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THE LING SIX-SOUND TEST AS A HEARING SCREENING MEASURE

by

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THESIS APPROVAL PAGE

This is to certify that the thesis prepared by Cecelia Kilcullen entitled The Ling Six-Sound Test as a Hearing Screening Measure has been approved by the thesis committee as satisfactorily completing the thesis requirement for the degree, Doctor of Audiology (Au.D.).

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ABSTRACT

The Ling Six-Sound Test as a Hearing Screening Measure

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The aim of this study was to develop a hearing screening measure using the Ling Six-Sound Test that would be easy to learn and use, while also being low-cost and brief. The Ling Six Sounds include /a/, /i/, /u/, /ʃ/, /s/, and /m/. This study examined whether different people could produce the six sounds from the Ling Six-Sound Test in a consistent way, so that a hearing screening would be possible without speech and/or speaker variations affecting the screening results. Twenty adult participants (10 men and 10 women) with normal hearing produced each of the Ling sounds eight times while sitting two feet from a microphone in a sound attenuated booth. Peak intensity and average intensity were measured for all sounds. The first and second formant frequency were measured for vowels, and the peak frequency was measured for consonants. The intensity and frequency of each production was compared within subject, between subjects, and between genders. There were statistically significant differences within subjects, between subjects and between men and women; however the differences may be large enough to affect the outcome in a clinical setting. The results from this study indicated that a future study should be conducted with a larger sample size in order to confirm these results.

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Chapter 1

Introduction

Hearing loss affects approximately 360 million people worldwide, mainly impacting one's ability to communicate with others (WHO, 2013). The vast majority of people with hearing loss go unidentified, and currently only 10% of those who could benefit from hearing aids worldwide actually have some form of amplification (WHO, 2013). In addition to communication, hearing loss also impacts employment, independent living and mental health (Lin, Thorpe, Gordon-Salant, & Ferrucci, 2011). Current hearing aid technology has the ability to provide an improvement in hearing and quality of life (QoL) to the majority of people with hearing loss, but 90% of those who could benefit from hearing aids do not have them (WHO, 2013).

One major problem seen with hearing loss is that presbycusis, or age related hearing loss, occurs gradually over time and is not noticed as an acute health problem that requires immediate care. While older adults regularly seek medical care for other health concerns, regular hearing health care is not often sought. Considering the significant impact that hearing loss can have on a person's QoL, this highlights the need for effective, inexpensive hearing screenings that can be conducted by professionals who provide regular service to the older adult population. Research suggests that untreated hearing loss older adults affects an older adult's ability to maintain social interaction, effective communication and overall health (Dalton, Cruickshanks, Klein, Klein, Wiley, & Nondahl, 2003; Lin, Metter et al., 2011; Pronk, Deeg, & Kramer, 2013; Strawbridge, Wallhagen, Shema, & Kaplan, 2000).

There is a wide range of hearing screenings currently available; however, none effectively combine ease of use, efficiency, reliability, and low cost (U.S. Preventative Services Task Force, 2012). Current screenings include self-report of hearing loss, questionnaires, audiometric screening, internet and phone-based screenings, and bedside tuning fork tests, among others. While self-reports and questionnaires have the benefit of low cost and ease of use, they are often unreliable (Boatman et al., 2007). If a patient is not accepting of hearing loss, they can easily report that they have no difficulty. Tuning fork tests do not assess for the primary type of hearing loss that affects older adults, and the cost of equipment for an audiometric screening is prohibitive for most facilities. Phone and internet-based tests can be affected by the environment in which the test is taken (Watson, Kidd, Miller, Smits & Humes, 2012). Furthermore, these phone and internet hearing screenings are often taken only by people who perceive that they have difficulty hearing in the first place (Watson et al., 2012).

The Ling Six-Sound Test, an assessment that has been used to test the function of hearing aids and cochlear implants since its original introduction in 1971, has the potential to be used as an effective bedside hearing screening, especially for older adults (Robb, Flexer & Rose, 2005). The Ling Six-Sound Test uses the speech sounds /a/, /i/, /u/, /ʃ/, /s/, and /m/, which range from low to high frequency (Robb et al., 2005). A medical professional could use these sounds as an assessment of one’s hearing across the range of speech frequencies, noting which frequencies one has difficulty hearing and explaining to the person how missing these sounds may affect speech understanding. The Ling Six-Sound Test as a hearing screening could provide an efficient, reliable, low cost, more detailed hearing screening for adults. This screening could be performed during a routine medical visit, which would be convenient for both the medical professional and the patient. This screening would also give medical professionals an opportunity to discuss hearing healthcare and management of hearing loss, which are the first steps toward improving communication, social interactions, and mental and physical health. This study examined whether different people could produce the six sounds from the Ling Six-Sound Test in a consistent way, so that a hearing screening would be possible without speech and/or speaker variations affecting the screening results.

Chapter 2

Literature Review

Of all adults over the age of 65 years, approximately one-third has hearing loss of a moderate degree or worse, significantly affecting communication (WHO, 2013). Especially in the elderly, hearing loss can have a significant negative impact on QoL and social interactions (Dalton et al., 2003; Lin, Metter et al., 2011). Untreated hearing loss in older adults is associated with depression, a decline in cognitive functioning and overall health, and most notably, a higher risk for dementia (Lin, Metter et al., 2011).

Due to the fact that age related hearing loss typically develops gradually, people do not view hearing loss as an urgent health concern that needs immediate intervention. Regular hearing assessments are often not a part of one's routine healthcare appointments; however, annual check-ups and visits to primary care physicians are common. Due to this fact, the primary care center may be the ideal location to discuss the importance of hearing healthcare. "The medical practitioner's role as a trusted source of information means that he or she often becomes the first point of contact for people seeking referral or advice about specialist health treatments including hearing rehabilitation" (Gilliver & Hickson, 2011, p. 851). In a survey conducted by Gilliver and Hickson (2011), the majority of physicians reported that their older patients' hearing was an important component of their overall health. Later in that same survey, 60% of the physicians responded that they felt that hearing loss occurs naturally with age and treatment is not necessary. This indicates that while physicians are aware of the effects of hearing loss in the elderly population, they may not be not actively bringing these effects to the attention of their patients (Gilliver & Hickson, 2011). Discussions about hearing loss, referrals, and more effective hearing screening methods in these healthcare settings would allow older adults to take steps toward diagnosis and management of hearing loss, thereby improving communication, social interactions, and the subsequent effects hearing loss can have on mental and physical health.

Aside from encouraging people with hearing loss to seek hearing healthcare and amplification, a medical professional should know the status of a patient's hearing prior to conveying medical information. Major decisions are often made in medical settings, where explanations, as well as the opportunity to ask questions and obtain details, are conducted in a verbal format. A patient's needs and safety could be compromised in a situation in which a medical professional conveys important information to a patient without knowing that the patient cannot hear the conversation adequately (Green & Pope, 2001).

Incorporating a hearing screening into medical examinations would be a quick and easy way to determine if a patient can adequately hear prior to conveying important information. However, with the wide variety of hearing screenings used, it is difficult to establish what screening methods may be effective. The U.S. Preventative Services Task Force currently reports that there is no effective hearing loss screening method for people who report no difficulty hearing in their daily lives (U.S. Preventative Services Task Force, 2012). People who sought hearing health care and hearing aids after failing a screening were likely to have subjective difficulty communicating in their daily life in the first place (U.S. Preventative Services Task Force, 2012). While screenings may identify and refer more people for evaluation, many people who fail hearing screenings are not accepting of their hearing loss, as hearing loss is associated with aging. While they may have difficulty communicating, they are not accepting of hearing loss, hearing aids, and the associated stigma. Current screening methods are not effective at encouraging these people to seek hearing healthcare (U.S. Preventative Services Task Force, 2012).

Screening tools for hearing loss

A wide range of screening techniques have been used as quick assessments of hearing loss for adults. When an audiometer is not available for pure tone screening, common hearing screening techniques include questionnaires, a single question, whispered voice tests, tuning fork tests, and phone screenings. Due to the fact that hearing loss most significantly affects one's communication and social life, self-report questionnaire screeners are frequently used alone or in combination with another screening method (Jupiter, 2009). Additionally, questionnaires require no equipment and are usually brief, increasing the likelihood that a medical professional will use them.

Questionnaire and self-report screenings for hearing loss. Some studies have found that self-report hearing screenings are successful at identifying people with hearing loss, while others describe just the opposite; these studies report a wide range of sensitivity and specificity (Boatman et al., 2007; Bushman, Belza, & Christianson, 2012). Some self-report screeners involve asking only one question, such as "do you feel that you have hearing loss?" while others use formal questionnaires along with a scoring system (Tomikoa et al., 2012). Asking a single question about one's self-perception of hearing loss often does not always prove to be an accurate screening method (Boatman et al., 2007). While it is important to positively identify people who have hearing loss, it is also valuable to correctly rule out people who are not currently having difficulty hearing. Even though a single question may have high sensitivity when asked to an elderly person, it has been found to have lower specificity than other self-report tools (Gates, Murphy, Rees, & Fraher, 2003). Furthermore, age related hearing loss is often characterized by a gradual decrease in hearing; this can be difficult to perceive over a long period of time. However, this single question screening has been found to be nearly as accurate as lengthier questionnaires (Boatman, Miglioretti, Eberwein, Alidoost, & Reich, 2007). If one has more than a mild hearing loss, this person is more likely to self-report that they feel like hearing loss affects them (U.S. Preventative Services Task Force, 2012).

