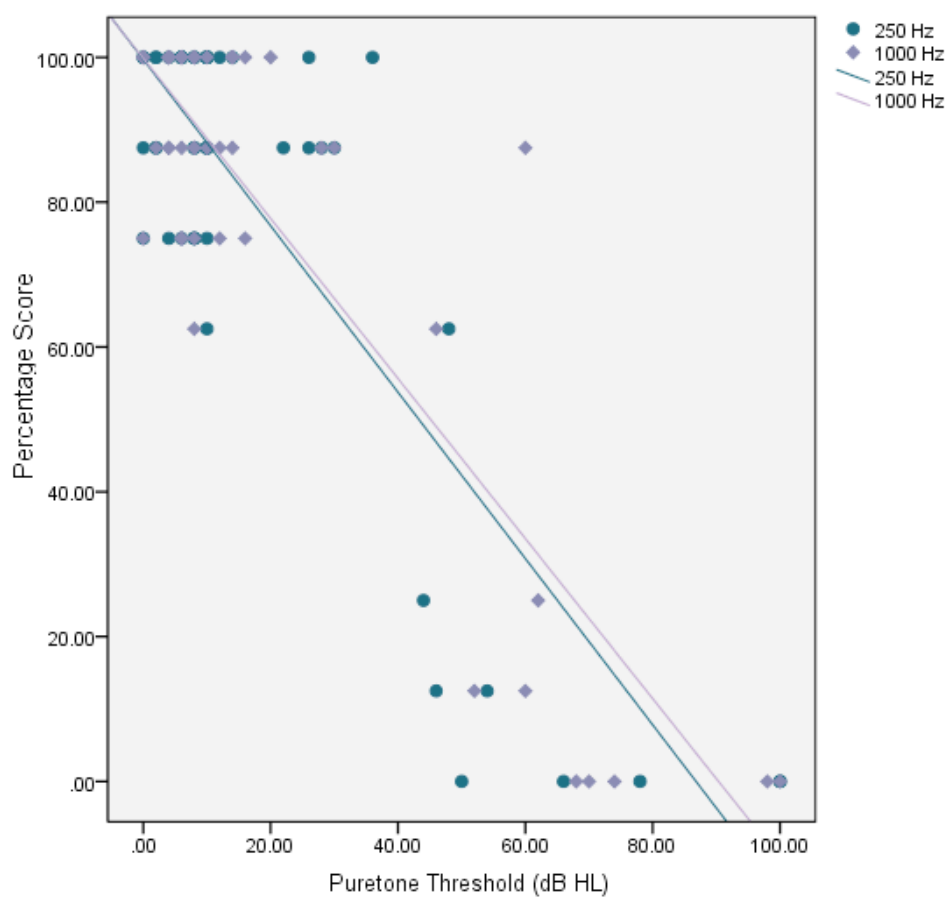


Figure 5. Comparison of pure tone thresholds at 250- and 1000 Hz and percentage scores obtained for the phoneme /u/. As the pure tone thresholds increased at 250- and 1000 Hz, the scores for /u/ decreased. Lines represent line of best fit.