Among self-report tools, the Hearing Handicap Inventory for the Elderly – Screening version (HHIE-S) is a popular one that only takes approximately five minutes to complete (Yueh et al., 2010). The original Hearing Handicap Inventory for the Elderly created by Ventry and Weinstein (1982) contained 25 questions that measured one's degree of social and emotional handicap caused by hearing loss. The HHIE-S is a ten-question screening tool asks about hearing handicap in social and everyday situations, relying heavily on self-perception of hearing difficulty (Deepthi & Kasthuri, 2012). Scores can range from zero (no perceived handicap) to 40 (maximum handicap), and the American Speech-Language Hearing Association has determined that a score greater than eight indicates some degree of hearing handicap (ASHA, 1997; Deepthi & Kasthuri, 2012; Tomikoa et al., 2012). Other researchers use a score of ten or greater on the HHIE-S as an indicator of potential hearing loss (Bushman et al., 2012; Gates et al., 2003; Menegotto, Soldera, Anderle, & Anhaia, 2011).

It has been frequently reported that the HHIE-S is better at ruling out a hearing loss than identifying people who actually have hearing loss (Deepthi & Kasthuri, 2012; Gates et al., 2003; Menegotto et al., 2011). People who do not have hearing loss often report accurate answers on the HHIE-S, while many people who do have some degree of hearing loss are not identified by this screening (Deepthi & Kasthuri, 2012). On the other hand, Bushman et al. (2012) reported that the HHIE-S has 80% sensitivity and 76% specificity. Degree of actual hearing loss may also affect the results of the HHIE-S, as people with greater than 40 dB hearing loss are more likely to be identified through the HHIE-S than people with a lesser degree of hearing loss (Tomikoa et al., 2012). The HHIE-S is more likely to identify people who perceive some difficulty hearing regardless of their actual measured degree of hearing loss, as this is a self-report screening. For adults who do not perceive hearing difficulties, or those who are not ready to address their hearing difficulties, the HHIE-S may be ineffective (Tomikoa et al., 2012). For better accuracy, ASHA (1997) recommends using a combination of a hearing handicap questionnaire along with a pure tone screening in the elderly population. Liu, Collins, Souza, and Yueh (2011) found that screening by a tone-emitting otoscope was more cost effective than using the HHIE-S among 2251 older adults.

Overall, this questionnaire used for hearing screenings can be beneficial, as questionnaires are low cost and brief. While the HHIE-S is the most popular screening among the literature, other questionnaires include the multimedia hearing handicap inventory (MHHI), and lengthier questionnaires such as the HHIE and the hearing handicap inventory for adults (HHIA) (Holcomb & Punch, 2006). Studies report that hearing screening questionnaires have varying degrees of sensitivity and specificity with little consistency (Liu et al., 2011; Tomikoa et al., 2012). Questionnaires can be helpful in identifying people with a moderate hearing loss or worse, but those with less than a moderate hearing loss are unlikely to be identified with questionnaire screenings

(Tomikoa et al., 2012). Additionally, people who are unwilling to admit that they have difficulty hearing will not likely be identified (Tomikoa et al., 2012).

Whispered voice as a hearing screening. Whispered voice screening is a method that is easily employed in any setting. This screening is typically done by standing near (six inches to two feet) the person who is being screened, but out of their field of vision so that lip reading cannot be employed (Macphee, Crowther, & McAlpine, 1988; Maguire, Prosser, Boland, & McDonnell, 1998). The distance between the speaker and the person who is being screened can vary, as it is an approximation. Screening results may be significantly affected by standing nearer or farther from the patient, as when a person is farther from the patient, their voice will be less intense. For example, doubling the distance between the tester and the patient will reduce the intensity by 6 dB. Single words, letters or numbers are used as the stimulus, and more than one inaccurate response or lack of response is considered a failed screening (Boatman et al., 2007; Macphee et al., 1988). Varying degrees of loudness (whisper, conversational speech) are used by the person performing the screening, and sometimes noise is made or occlusion is used in an attempt to rule out the hearing of the opposite ear.

Whispered voice at about two feet (estimated at about arm's length) from a patient was found to be an effective screener (Macphee et al., 1988; Pirozzo, Papinczak, & Glasziou, 2003). Pirozzo et al. (2003) surveyed four studies of the whispered voice test on adults, finding that the screening conducted at about two feet from the patient had a range of sensitivity from 90 to 100%, and specificity from 70 to 87%. Contrasting this study, use of the whisper test as a screener on members of the military was found to be a poor indicator of objective hearing loss, with the authors citing that environmental noise, full occlusion of the non-test ear, and variations between test administrators and administration affected testing (Goldman, 1945). Similarly, Maguire et al. (1998) found that the whispered voice test identified fewer people with hearing loss than a questionnaire. Furthermore, it was noted that it is very difficult to control for a practitioner's whispered voice loudness, which may account for variations between studies (Macguire et al., 1998). Because of this, a positive result on the whispered voice test could be easily dismissed as an error in test administration.

Tuning fork tests. Tuning fork tests using 128, 256 and 512 Hz tuning forks are portable, easy to use, and often used for hearing screenings in medical settings (McCullage & Frank, 2012; Ponizov & Meshcheryakov, 2012). However, tuning fork tests do not screen for the most common type of age related hearing loss, presbycusis. Tuning fork tests are most successful at identifying conductive or unilateral hearing losses, not a bilateral hearing loss of sensorineural origin (McCullage & Frank, 2012; Ponizov & Meshcheryakov, 2012). Because of this, tuning forks are useful in a medical setting, but limited in identifying older adults with sensorineural hearing loss who need a full audiological evaluation.

One tuning fork test, the Rinne test, was developed and is used to determine the presence of a conductive hearing loss or the need for a referral to a hearing healthcare specialist (Burkey, Lippy, Schuring, & Rizer, 1998). The 512-Hz tuning fork is struck on a hard surface and placed alternatively about an inch from the ear canal and then on the mastoid. If the mastoid placement sounds louder to the patient, this is a negative Rinne, which indicates that there is likely a conductive component. If the placement near the ear canal opening is perceived as louder, this is a positive Rinne, indicating no conductive hearing loss. Applications for this test include medical settings in which a conductive hearing loss is suspected. The Rinne test has high sensitivity (96.6%) and specificity (73.1%), with better sensitivity in identifying larger air-bone gaps (Burkey et al., 1998). However, the most common form of age-related hearing loss is sensorineural, not conductive and this test does not address this type of hearing loss at all.

A second tuning fork test that is often used is the Weber test (McCullagh & Frank, 2012; Ponizov & Meshcheryakov, 2012). This test is only effective in determining if there is an asymmetrical hearing loss. The struck tuning fork is placed at the midline at the top of the head. If the sound is equally loud in both ears, the hearing loss is symmetrical or hearing is within normal limits. If one ear hears the sound louder, that ear may have a conductive component to the hearing loss or one ear may have worse hearing than the other (Ponizov & Meshcheryakov, 2012). The Rinne and Weber combined are often used as an informal hearing assessment in medical settings (Boatman et al., 2007). Postive results may indicate that a full audiologic evaluation is necessary. Similar to the Rinne test, this tuning fork test does not address most common forms of hearing loss. Asymmetry is not commonly seen in age-related hearing loss, and the Weber test cannot identify if an individual has any degree of symmetrical hearing loss in both ears (Boatman et al., 2007).

Using the telephones/computers as a screening for hearing loss. For the elderly, using the telephone to screen for hearing loss has been attempted, as this is a device that is in nearly every home. Smits, Kapteyn and Houtgast (2004) initially devised a Dutch telephone speech-in-noise screening that is currently used in seven countries (Watson et al., 2012). Understanding speech in the presence of background noise is often the most difficult listening situation for people with hearing loss (Smits et al., 2004). This phone screening is fully automated, and the person calls the number to connect to a computer system. The person being screened is asked to identify three monosyllabic digits that have been said in a background of noise using the touch-tone phone keypad. The intensity of the speech is increased or decreased in 2 dB steps depending on the individual's response, and a speech reception threshold (SRT) in noise is established after 23 sequences. Benefits of this phone screening include its objectivity when compared to more subjective measures like questionnaires, as the individual's opinion is not a factor (Smits et al., 2004). Additionally, no significant differences were found using several different telephones, and the SRT in noise that was established have a strong correlation with the subjects' pure tone averages (PTA) in the original study (Smits et al., 2004).

A version of this three-digit speech in noise screening was created based on the design by Smits et al. (2004) for use in the United States (Watson et al., 2012). After modifications and new stimuli were recorded in American English, 64 sets of three numbers each were determined as the stimuli to be used. The correlation between the results of the phone screening and the PTA on the 90 listeners in the study was 0.74, similar to what was found in other countries using this telephone screening model. They found that this is a valid hearing screening measure, although scores on the Hearing In Noise Test (HINT) were not found to correlate well with the telephone screening results. This test was estimated to cost about $3 to $4 per call. While this may be a valid screening measure, telephone screenings require funding, staffing and advertisement. There is no clear answer as to how such a program would be funded (Watson et al., 2012). This method is much more involved and expensive than a brief screening that could be conducted as a part of a routine visit to a physician.

Internet and smartphone hearing screenings have also arisen in recent years. Internet screenings can be found on countless websites, and many even incorporate speech-in-noise testing (Stenfelt, Janssen, Schirkonyer & Grandori, 2011). Frequently, a person will be asked to identify a target word or sentences from a closed-set of choices. This is a great method for reaching the public, as the internet is easily accessible. Another popular smartphone application is uHear (Szudek et al., 2012). This hearing screening is conducted on a personal Apple iPhone using earphones. For people with a pure-tone average (PTA) greater than 40 dB HL, uHear proved to be an accurate screening method; however, the application also over-estimated the PTA of normal hearing individuals by 8 to 14 dB (Szudek et al., 2012). Furthermore, this application was most successful in a sound-attenuated room, which is rarely available for hearing screenings (Szudek et al., 2012). Problems with internet and mobile phone screeners are that they are often not validated, they are either overly sensitive or not sensitive enough, and calibration of individual speakers and earphones is not accounted for (Stenfelt et al., 2011). Furthermore, the room in which the screening is conducted and one's distance from the sound source may not be controlled for during computer based screenings when the patient is conducting them in the home independently.

While there are several methods used for hearing loss screenings, no gold standard has been established. Many screening methods have numerous factors that cannot be controlled for, while others rely heavily on an individual's self-perception, which is not always an accurate measure. An effective hearing screening that is easy to use and reliable would be ideal for use in a medical setting.