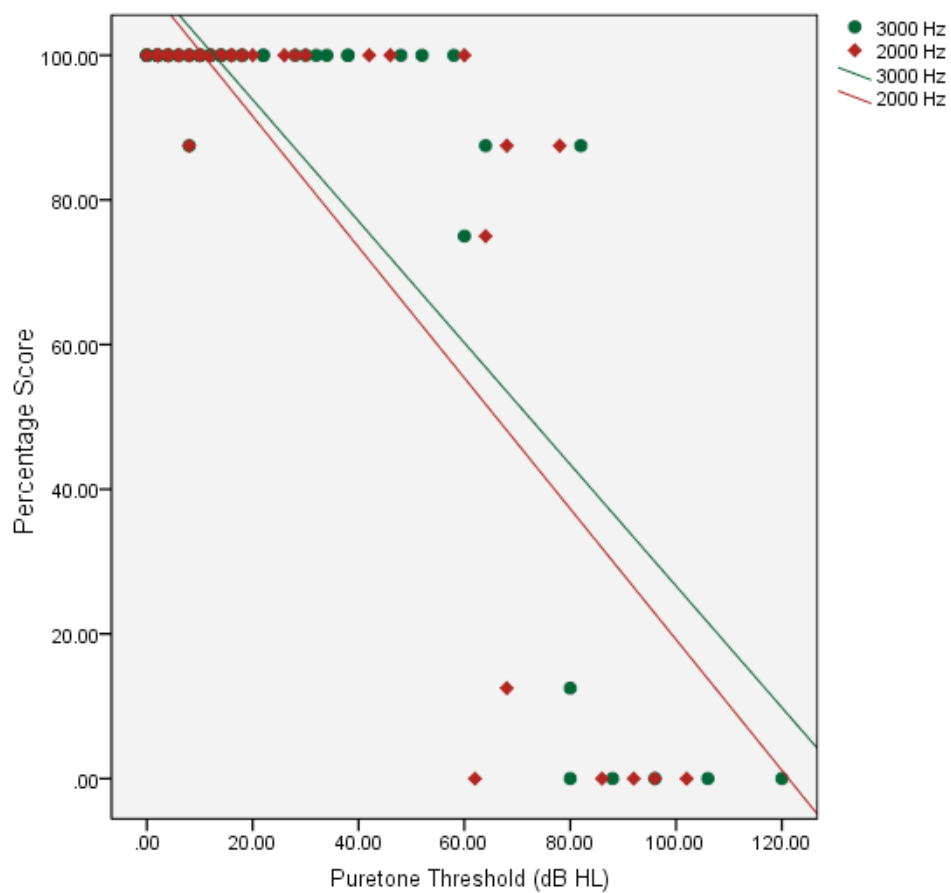


Figure 6. Comparison of pure tone thresholds at 3000- and 2000 Hz and percentage scores obtained for the phoneme /f/. As the pure tone thresholds increased at 3000- and 2000 Hz, the scores for /f/ decreased. Lines represent line of best fit.

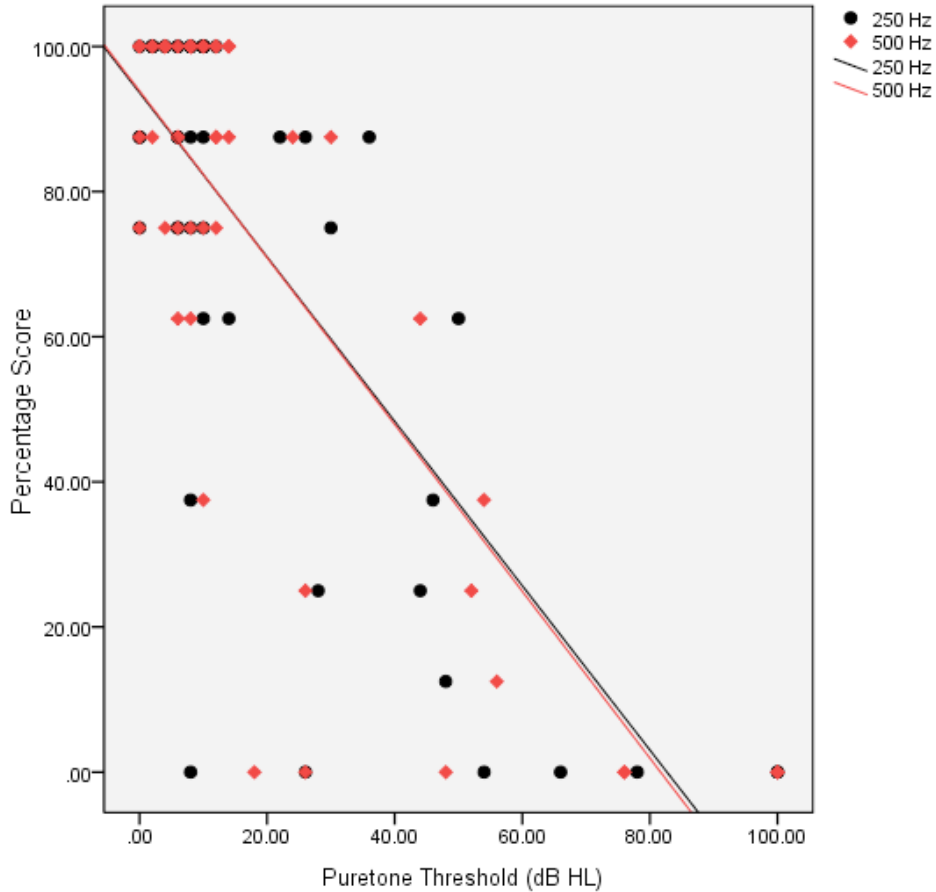


Figure 7. Comparison of pure tone thresholds at 250- and 500 Hz and percentage scores obtained for the phoneme /m/. As the pure tone thresholds increased at 250- and 500 Hz, the scores for /m/ decreased. Lines represent line of best fit.

Gender Effects

Finally, a repeated measures repeated measures design analysis of variance was used to compare percentage scores obtained from male and female speakers.

Overall, a repeated measures ANOVA indicated there was a significant main effect of Ling-6 sound, $F(5, 245) = 11.86, p < .001$. There was a significant main effect for speaker gender, indicating that percentage scores obtained from male and female speakers were in general different, $F(1, 49) = 7.97, p = .007$. There was a significant interaction effect between speaker gender and Ling-6 sound, $F(5, 245) = 16.25, p < .001$. Different effects of speaker gender for different

sounds can explain the interaction between speaker gender and Ling-6 sound. Specifically, participants had higher scores for male speakers across most sounds, but especially for /u/ and /s/ sounds. Additionally, this pattern did not hold true for the /m/ sound, which was the only sound where participants scored better with a female speaker. A comparison of mean percentage scores from male and female speakers is presented in Figure 8.

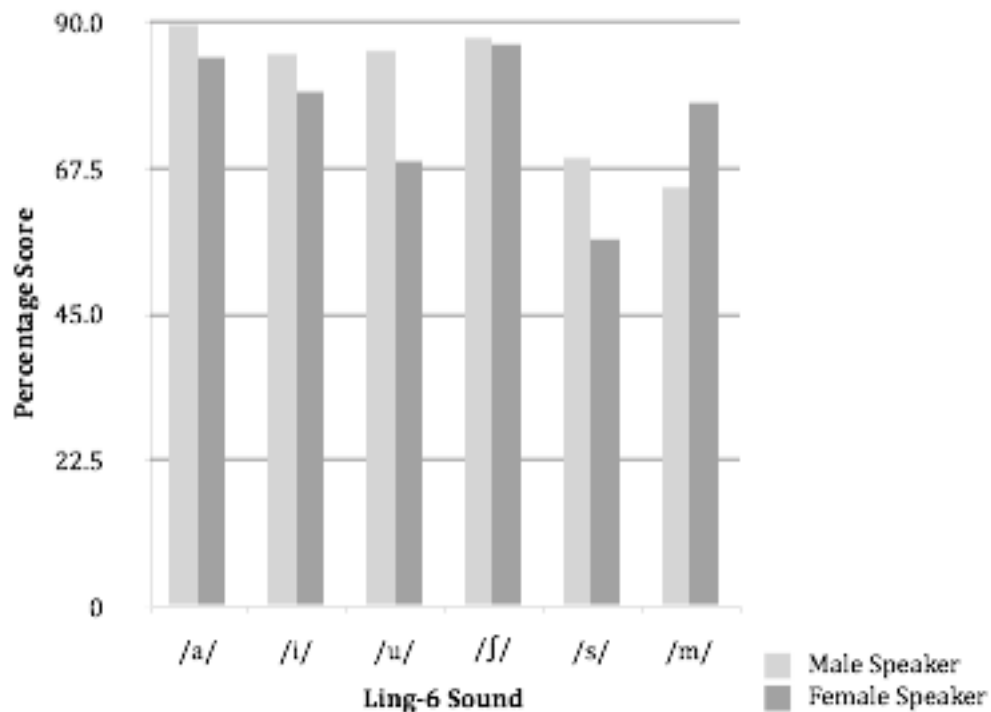


Figure 8. Comparison of participants' percentage scores from male and female speakers. All differences between scores for each Ling-6 sound were significant. Participants had higher scores for male speakers for most sounds, especially /u/ and /s/. The /m/ sound was the only speech sound for which participants had a higher score for female speakers. Error bars represent one standard deviation of the sample mean.

Sensitivity and Specificity

Sensitivity and specificity were calculated for each Ling-6 sound using a passing criterion of 100% (8/8 correctly repeated) for each individual Ling-6 sound. Sensitivity and specificity for each individual Ling-6 sound are listed in Table 6.