The need for effective hearing screenings. Hearing loss adversely affects communication, but it is also associated with depression and a decline in one's social and cognitive functioning in the elderly population (Boatman et al., 2007; Lindenberger & Baltes, 1994). Lin (2011) found that adults age 60 to 69 years who were identified with hearing loss also scored lower on an assessment of cognitive functioning. In a study through the Baltimore Longitudinal Study of Aging, the risk of dementia was found to increase linearly with severity of hearing loss for older adults (Lin, Metter et al., 2011). Cognitive decline is concerning for older adults, as it can compromise independent living and safety. Older adults with hearing loss have reported more difficulty with activities of daily living than those with normal hearing, and more severe hearing loss was associated with increased difficulty completing daily tasks (Gopinath et al., 2011). If an effective hearing screening were administered prior to cognitive and social effects of hearing loss, steps may be taken to reduce these negative consequences.

Furthermore, hearing aid use has been associated with higher scores on assessments of cognitive functioning (Lin, 2011). Older adults who are identified with hearing loss and fit with hearing aids shortly after their diagnosis have been found to be more successful hearing aid users than those who do not obtain hearing aids until several years after a diagnosis of hearing loss (Davis, Smith, Ferguson, Stephens, & Gianopoulos, 2007). With effective, systematic screening methods, an estimated 10% increase in hearing aid fittings could be expected (Davis et al., 2007). Increased hearing aid use can lead to easier communication, more opportunity and desire for social interaction, and subsequently better overall cognitive functioning in older adults (Lin, 2011).

Reports of the necessity of screening measures for the adult population vary. ASHA (1997) recommends that people over age 50 years have a hearing screening every three years, as this population has a higher prevalence of hearing loss than younger people. For people under 50, a screening every ten years is recommended (ASHA, 1997). Among adults age 50 or older who are not complaining of hearing loss, the U.S. Preventative Services Task Force did not find enough evidence to support the benefits of hearing screenings (U.S. Preventative Services Task Force, 2012). If effective and low cost screening methods were available, it is likely that there would be more support for the use of hearing loss screenings in older adults. The U.S. Preventative Services Task Force (2012) views obtaining and benefitting from hearing aids as the goal of hearing screenings, and most older adults who had a positive screening result but no objective hearing loss did not obtain hearing aids. People who already perceived hearing loss at the time of the hearing screening were more likely to obtain and benefit from hearing aids (U.S. Preventative Services Task Force, 2012).

The cost of hearing screenings. The cost of a hearing screening varies greatly depending on the method, equipment, overhead and staff time involved in the screening. Aside from monetary cost, value of a screening must also be determined by the sensitivity and specificity of a method (U.S. Preventative Services Task Force, 2012). For best accuracy, the method must both rule out those with normal hearing and identify those with hearing loss.

Questionnaires, self-report, and other screenings that require no equipment (i.e. whispered voice test) have the lowest cost overall, especially if they are a component of a physical or regular in-office visit. Costs of these assessments include the medical professional's time, both in the form of test administration time and follow-up counseling. However, these screening methods have a wide range of reported sensitivity and a higher rate of false positives than a brief audiometric screening (Boatman et al., 2007).

A survey conducted by Smith et al. (2007) found that an audiometric screening at the level of 35 dB HL at 3000 Hz had high sensitivity (97%). Using 35 dB HL as the screening intensity was aimed at reducing false positives and excluding those with a mild degree of hearing loss who were unlikely to seek intervention. When combined with a short questionnaire about subjective hearing loss, this two step screening method "... has the capacity to identify those who would gain significant benefit from wearing a hearing aid compared with those who would not" (Smith et al., 2007, p. 87). The cost per person screened was estimated at about $20. This took into consideration tester time, equipment and supply and overhead costs (Smith et al., 2007).

While an audiometric screening is the most efficient method in identifying people who should be referred for full audiologic evaluations, the general population is unlikely to have access to the equipment necessary for this measure (Smith et al., 2007). The questionnaire screenings, while less efficient and effective, may be the most viable option in many cases due to their ease of access (Smith et al., 2007).

By targeting the older adult population, screenings can be more cost effective, as this age group has the highest prevalence of hearing loss (Smith et al., 2007). Furthermore, screening adults age 60 to 70 could identify hearing loss in a less severe stage, when hearing aids and aural rehabilitation could prove to be most beneficial (Smith et al., 2007). Rehabilitation in this age range could benefit hearing aid use, and act as a preventative measure for improved overall health, cognition, and social wellbeing (Smith et al., 2007).

The cost of hearing loss is more than just the cost of hearing healthcare and hearing aids; hearing loss affects one's ability to earn an income, live independently and function in society (Green & Pope, 2001). In 2007, the cost of hearing loss to Europe's economy was estimated at over $300 billion annually (Smith et al., 2007). Additionally, people with hearing loss often have increased healthcare costs related to the effects of hearing loss on mental health and physical wellbeing (Green & Pope, 2001). Lin, Metter et al. (2011) reported that with more severe hearing loss, one is more likely to have dementia, which comes with the costs of adult care, increased medical expenses, and most importantly, the cost of one's independence.

By establishing an effective, low cost hearing screening, hearing healthcare could be initiated at earlier stages of hearing loss. Currently, there is no hearing screening that fulfills this need. The Ling Six-Sound Test has the potential to be used as a bedside hearing screening in many professional settings.

The Ling Six-Sound Test

Current uses. The Ling Six sounds are frequently used to assess the function of one's amplification device (hearing aid or cochlear implant). These sounds were selected because they cover the range of speech frequencies from low to high (Robb et al., 2005). First established by Daniel Ling in 1976, the Ling sounds initially included /a/, /i/, /u/, /ʃ/, and /s/. The sixth sound to be added to the Ling sounds was /m/, to include a lower frequency sound. (Robb et al., 2005). The sounds are used in isolation, and they are often used as an informal assessment of one's hearing ability (Smiley, 2004; Tenhaaf &

Scollie, 2005). Commonly, teachers, parents and therapists use the Ling Six-Sound Test at the beginning of each day or session to ensure that a child's hearing aid or cochlear implant is functioning as expected. The sounds are typically made at progressively further distances from the child, with no lip reading or visual cues provided. The speaker must be careful to use a normal conversational level with each sound produced, regardless of the distance from the listener (Robb et al., 2005). Once a child is able to perform the task from a few inches away, the speaker may move to three, six or nine feet away to further challenge the listener (Dickson, 2010). The child can indicate that they heard a sound (detection), or they can respond with the sound that they heard (identification) (Scollie et al., 2012). For young children, toys are props can be used to associate the sounds, such as a toy snake for the /s/ sound (Robb et al., 2005). The application of the Ling Six-Sound Test can be made more difficult as a child progresses (Scollie et al., 2012).

If a child is asked to detect sounds by associating a sound with play, such as dropping a block in a bucket, then the speaker knows that the child is hearing speech sounds (Smiley, 2004). If a child is able to identify several sounds but not all sounds at baseline, the sounds missed may be targeted in therapy. Alternately, if a child was previously able to detect or identify a sound and now cannot, this is an indicator that either hearing aid/cochlear implant function or hearing thresholds may have changed and should be looked into further (Smiley, 2004). Ideally, the Ling Six-Sound Test should be performed with one hearing aid or cochlear implant coupled to the child at a time each day (Robb et al., 2005).

The problem with using the Ling Six-Sound Test is that it is an uncalibrated, informal assessment (Tenhaaf & Scollie, 2005). Furthermore, there is no normative data regarding the levels at which a normal hearing individual is expected to hear each sound. Tehaaf and Scollie (2005) recorded the Ling Six sounds using a female speaker, and edited each sound so that it was approximately one second long without any significant peaks in intensity. These phonemes were presented to ten normal hearing listeners to determine the threshold for each sound. The listeners were asked to identify if they heard a sound or did not hear a sound. The mean thresholds ranged from -3.1 dB SPL (for /ʃ/) to 21.8 dB SPL (for /m/). Cutoff for what would be expected for a normal hearing individual were created, with a 95% confidence interval, and are outlined in the table below (Tenhaaf & Scollie, 2005).

Table 1

Mean Intensity for Audibility of Ling Six Sounds

Ling Sound	Mean Threshold	Cutoff for Normal Hearing
/a/	0 dB SPL	5.0 dB SPL
/i/	5.9 dB SPL	16.6 dB SPL
/u/	7.9 dB SPL	18.4 dB SPL
/ʃ/	-3.1 dB SPL	1.4 dB SPL
/s/	16.7 dB SPL	20.5 dB SPL
/m/	21.8 dB SPL	26.1 dB SPL

Note. Tenhaaf and Scollie (2005) data.

Of note, this same threshold assessment was completed on one adult with a high frequency hearing loss (Tenhaaf & Scollie, 2005). While more subjects would need to be tested in order to determine if this is an actual pattern, this subject was unable to hear the /s/ and /ʃ/ phonemes at the cutoff level, but was able to hear all other phonemes. With further assessment on additional people with varying degrees and configurations, one would better be able to determine if the Ling Six-Sound Test could be sensitive to hearing loss (Tenhaaf & Scollie, 2005).

Speaker effects. Another consideration that could change the threshold at which one may hear the Ling Six sounds is the difference between speakers (Huber, Stathopoulos, Curione, Ash, & Johnson, 1999). . Differences in articulation and anatomical structures affect the production of sounds (Huber et al., 1999). Energy is produced by the vibration of one's vocal folds, and that energy is then shaped by the resonant features of the individual's anatomy and vocal tract (Kent, 1997). The shape of the vocal tract also changes with the production of different vowels (Kent, 1997). When making the /i/ phoneme, the back of the vocal tract creates a large cavity relative to the front portion of the vocal tract. Just the opposite happens when the vowel /a/ is made, where the front cavity of the vocal tract is large compared to the back of the vocal tract. When one produces the /u/ sound, the vocal tract is constricted in the middle. The /i/ and /u/ vowels have a high first formant (F1) frequency, which has to do with the height of the tongue when these sounds are produced. For the frequency of the second formant (F2), /i/ has a high frequency while /u/ and /a/ have a low F2 frequency (Kent, 1997).