Table 6

Sensitivity and Specificity for Individual Ling-6 Sounds

Ling-6 Sound	Sensitivity	Specificity
/a/	75.00	100.00
/i/	66.67	93.75
/u/	100.00	52.94
/j/	50.00	100.00
/s/	66.67	69.23
/m/	100.00	55.56

Chapter 5

Discussion

The intent of this study was to correlate the Ling-6 sounds to individuals' audiograms and examine its feasibility as a bedside hearing screener. Data on a sample of adults with normal hearing and hearing loss provided preliminary description of Ling-6 sounds as a hearing screening measure. The results indicated that the Ling-6 sounds are a simple and accurate method for detecting hearing loss across the frequencies of speech.

Speech Samples Analysis

Analysis of the individual speech sounds from each male and female speaker confirmed that the Ling-6 sounds contain energy from frequencies spanning the entire spectrum of speech. Formant 1 and 2 measurements for vowel sounds ranged from 281- and 783 Hz (for the /u/ sound) to 371 and 2827 Hz (for the /i/ sound). This is consistent with previous reports of the acoustic characteristics of vowels (Hillenbrand, Getty, Clark, & Wheeler, 1995; Raphael et al., 2007). Peak frequency measurements for consonant sounds ranged from 253 Hz (for the /m/ sound) to 6607 Hz (for the /s/ sound). This is also consistent with previous reports of the acoustic characteristics of consonants (Agung et al., 2005; Raphael et al., 2007).

Comparison of Percentage Scores

Analysis of percentage scores revealed that there was a significant effect of both Ling-6 sound and hearing loss. Scores obtained for each Ling-6 sound were significantly different from each other. This is likely due to the sounds containing energy from different frequencies. A significant difference also existed in percentage scores from normal hearing and hearing loss groups for every Ling-6 sound. Participants with

hearing loss were less accurate at repeating back Ling-6 sounds than normal hearing participants, and had an average score that was lower than the normal hearing participants for every Ling-6 sound. This is to be expected, as the Ling-6 sounds presented to normal hearing individuals at the level of conversational speech were always suprathreshold. Depending on the frequency region in which they were located, Ling-6 sounds may have been at or below the puretone threshold for individuals with hearing loss. Individuals would be less accurate (or completely unable) to repeat back sounds that were at or below their puretone threshold because these sounds were not consistently audible.

Differences in percentage scores also existed for speech stimuli that came from either a male or female speaker. Regardless of hearing status, participants scored higher for nearly every speech sound when the stimuli came from a male speaker. This was especially true for the speech sounds /u/ and /s/. The only speech sound for which participants scored higher when a female was speaking was the speech sound /m/. Interestingly, in the present study, the frequency measurements from both the male and female speakers were very similar. Men normally have fundamental frequencies, formants, and peak frequencies that are lower than women (Agung et al., 2005; Hillenbrand et al., 1995). The male speakers in this study did have speech productions that were higher in intensity than the female speakers. The difference in scores from male and female speakers likely stemmed from the males having more intense speech productions, rather than speech productions that were lower in frequency. This is particularly true since even normal hearing listeners scored better for nearly every speech sound produced by a male speaker. It would be expected that normal hearing listeners

score the same regardless of speaker gender because they are not listening through an impaired auditory system.

Correlation of Ling-6 Accuracy and Thresholds

A significant correlation existed between puretone thresholds and accuracy in repeating back each of the Ling-6 sounds. Puretone threshold and accuracy had a negative relationship. As an individual's puretone thresholds increased, their accuracy in repeating back Ling-6 sounds decreased. This was expected, as increasing amounts of hearing loss make it harder and harder for an individual to detect speech sounds. Ching and Dillon (2013) have indicated individuals have a decreasing ability to hear speech sounds presented at an audible level as their hearing loss increases. The relationship between threshold and accuracy in the present study was consistent with findings from Tenhaaf and Scollie (2005), who examined detection thresholds for Ling-6 sounds in an individual with high frequency hearing loss. Their results indicated the detection thresholds for /s/ and /l/ were the highest in intensity, and these sounds were located in the region with the greatest amount of hearing loss. It should be noted, however, that their individual was tested in the aided condition (Tenhaaf & Scollie, 2005).