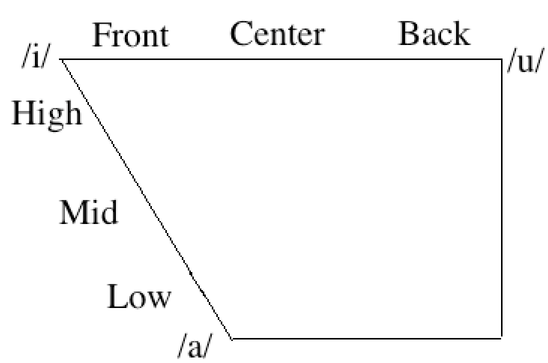

Figure 1. American English vowel quadrilateral indicating tongue height and location for

production of Ling vowel sounds, based on Dillon (2003).

The vocal tract shape forms consonants as well. For voiceless fricatives such as /s/ and /ʃ/, the vocal folds do not vibrate, but the vocal tract itself creates the sound by increased constriction at a certain location (Kent, 1997). Fricatives are identified by formants (increased sound energy). Nasals, such as the /m/ sound, are similar to fricatives, as they too have formants and antiformants due to energy absorption as the sound travels through the nasal cavity. Nasal consonants are produced by both the vocal tract and the nasal cavity. Combining the vocal tract and nasal passages increases the length that the sound can travel, lowering the formant frequencies of the sound to about 250-300 Hz for an adult male (Kent, 1997).

Because the vocal tract is a tube with an opening at one end, the longer the tube is, the lower the resonant frequency of the tube will be (Kent, 1997). This is supported by the differences in formant frequencies between men, women and children producing the same sound. Reports in the literature indicate that female voices will have higher formant frequencies and lower formant amplitudes for the production of vowels. Huber et al. (1999) found that the formant frequencies of vowels were almost always higher for females than males, even in young children. Women usually have shorter vocal tracts, smaller jaws and different face shapes than men, which all contribute to the differences in formants produced by women (Huber et al., 1999). The female vocal tract is about 15 cm long, while the male vocal tract is about 17.5 cm long (Kent, 1997). With the change in the length of the vocal tract, the resonant frequency of the tract changes (Kent, 1997).

The Ling consonant sounds include /m/, /s/, and /ʃ/. For the /m/ nasal consonant, the peak energy occurs at approximately 250 to 350 Hz, which is a low frequency Ling sound (Agung, Purdy, & Kitamura, 2005). The remaining two consonants, /s/ and /ʃ/, are voiceless fricatives, as the vocal folds do not vibrate during production. The /s/ fricative has peak energy located at approximately 5000 Hz, while /ʃ/ has peak energy at about 3000 Hz (Agung et al., 2005).

The Ling vowel sounds include /u/, /i/, and /a/. These sounds have two formants; F1 is a lower frequency and F2 is a higher frequency. These two formants, in addition to the distance between the two formants, help listeners to discriminate between vowel sounds (Kent, 1997). The frequency of the vowel formants varies slightly between male and female speakers, with male speakers generally producing lower frequencies. Below is an outline of average formant frequencies compared between men and women (Kent, 1997).

Table 2

Average Formant Frequencies Compared Between Male and Female Speakers

Vowel Sound	Male		Female	
	First Formant Frequency	Second Formant Frequency	First Formant Frequency	Second Formant Frequency
/a/	730 Hz	1090 Hz	850 Hz	1220 Hz
/i/	270 Hz	2290 Hz	310 Hz	2790 Hz
/u/	300 Hz	870 Hz	370 Hz	950 Hz

Note. Average formant frequencies of vowels according to Raphael, Borden, and Harris (2007).

People also adjust their speaking style when performing specific tasks or speaking to certain conversation partners, such as a person with hearing loss (Ferguson & Kewley-

Port, 2007; Lam, Tjaden, & Wilding, 2012). When attempting to speak more clearly, speakers often slow their rate of speech, increase pauses, and speak at a louder intensity. Over-enunciation may also change the spacing between the formants of vowels. Often an increase in vowel duration is also seen (Ferguson & Kewley-Port, 2002; Picheny, Durlach, & Braida, 1985). It has been suggested that instructing a person on how to speak can affect the talker's characteristics of speech (Lam et al., 2012). Instructions can vary; some can be asked to speak as though they are conversing with a non-native speaker or someone with hearing loss, while others may simply be asked to speak clearly (Ferguson & Kewley-Port, 2007).

Ferguson (2012) found that speakers had varying improvement in speech intelligibility when instructed to speak clearly. For 54 listeners with high frequency hearing loss, vowels were more intelligible when the talkers were using clear speech instead of conversational speech (Ferguson & Kewley-Port, 2007). However, among the 41 talkers in the study, intelligibility varied greatly between individuals regardless of whether the talker was trying to make their speech more clear or not. Another interesting finding of this study was that male and female voices were equally easy to understand. This is contrary to reports from many people with high frequency hearing loss that female speech is more difficult to understand. Furthermore, it is not clear which changes between conversational and clearly enunciated speech actually made a difference in intelligibility for the listener, especially listeners with hearing loss (Ferguson & Kewley-Port, 2007).

In older adults, age related hearing loss does not affect all frequencies in the same way (Weinstein, 2009). Age-related damage to the cochlea affects the basal region first, which correlates to a decrease in hearing primarily in the high frequencies. As a result, a hearing screening that uses speech or other sounds that cover a broad frequency spectrum may not identify high frequency hearing loss in older adults (Weinstein, 2009). On the other hand, the Ling Six sounds each have a concentration of energy in a specific frequency region (Robb et al., 2005). This may allow a person administrating a hearing screening to determine if an individual can hear sounds at certain frequencies and not at others. For example, a person with high frequency hearing loss may hear /a/, /i/, /o/ and /m/ but may not hear /ʃ/ and /s/.

Summary

As the population ages and advances in medicine increase life expectancy, older adults will continue to experience the effects of hearing loss, highlighting the need for effective, efficient hearing loss screening measures. There are a number of hearing screening methods, including questionnaire, self-report, tuning fork tests, and audiometric screenings, among others. While current screening methods can identify people who are having difficulty communicating in everyday life, there are many barriers to success. An audiometric screening is efficient and reliable, but the cost of equipment needed is prohibitive (Smith et al., 2007). Questionnaires and self-reported hearing loss have the benefit of ease of use and little overhead cost, but this method is much less effective in identifying people with hearing loss (Boatman et al., 2007). Due to the gradual nature of age related hearing loss, people often do not perceive that their hearing has diminished, or they may be unwilling to admit that they have hearing difficulty due to the associated stigma.

The Ling Six-Sound Test uses the speech sounds /a/, /i/, /u/, /ʃ/, /s/, and /m/, which range from low to high frequency (Robb et al., 2005). The application of these sounds as a hearing screening could be beneficial in identifying a hearing loss that affects some frequencies and not others, as is often seen with age related hearing loss. Presbycusis is characterized by hearing loss in the middle to high frequencies, which can greatly affect speech understanding (NIH, 2002). Because older adults are a target population for hearing screenings, this screening method could provide a more objective measure of hearing than a questionnaire alone without additional equipment costs.

The administration of the Ling Six-Sound Test as a hearing screening is feasible for medical professionals to perform in the office, taking only a few minutes. This could be in conjunction with a check-up or follow-up at the primary care physician's office, with little expense to the physician. Many different speakers would administer the Ling Six-Sound Test as a hearing screening measure, and as a result, concerns arise regarding inherent variations between the rate and intensity of speech between different speakers. This study examined if numerous different people can produce the six sounds from the Ling Six-Sound Test in a consistent way, so that in theory, hearing screening would be possible without speech and/or speaker variations affecting the screening results. This study seeks to answer three questions:

1. How much variation in intensity and frequency exists among the eight productions of the same sound within each subject?
2. Across subjects, is there a difference between the intensity and frequency of male and female sound production?
3. How much variation is seen across all subjects for each of the six sounds?

The results of this study seek to answer these questions and help to ultimately determine if medical professionals who are unfamiliar with audiology or speech-language pathology could successfully administer the Ling Six-Sound Test as a hearing screening for adults.

Chapter 3

Methods

Participants

Ten men and 10 women, age 20 to 55 years old with a mean age of 27.15 (8.76), produced the Ling six sounds eight times each while seated two feet from the microphone in a sound-attenuated booth. All participants passed a pure tone air conduction hearing screening in both ears at 25 dB HL at test frequencies from 250 to 8000 Hz (ASHA, 1997). No subjects reported a speech, language or voice disorder, or symptoms of an upper respiratory infection. All participants were non-smoking native English speakers.

Procedures and equipment

This study was approved by the Towson University Institutional Review Board (Appendix A). Prior to collecting data, participants were given information about the study, and informed consent was signed (Appendix B). First, participants were asked to produce two sustained vowels in their clearest voice at normal conversational volume for three to five seconds each (/a/ followed by /i/), followed by reading the sentences of the Consensus Auditory-Perceptual Evaluation of Voice (CAPE-V), a clinical voice assessment tool (ASHA, 2006). This was used as a brief assessment of the participant's voice quality. A speech-language pathologist with over ten years experience in the area of voice disorders analyzed these samples and determined that each participant's vocal quality fell within the range of normal.

Participants were seated in the center of a sound attenuated booth, in front of a microphone that was connected to a laptop computer. Each subject's mouth was two feet from the microphone during recordings. Recordings were collected using Adobe Audition 6.0. At the beginning of each recording, a two second constant 1000 Hz warble tone was played, followed by a two second constant narrowband noise. These two reference tones were played at 50 dB HL and then at 60 dB HL through a GSI-61 clinical audiometer and two soundfield speakers. The two speakers were located at the front two corners of the booth, and the microphone was located in the spot to which these speakers are calibrated.

Participants were asked to produce speech sounds from a list of sounds given to them. Written and verbal instructions were provided (Appendix C). The sounds to be produced were /a/, /i/, /o/, /ʃ/, /s/, and /m/. Each participant produced each sound eight times in a row before moving on to the next sound. Participants were asked to use their clearest voice at a normal speaking volume and to produce each sound for about one second. A sheet with example of each of the six sounds within a word was provided to the participant to clarify the sound that they were expected to make (Appendix D). The examples were used include: /ah/ as in ta-d**a**, /ee/ as in k**ee**p, /oo/ as in sh**oe**, /sh/ as in **sh**ow, /ss/ as in **s**ee, and/mm/ as in **m**ine.

Data analysis

Each speech sample was analyzed individually to determine the frequencies of each sound. Prior to frequency analysis, noise reduction was applied in Adobe Audition 6.0. A two second sample of ambient noise from the beginning of each sample was selected using "capture noise print" in Adobe Audition. Noise reduction was then applied to the entire recording based on the selected noise print. After noise reduction was applied, frequency analysis was conducted using Wavesurver 1.8.8. Visualizing the waveform and spectrum, the entire sound was selected, and a halfway point was calculated. A 100 ms selection from the halfway point was highlighted, and “spectrum section” was selected. The linear predictive coding (LPC) analysis and a hamming window were used, as used in the study of acoustic characteristics of vowels (Hillenbrand, Getty, Clark, & Wheeler, 1996). Order was kept at 20 unless peaks or formants were not visible, at which time order was increased past 20, up to 40 if necessary. For consonant sounds, the peak frequency of each sound was identified. For vowel sounds, the first and second formant frequency was identified. If formants or peaks could still not be identified, the FFT analysis (512 points) was viewed as a cross-reference. The 100 ms time at which the frequencies were measured was also recorded for each sound so that the same point in time could be used for intensity analysis.

The average intensity and peak intensity of each sound was obtained at the 100 ms time as outlined above. The original samples without noise reduction were used for intensity analysis, as it was determined that noise reduction affected the intensity of speech sound measurements. Intensity measurements were analyzed using Adobe Audition 6.0. First, a 100ms portion at the center of the 60 dB HL narrowband noise was selected, and the average intensity was recorded. This was used as a reference, and the absolute intensity of speech sounds was determined using this number.

For the Ling consonants, the outcome variables were peak frequency, average intensity and peak intensity. For the Ling vowels, the outcome variables were the frequency of the first formant, the frequency of the second formant, average intensity and peak intensity.

Statistical analysis

The goal of this study was to answer three questions:

1. Is there variation in intensity and frequency among the eight productions of the same sound within each subject?

After the frequency and intensity of each sound production was identified, a range was calculated showing the minimum to maximum frequency and intensity produced by each participant for each sound. The first and last utterances were removed, as the middle six were most consistent. Frequency and intensity values for the six utterances were split into two lists of three measurements, and Pearson product-moment correlations were obtained to assess the relationships between the measurements within each subject.

2. Across subjects, is there a difference between the intensity and frequency of male and female sound production?

This was examined for each Ling Six sound, using a one-way analysis of variance (ANOVA) with intensity and frequency measurements as the outcome variables and gender as the between subjects factor.

3. How much variation is seen across all subjects for each of the six sounds?

Descriptive statistics (mean, median, standard deviation) were calculated for each sound, as well as a range from maximum to minimum measurement across subjects. A one-way ANOVA was performed for each sound, with frequency and intensity measurements as outcome variables, and speaker/subject as the between-subjects variable.

Chapter 4

Results

Data analysis

The first and last productions of each sound were removed from data analysis, and the middle six productions were used. Frequency data for each of the Ling six sounds was analyzed using WaveSurfer 1.8.8. For consonants, peak frequency data was collected, and for vowels, the frequency data of F1 and F2 was collected. For intensity, speech recordings were analyzed in Adobe Audition 6.0; peak and average intensity of each Ling sound was collected.

Within subject variability. The six productions of each Ling sound were analyzed to determine if each subject repeated the sounds with a consistent frequency and intensity. Figures 2 and 3 display the variation in peak intensity and average intensity between individuals' six utterances of each Ling sound. Most subjects' intensity values ranged between 1 and 5 dB HL, and vowels were more consistently produced than consonants. Tables 3 and 4 describe the mean and standard deviation of the range of intensity variability for each of the Ling sounds.

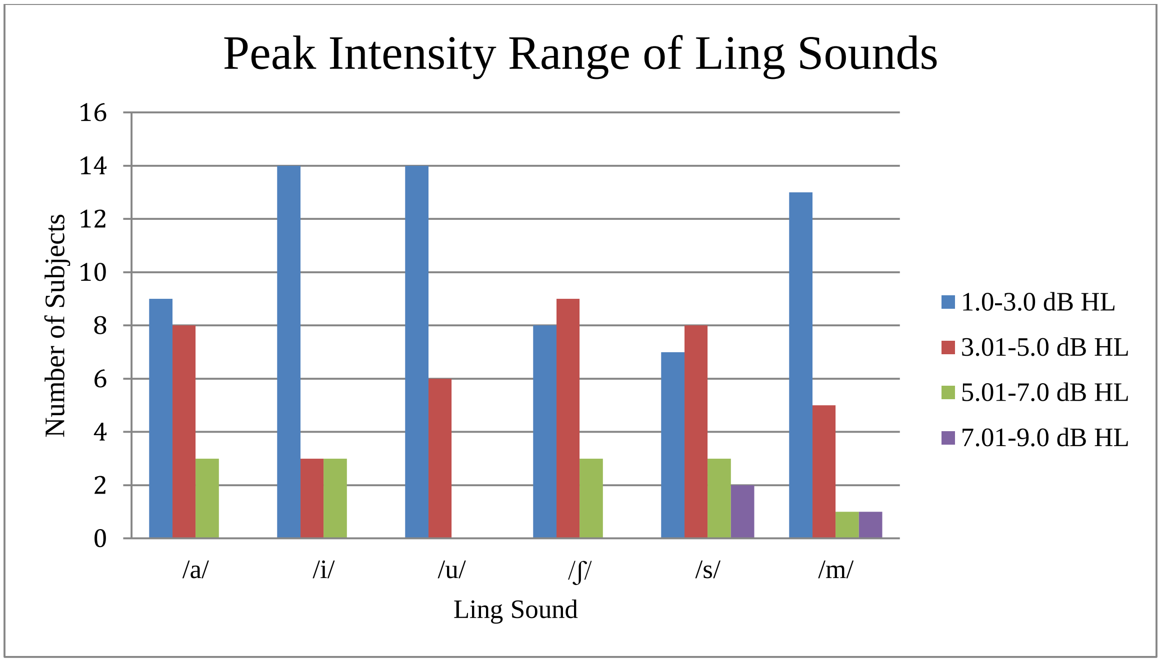

Figure 2. Within subject variability for peak intensity of the Ling Six sounds. Six repetitions of each speech sound were analyzed from recorded speech of 20 adult speakers. Minimum to maximum ranges were used to determine the within subject range of peak intensity values for each participant. Of the six sounds, the /i/ vowel sound was most consistent across participants.

Table 3

Range Values for Peak Intensity

	/a/	/i/	/u/	/ʃ/	/s/	/m/
Mean	3.47	2.67	2.61	3.63	4.16	2.56
(SD)	(3.24)	(1.58)	(1.16)	(1.43)	(1.70)	(1.72)

Note. All values are in dB HL.

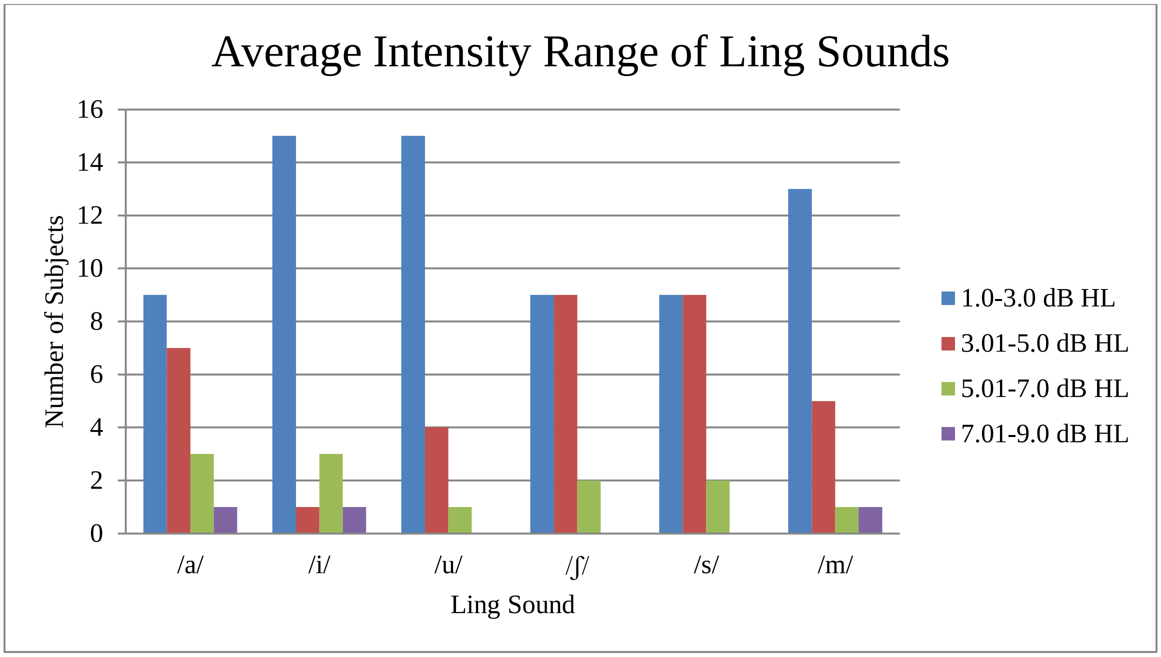

Figure 3. Within subject variability for average intensity of the Ling Six sounds. Six repetitions of each speech sound were analyzed from recorded speech of 20 adult speakers. Minimum to maximum ranges were used to determine the within subject range of average intensity values for each participant. Vowels were more consistent than consonants overall.