Clinical Utility

The Ling-6 Sound Test is quick to administer and spans the important frequencies for speech, making it ideal for effectively screening hearing loss. The use of an earplug to occlude the non-test ear allows a clinician to screen one ear at a time. The total duration of the CD used to administer the sounds was 4.2 minutes. Allowing time to switch which ear was occluded brought the total test time up to just ten minutes. Although the speech stimuli in this study were recorded and presented via a CD player,

the test could easily be adapted for administration without a CD player or recorded materials. Instead of a calibrated CD of speech sounds, clinicians can be provided with a printed, randomized, list of twenty-four Ling-6 sounds to read to their patient at a normal conversational level. The patient can be instructed to close their eyes while the test is administered to prevent them from reading the clinician's lips. Removing the need for a CD player would make the Ling-6 Sound Test very inexpensive to administer. Clinicians would only need a printed sheet of the sounds and an ear plug.

A major issue with the currently available screening measures is although they are quick and easy to administer, they do not have good sensitivity for hearing loss (Boatman et al., 2007). Other screening measures are only capable of measuring hearing handicap or detecting the specific type of hearing loss for which they were designed to identify (Sindhusake et al., 2001; Vento & Durrant, 2009). The Ling- 6 Sound Test has the potential to screen for hearing loss regardless of etiology. Although all of the participants in this study had sensorineural hearing losses, individuals with a conductive or mixed hearing loss would also have reduced accuracy for repeating back Ling-6 sounds. Furthermore, the Ling-6 Sound Test has good sensitivity for hearing loss. When using a passing criterion of 100% (8/8 correctly repeated) for each individual Ling-6 sound, and a composite passing score of 100% (receiving a passing score for each of the individual sounds), the Ling-6 Sound Test has a sensitivity of 100% and a specificity of 66.67%. Sensitivity measures for each individual Ling-6 sound are lower, but it would be imprudent to rely on only one isolated speech sound to identify hearing loss. Depending on the frequency range of an individual's hearing loss, it is possible that they could pass a hearing screening that only utilized one isolated speech sound. For example, if an

individual had hearing loss only in the low to mid frequencies (from 250- to 2000 Hz) and normal hearing in the high frequencies (3000- to 8000 Hz), they would pass a screening that only used the /s/ sound because its peak frequency is around 5000 Hz. Likewise, someone with a high frequency hearing loss (3000- to 8000 Hz) and normal low to mid frequency hearing (250- to 2000 Hz) would be able to pass a screening that only utilized the /m/ sound because its peak energy is located around 250 Hz. The use of a composite score improves the sensitivity of the Ling-6 Sound Test because it is better capable of identifying individuals who have rising or sloping hearing losses. A required passing score of 100% is utilized for both individual phoneme scores and the composite score because individuals with normal hearing should be able to repeat back all of the Ling-6 sounds with perfect accuracy. Using a passing score of 100% does give a lower specificity, but it would be better to over refer normal individuals for diagnostic testing than to miss individuals who do have a hearing loss.

Limitations

The first limitation of the present study is further investigation using a sound level meter indicated that the microphone used to record the speech samples did not have as much of an omnidirectional polar plot (recording sound equally from all directions) as was originally thought. When a 50 dB HL tone was produced through the audiometer and measured at the calibrated point within the sound booth, it was measured at 50 dB HL by a sound level meter. However, when the recorded 50 dB HL reference tones were played through the audiometer, they did not measure at 50 dB HL on the sound level meter until the intensity on the audiometer was turned up by 22 dB HL. When the reference tones were recorded before each speech sample acquisition, the microphone

was pointed at the individual being recorded rather than the speakers. With this kind of set up, it is possible that part of the sound energy was located within the null point of the microphone's polar plot, making the reference tone recordings less intense than 50 dB HL. This, in turn, could have made each of the Ling-6 sounds misleadingly more intense once average intensity measurements were completed. It would have also made the speech sounds presented to the participants less intense than intended.

A second limitation of the current study is the use of only one CD to test every participant. While the forty-eight Ling-6 sounds were randomized before being burned to the calibrated CD, the same CD was used to test both ears of each participant. It is possible that this led to practice effects, where participants performed better with the second ear that was tested because of familiarity with the order of the speech sounds. Familiarity with order of the speech sounds may have increased an individual's ability to make guesses about the sounds they were hearing.

Future Research

The current study collected pilot data regarding the use of the Ling-6 Sound Test as a hearing screener. As such, a very small number of participants were tested. I would recommend collecting data on a larger group of normal and hearing impaired individuals to further investigate using the Ling-6 Sound Test as a hearing screener. I would also recommend investigating the test's performance when it is administered in a way that more closely imitates how it would be used by a clinician in a hospital or primary care setting. This would include testing individuals in a room that was not sound treated and using the researcher's live voice.

Chapter 6

Conclusion

There are several currently available screening methods that are free but suffer from a lack of standardization and poor sensitivity for lesser degrees of hearing loss (Boatman et al., 2007). A promising new screening method, the Ling-6 Sound Test, has six speech sounds that span all of the speech frequencies. Speech analysis in the present study indicated that, regardless of examiner, the Ling-6 sounds represent the different frequencies found in speech. The difference in scores between normal hearing participants and hearing loss participants, as well as the correlations of accuracy to puretone thresholds, indicated that it can be successfully used to identify those with hearing loss.

The significant difference in accuracy for repeating back Ling-6 sounds between normal hearing and hearing loss participants, as well as the significant correlation between accuracy and thresholds, also have implications for using the Ling-6 Sound Test as a hearing screening method. Individuals with hearing loss are likely to be less accurate at repeating back speech sounds than their normal hearing counterparts (Ching & Dillon, 2013). Hearing loss has a very high prevalence amongst adults, and unidentified hearing losses can have several negative impacts on an individual's wellbeing. The only way to effectively combat these negative impacts is to identify that it exists and then treat it. One of the easiest ways to do so is with a hearing screening. The Ling-6 Sound Test's simplicity and ease of use makes it an ideal candidate for use as a screening measure in adults. Its six phonemes make it feasible to screen hearing sensitivity across the entire speech spectrum in a matter of minutes.


Appendices

Appendix A



APPROVAL NUMBER: 14-A041

To: Cecelia Kilcullen
8000 York Road
Towson MD 21252

From: Institutional Review Board for the Protection of Human
Subjects Stacy Spaulding, Member 

Date: Wednesday, November 13, 2013

RE: Application for Approval of Research Involving the Use of
Human Participants

Office of Sponsored Programs
& Research

Towson University
8000 York Road
Towson, MD 21252-0001
T. 410 704-2236
F. 410 704-4494

Thank you for submitting an Application for Approval of Research Involving the Use of Human Participants to the Institutional Review Board for the Protection of Human Participants (IRB) at Towson University. The IRB hereby approves your proposal titled:

Ling-6 Sounds as a Hearing Screening Measure

If you should encounter any new risks, reactions, or injuries while conducting your research, please notify the IRB. Should your research extend beyond one year in duration, or should there be substantive changes in your research protocol, you will need to submit another application for approval at that time.

We wish you every success in your research project. If you have any questions, please call me at (410) 704-2236.

CC: S. Nagle
File



Date: Wednesday, November 13, 2013

NOTICE OF APPROVAL

TO: Cecelia Kilcullen **DEPT:** ASLD

PROJECT TITLE: *Ling-6 Sounds as a Hearing Screening Measure*

SPONSORING AGENCY:

APPROVAL NUMBER: 14-A041

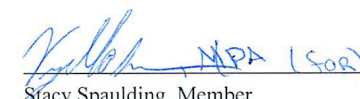
The Institutional Review Board for the Protection of Human Participants has approved the project described above. Approval was based on the descriptive material and procedures you submitted for review. Should any changes be made in your procedures, or if you should encounter any new risks, reactions, injuries, or deaths of persons as participants, you must notify the Board.

A consent form: ☒ is ☐ is not required of each participant

Assent: ☐ is ☒ is not required of each participant

This protocol was first approved on: 2013-11-13

This research will be reviewed every year from the date of first approval.


 Stacy Spaulding, Member
 Towson University Institutional Review Board

Appendix B

Ling Six-Sound Screener Score Sheet

Participant Number: _____

Ear: _____

Track 1

---	U _{F1}	I _{M1}	I _{F1}	S _{F2}	M _{M2}	S _{M1}	SH _{M2}	U _{M2}	M _{F1}	A _{F2}	SH _{F2}	A _{M1}

Track 2

M _{M2}	SH _{F2}	M _{F2}	A _{F1}	---	SH _{M1}	U _{F2}	A _{M2}	I _{F2}	I _{M1}	S _{M1}	S _{F1}	U _{M2}

Track 3

I _{M2}	A _{F1}	---	M _{F2}	I _{F1}	U _{M1}	U _{F1}	SH _{M2}	S _{M2}	M _{M1}	A _{M2}	S _{F1}	SH _{F1}

Track 4

M _{M1}	I _{F2}	S _{M2}	U _{M1}	M _{F1}	A _{F2}	SH _{F1}	---	S _{F2}	A _{M1}	I _{M2}	U _{F2}	SH _{M1}

Ling Sound	/a/	/i/	/u/	/sh/	/s/	/m/
Total Percent Score						
Male Sounds Percent Score						
Female Sounds Percent Score						