Table 4. Range Values for Average Intensity

	/a/	/i/	/u/	/ʃ/	/s/	/m/
Mean	3.64	2.76	2.52	3.52	4.21	2.64
(SD)	(1.83)	(1.77)	(1.20)	(1.19)	(1.78)	(1.82)

Note. All values are in dB HL.

The peak frequency of consonants was analyzed. Within subject consistency is shown in Figure 4. Of the three consonants, /m/ was most consistently produced. The most variation seen within a subject for /m/ was 161 Hz. The /s/ consonant was least consistent, with two subjects varying more than 1800 Hz between productions.

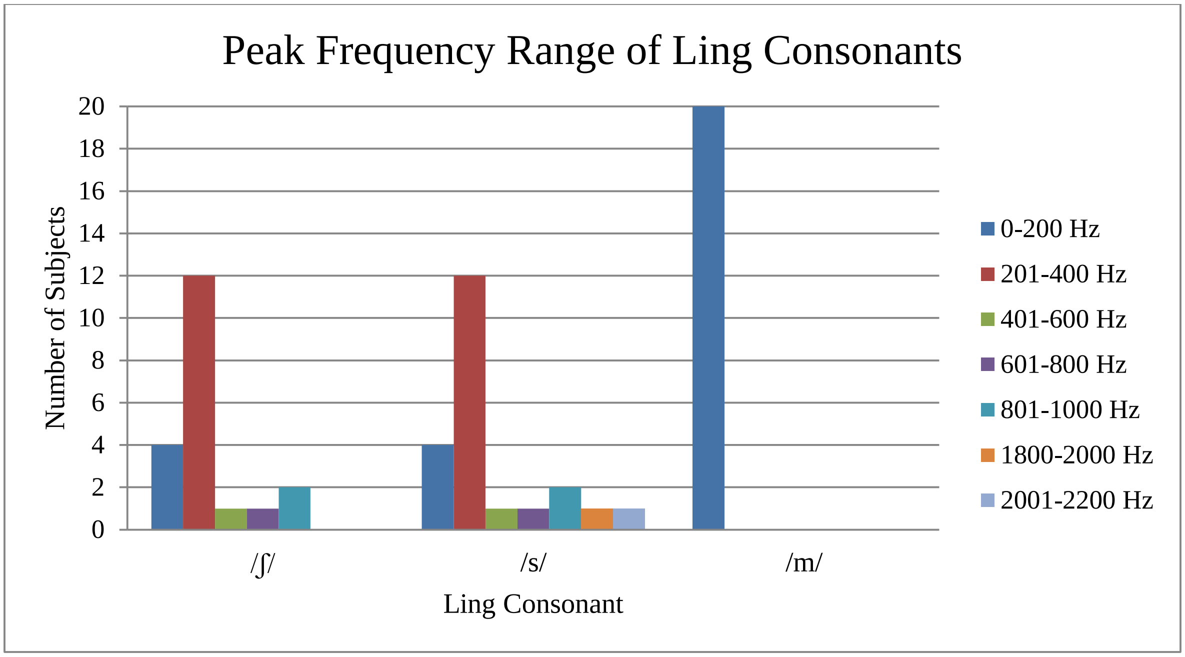

Figure 4. Within subject variability for peak frequency of the Ling consonants /ʃ/, /s/, and /m/. Six repetitions of each speech sound were analyzed from recorded speech of 20 adult speakers. Minimum to maximum frequency ranges were used to determine the within subject variability for each participant. The /m/ sound was most consistently produced of the three consonants.

Less variability was seen in vowel production than in consonant production overall. Within subject consistency for F1 and F2 frequency of vowels is shown in Figures 5 and 6. The most variability observed for vowels was a 431 Hz difference observed in one subject for the /u/ vowel. Subjects produced the F1 frequency more consistently than the F2 frequency. The F1 frequency of /i/ was most consistent, with a maximum variation of 100 Hz observed in one subject.

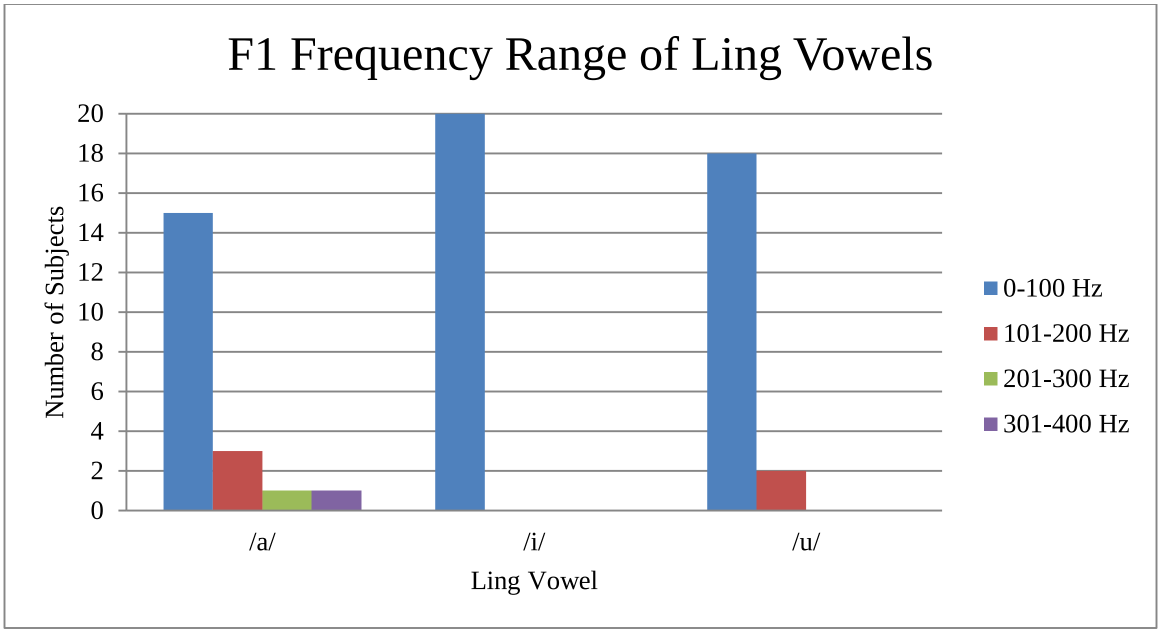

Figure 5. Within subject variability for F1 frequency of the Ling vowels /a/, /i/, and /u/. Six repetitions of each speech sound were analyzed from recorded speech of 20 adult speakers. Minimum to maximum frequency ranges were used to determine the within subject variability for each participant. The /i/ vowel was most consistently produced.

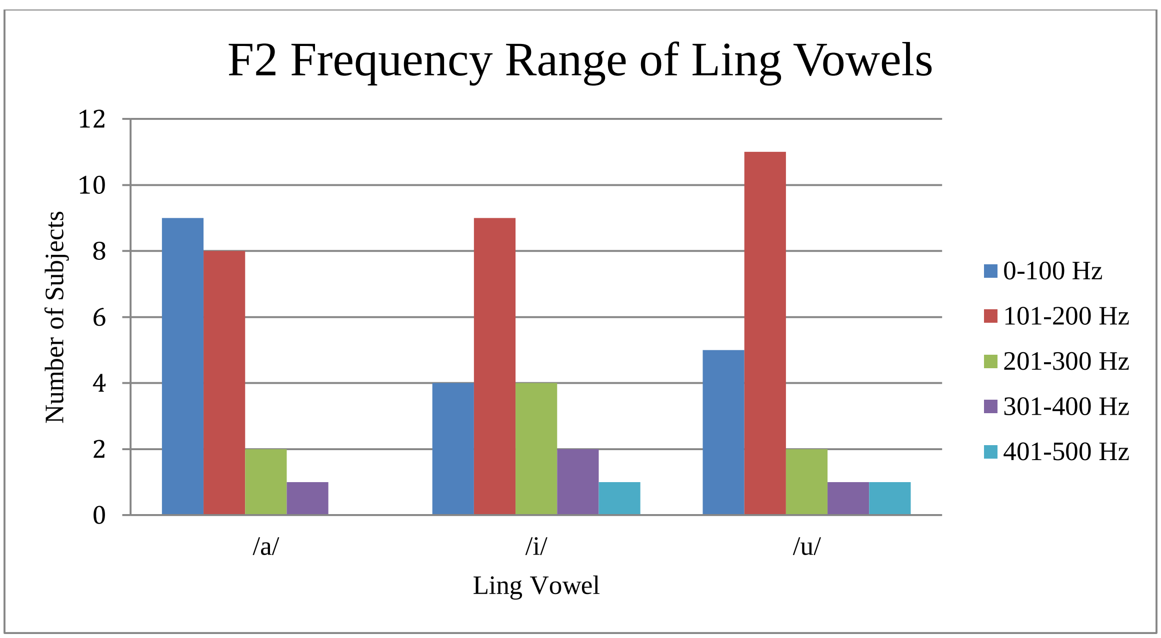

Figure 6. Within subject variability for F2 frequency of the Ling vowels /a/, /i/, and /u/. Six repetitions of each speech sound were analyzed from recorded speech of 20 adult speakers. Minimum to maximum frequency ranges were used to determine the within subject variability for each participant. The /a/ vowel sound was most consistent.

To determine if significant variation in intensity and frequency occurred within each subject's six productions of each sound, Pearson product-moment correlations were conducted. The second, third and fourth productions of each sound were correlated with the fifth, sixth and seventh production of each sound. Out of 420 correlations, 18 were significant at the $p < 0.05$ level, indicating that the repeated productions were consistent in these instances. The consistent productions were scattered among subjects, Ling sounds, intensity and frequency. That is, no single subject was consistent throughout all of his or her productions. Five subjects had two instances in which they produced the intensity or frequency of one sound consistently, and eight subjects had one instance in which they produced the intensity or frequency of one sound consistently. For the majority of the correlations (402 out of 420), the results indicated that the productions were inconsistent.

Gender effects. The speech productions of male speakers ($n = 10$) and female speakers ($n = 10$) were analyzed for intensity and frequency differences. Male participants produced higher mean intensity levels than females for all Ling sounds, with the exception of /m/. Maximum intensity levels for /a/, /i/, /u/, /ʃ/, and /s/ were also higher for males, but the intensity of /m/ was again louder for females. Tables 5 and 6 describe male and female peak intensity data. Tables 7 and 8 contain average intensity data for male and female speech sounds.

Table 5

Peak Intensity of Male Ling Sounds

	/a/	/i/	/u/	/ʃ/	/s/	/m/
Mean	75.99 (5.37)	74.82 (3.83)	76.78 (2.57)	73.19 (5.82)	69.83 (5.91)	71.42 (5.03)
Min	65.48	66.88	72.57	60.00	59.82	56.07
Max	83.50	82.80	81.43	83.26	78.51	79.18

Note. All values were converted to dB HL.

Table 6

Peak Intensity of Female Ling Sounds

	/a/	/i/	/u/	/ʃ/	/s/	/m/
Mean	72.78 (5.09)	70.82 (5.15)	72.5 (4.44)	70.76 (5.33)	64.72 (6.72)	73.28 (6.12)
Min	59.04	59.40	63.63	57.66	49.62	61.38
Max	81.62	81.04	78.96	81.22	80.03	82.10

Note. All values were converted to dB HL.

Table 7

Average Intensity of Male Ling Sounds

	/a/	/i/	/u/	/ʃ/	/s/	/m/
Mean	75.35 (5.4)	74.37 (3.84)	76.28 (2.54)	72.52 (5.76)	69.21 (5.88)	70.87 (5.17)
Min	64.45	65.70	72.34	59.27	59.57	55.12
Max	83.24	82.36	80.78	82.00	78.26	78.74

Note. All values were converted to dB HL.

Table 8

Average Intensity of Female Ling Sounds

	/a/	/i/	/u/	/ʃ/	/s/	/m/
Mean	72.26 (5.17)	70.33 (5.16)	72.19 (4.45)	69.97 (5.5)	64.16 (6.6)	72.8 (6.14)
Min	58.40	57.92	63.33	57.00	49.19	61.11
Max	81.39	79.83	78.80	80.13	79.40	81.91

Note. All values were converted to dB HL.

Frequency differences between male and female speakers were larger than intensity differences. Overall, the frequency of male speech was lower than the frequency of female speech for each of the Ling sounds. Frequency analysis was broken down into peak frequency for consonants (Tables 9 and 10) and F1 and F2 frequency for vowels (Tables 11 and 12).

Table 9

Peak Frequency of Male Ling Consonants

	/ʃ/	/s/	/m/
Mean (SD)	3073.25 (323.41)	5309.58 (459.61)	275.01 (35.36)
Min	2401	4549	216
Max	3762	6335	382

Note. All values are in Hz.

Table 10

Peak Frequency of Female Ling Consonants

	/ʃ/	/s/	/m/
Mean (SD)	3531.5 (353.18)	5459.78 (770.53)	289.25 (42.13)
Min	2774	3172	191
Max	4295	7086	369

Note. All values are in Hz.

Table 11

F1 and F2 Frequency of Male Ling Vowels

	/a/		/i/		/u/	
	F1	F2	F1	F2	F1	F2
Mean (SD)	736.95 (56.91)	1175.85 (111.16)	287.9 (28.62)	2444.37 (200.98)	318.95 (35.12)	1042.97 (208.12)
Min	609	862	238	2118	248	630
Max	837	1382	350	2858	401	1480

Note. All values are in Hz.

Table 12

F1 and F2 Frequency of Female Ling Vowels

	/a/		/i/		/u/	
	F1	F2	F1	F2	F1	F2
Mean (SD)	815.23 (146.97)	1332.05 (144.08)	351.87 (40.62)	2932.28 (139.95)	412.05 (45.27)	1190.77 (181.62)
Min	497	962	274	2621	296	792
Max	1091	1548	435	3284	479	1566

Note. All values are in Hz.

To determine if significant differences in intensity production occurred between male and female speakers, a one-way analysis of variance (ANOVA) was conducted to compare average and peak intensity productions by gender for each Ling sound. A Bonferroni correction was used (0.05/12) so that $p < .0041$ is significant. For peak intensity, a significant main effect for gender was observed for /a/, /u/, and /s/. Specific information regarding the results of the main effects for gender on peak intensity is described in Figure 7. For average intensity, a significant main effect for gender was observed for /a/, /i/, /u/, and /s/. Specific information regarding the results of the main effects for gender on average intensity is described in Figure 8.

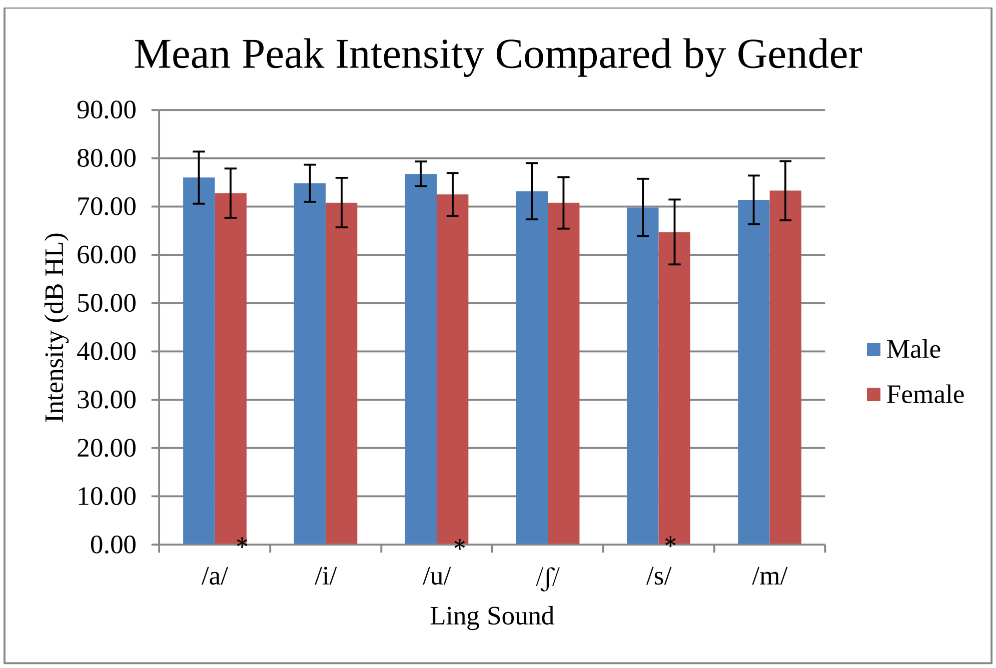

Figure 7. Mean peak intensity of the Ling Six sounds compared by gender, with error bars indicating standard deviation. Data was compared by gender using a one-way ANOVA. The * indicates statistically significant differences between the genders at the Bonferroni adjusted level of *p*<.0041.

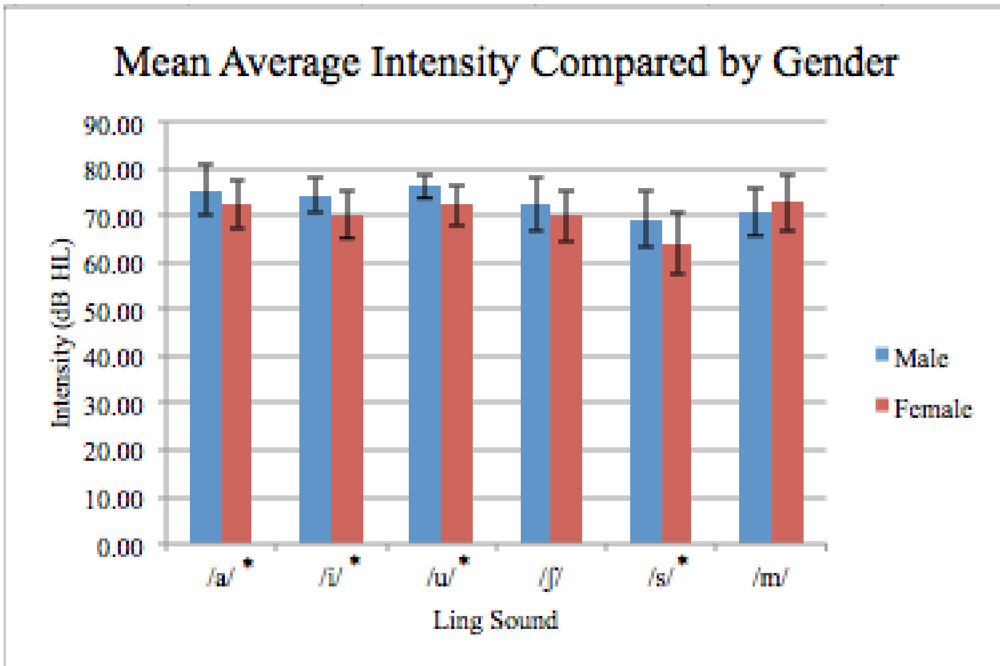

Figure 8. Mean average intensity of the Ling Six sounds compared by gender, with error bars indicating standard deviation. Data was compared by gender using a one-way ANOVA. The * indicates statistically significant differences between the genders at the Bonferroni adjusted level of $p<.0041$.

Gender had a main effect on F1 and F2 frequency for all Ling vowels, as shown in Figures 9 and 10. A Bonferroni correction was used (0.05/9) so that $p < .0056$ is significant. Additionally, gender had a main effect for the peak frequency of /ʃ/, but there was no significant main effect for /s/ or /m/, as shown in Figure 11.