References

- Agrawal, Y., Platz, E., & Niparko, J. (2008). Prevalence of hearing loss and differences by demographic characteristics among U.S. adults. *Archives of Internal Medicine*, 168(4), 1522-1530.
- Agung, K. B., Purdy, S. C., & Kitamura, C. (2005). The Ling sound test revisited. *The Australian and New Zealand Journal of Audiology*, 27(1), 33.
- American Speech-Language-Hearing Association. (1997). *Guidelines for audiologic screening*. Retrieved from <http://www.asha.org/policy>.
- Bagai, A., Thavendiranathan, P., & Detsky, A. S. (2006). Does this patient have a hearing impairment?. *Journal of the American Medical Association*, 295, 416-428.
- Boatman, D. F., Miglioretti, D. L., Eberwein, C., Alidoost, M., & Reich, S. G. (2007). How accurate are bedside hearing tests?. *Neurology*, 68, 1311-1314.
- Ching, T. Y., & Dillon, H. (2013). A brief overview of factors affecting speech intelligibility of people with hearing loss: Implications for amplification. *American Journal of Audiology*, 22(2), 306-309.
- Chisolm, T., & Abrams, H. (2008). Outcome measures and evidence-based practice. In H. Hosford-Dunn, R. Roesser, & M. Valente (Eds.), *Audiology: Practice management* (171–194). New York: Thieme.
- Cordova, A. C., Logishetty, K., Fauerbach, J., Price, L. A., Gibson, B. R., & Milner, S. M. (2013). Noise levels in a burn intensive care unit. *Burns*, 39, 44-48.
- Dickson, C. L. (2010). Ling-6 sounds daily check. Retrieved from http://hope.cochlearamericas.com/sites/all/themes/cochlear_hope/PDFs/SF_Ling_6_SoundTest.pdf.

- Eekhof, J. A., de Bock, G. H., de Laat, J. A. P. M., Dap, R., Schaapveld, K. & Springer, M. P. (1996). The whispered voice: The best test for screening for hearing impairment in general practice?. *British Journal of General Practice*, 46, 473-474.
- Hillenbrand, J., Getty, L. A., Clark, M. J., & Wheeler, K. (1995). Acoustic characteristics of american english vowels. *The Journal of the Acoustical Society of America*, 97(5), 3099-3111.
- Holcomb, S. S., & Punch, J. L. (2006). Multimedia hearing handicap inventory: Reliability and clinical utility. *American Journal of Audiology*, 15(1), 3-13.
- Kerr, M., McCullagh, M., Savik, K., & Dvorak, L. (2003) Perceived and measured hearing ability in construction laborers and farmers. *American Journal of Industrial Medicine*, 44, 431–437.
- Lin, F. R., Thorpe, R., Gordan-Salant, S., & Ferrucci, L. (2011). Hearing loss prevalence and risk factors among older adults in the united states. *Journal of Gerontology*, 66A(5), 582-590.
- Ling, D. (1976). *Speech and the hearing impaired child: Theory and practice*. Washington, DC: Alexander Graham Bell Association for the Deaf.
- Liu, C. F., Collins, M. P., Souza, P. E., & Yueh, B. (2011). Long-term cost-effectiveness of screening strategies for hearing loss. *Journal of Rehabilitation Research & Development*, 48, 235-244.
- Meehan, T. (2012). *The ling six-sound test*. Retrieved from http://http://ehdimeeting.org/2012/Users/Uploads/Handout_535TracyMeehan.pdf

- Menegotto, I. H., Soldera, C. L. C., Anderle, P., & Anhaia, T. C. (2011). Correlation between hearing loss and the results of the following questionnaires: Hearing handicap inventory for the adults-screening version HHIA-S and hearing handicap inventory for the elderly-screening version-HHIE-S. *Arquivos Internacionais de Otorrinolaringologia*, 15(3), 319-326.
- Miltenburg, D. M. (1994). The validity of tuning fork tests in diagnosing hearing loss. *Journal of Otolaryngology*, 23(4), 254-259.
- Mulrow, C. D., Aguilar, C., Endicott, J. E., Tuley, M. R., Velez, R., Charlip, W. S...DeNino, L. A. (1990). Quality-of-life changes and hearing impairment: A randomized trial. *Annals of Internal Medicine*, 113, 188-194.
- Newman, C. W., & Sandridge, S. A. (2004). Hearing loss is often undiscovered, but screening is easy. *Cleveland Clinic Journal of Medicine*, 71, 225-232.
- North, S., & Sindrey, D. (2007). *Ling 6 sounds screen*. Retrieved from <http://www.hearingjourney.com/userfiles/file/ling6screeninstr.pdf>
- Raphael, L. J., Borden, G. J., & Harris, K. S. (2007). *Speech science primer: Physiology, acoustics, and perception of speech*. Philadelphia, PA: Lippincott Williams & Wilkins.
- Sindhusake, D., Mitchell, P., Smith, W., Golding, M., Newall, P., Hartley, D., & Rubin, G. (2001). Validation of self-reported hearing loss. The blue mountains hearing study. *International Journal of Epidemiology*, 30(6), 1371-1378.
- Smiley, D. F. (2004). *Using the ling 6-sound test everyday*. Retrieved from <http://audiologyonline.com/articles/using-ling-6-sound-test-1087>

- Strawbridge, W. J., Wallhagen, M. I., Shema, S. J., & Kaplan, G. A. (2000). Negative consequences of hearing impairment in old age: A longitudinal analysis. *The Gerontologist*, 40(3), 320-326.
- Swan, I. R. C., & Browning, G. G. (1985). The whispered voice as a screening test for hearing impairment. *The Journal of the Royal College of General Practitioners*, 35, 197.
- Szudek, J., Ostevik, A., Dziegielewska, P., Robinson-Anagor, J., Gomaa, N., Hodgetts, B., & Ho, A. (2012). Can uhear me now? Validation of an ipod-based hearing loss screening tool. *Journal of Otolaryngology-Head & Neck Surgery*, 41, S78-S84.
- Tenhaaf, J. J., & Scollie, S. D. (2005). Normative threshold levels for a calibrated, computer-assisted version of the Ling six-sound test. *Canadian Acoustics*, 33(3), 44-45.
- Tomioka, K., Ikeda, H., Hanaie, K., Morikawa, M., Iwamoto, J., Okamoto, N., Kurumatani, N. (2012). The hearing handicap inventory for elderly-screening (HHIE-S) versus a single question: Reliability, validity, and relations with quality of life measures in the elderly community, Japan. *Quality of Life Research*, 22(5), 1151-1159.
- Torres-Russotto, D., Landau, W. M., Harding, G. W., Bohne, B. A., Sun, K., & Sinatra, P. M. (2009). Calibrated finger rub auditory screening test (CALFRASST). *Neurology*, 72, 1595-1600.
- U.S. Department of Health and Human Services. (2008). *NORC final report: Healthy people user study*. Bethesda, MD: National Opinion Research Center.

- U.S. Preventative Services Task Force. (2012). Screening for hearing loss in older adults: U.S. preventive services task force recommendation statement (AHRQ Publication No. 11-05153-EF-2). Rockville, MD: USPSTF Program Office.
- Valente, M., Potts, L. G., Valente, L. M., St. George, M. F., & Goebel, J. (1992). High-frequency thresholds: Sound suite versus hospital room. *Journal of the American Academy of Audiology*, 3, 287-294.
- Vento, B. A., & Durrant, J. D. (2009). Assessing bone conduction thresholds in clinical practice. In J. Katz, L. Medwetsky, R. Burkhard, & L. Hood (Eds.), *Handbook of Clinical Audiology* (pp. 50-63). Baltimore: Lippincott Williams & Wilkins.
- Yueh, B., Collins, M. P., Souza, P. E., Boyko, E. J., Loovis, C. F., Heagerty, P. J...Hendrick, S. C. (2010). Long-term effectiveness of screening for hearing loss: The screening for auditory impairment—which hearing assessment test (SAI-WHAT) randomized trial. *Journal of the American Geriatrics Society*, 58(3), 427-434.

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