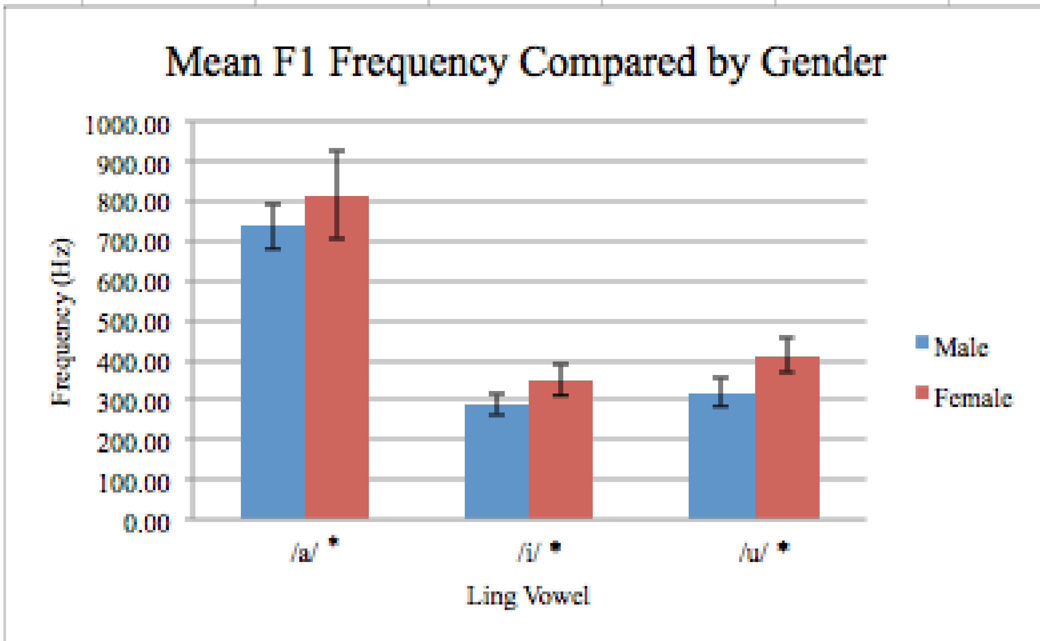

Figure 9. Mean F1 frequency of the Ling vowels compared by gender, with error bars indicating standard deviation. Data was compared by gender using a one-way ANOVA. The * indicates statistically significant differences between the genders at the Bonferroni adjusted level of *p*<.0056.

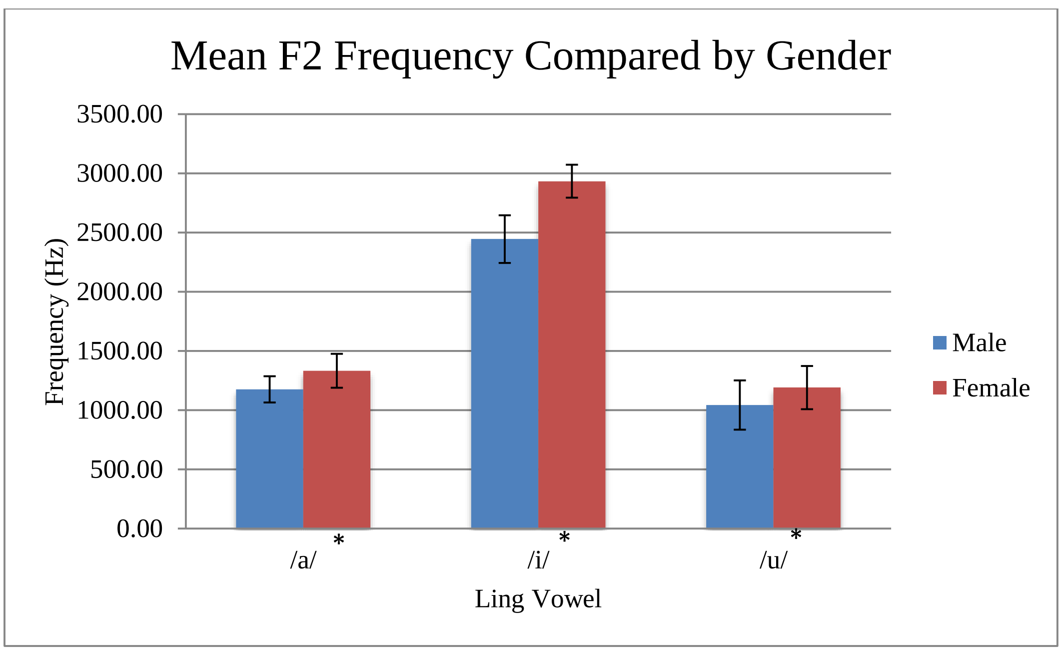

Figure 10. Mean F2 frequency of the Ling vowels compared by gender, with error bars indicating standard deviation. Data was compared by gender using a one-way ANOVA. The * indicates statistically significant differences between the genders at the Bonferroni adjusted level of *p*<.0056.

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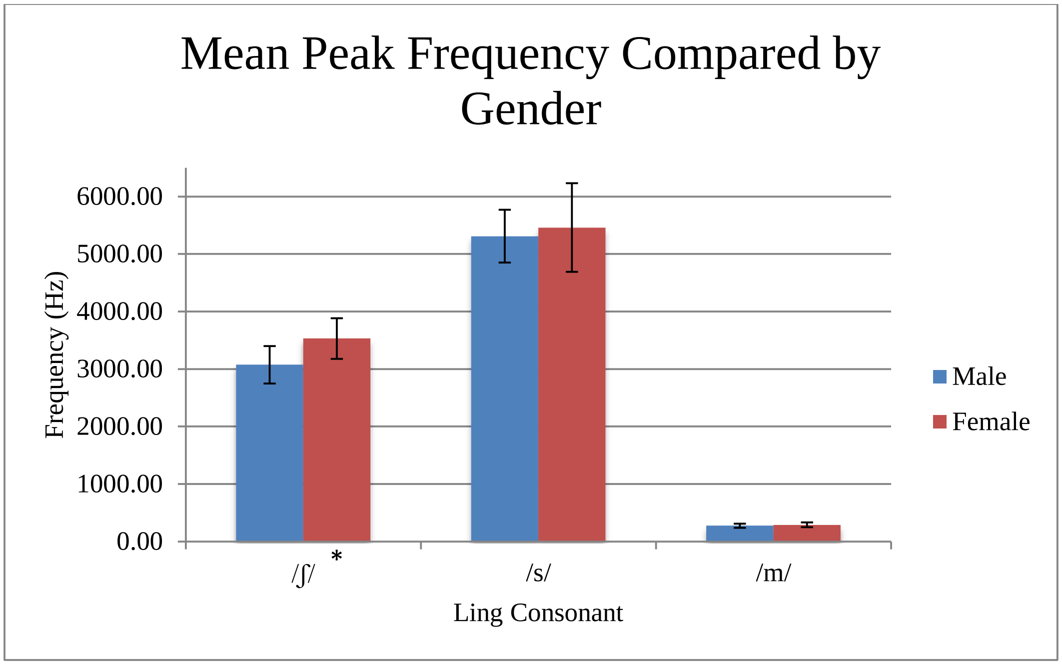

Figure 11. Mean peak frequency of the Ling consonants compared by gender, with error bars indicating standard deviation. Data was compared by gender using a one-way ANOVA. The * indicates statistically significant differences between the genders at the Bonferroni adjusted level of $p<.0056$.

Between subjects effects. The speech productions of the 20 subjects were analyzed for intensity and frequency differences regardless of gender. A series of one-way ANOVAs were conducted to determine if there were significant differences between the frequency and intensity productions of all participants. For all intensity and frequency measurements, there was a significant difference between speakers ($p < .001$), with the exception of the peak intensity of the /i/ vowel, which was not significant. Tables 13 and 14 outline intensity data for all subjects, and Tables 15 and 16 outline frequency information.

Table 13

Peak Intensity of Ling Sounds for All Subjects

	/a/	/i/	/u/	/ʃ/	/s/	/m/
Mean (SD)	74.53 (5.52)	72.42 (6.93)	74.72 (4.31)	72.1 (5.67)	67.43 (6.75)	72.39 (5.56)
Min	58.61	59.4	60.96	57.66	49.62	56.07
Max	83.89	84.44	82.15	83.26	80.03	82.72

Note. All values are in dB HL.

Table 14

Average Intensity of Ling Sounds for All Subjects

	/a/	/i/	/u/	/ʃ/	/s/	/m/
Mean (SD)	74.53 (7.41)	72.34 (5.01)	74.28 (4.29)	71.38 (5.7)	66.82 (6.68)	71.88 (5.65)
Min	58.61	57.92	60.28	57.00	49.19	55.12
Max	83.62	84.26	81.94	82.00	79.40	82.54

Note. All values are in dB HL.

Table 15

F1 and F2 Frequency of Ling Vowels for All Subjects

	/a/		/i/		/u/	
	F1	F2	F1	F2	F1	F2
Mean	781.26 (120.12)	1253.73 (149.26)	318.71 (47.57)	2693.06 (305.18)	363.6 (60.71)	1119.41 (205.12)
Min	497.00	862.00	232.00	2118.00	248.00	630.00
Max	1091.00	1548.00	435.00	3333.00	479.00	1646.00

Note. All values are in Hz.

Table 16

F1 and F2 Frequency of Ling Consonants for All Subjects

	/ʃ/	/s/	/m/
Mean (SD)	3296.49 (409.47)	5399.29 (632.68)	282.47 (40.91)
Min	2401	3172	191
Max	4304	7086	382

Note. All values are in Hz.

Chapter 5

Discussion

The original purpose of this study was to determine if medical professionals who are unfamiliar with audiology or speech-language pathology could reliably administer the Ling Six-Sound Test as a hearing screening for adults. While the Ling Six-Sound Test is brief and requires no specialized equipment, the question is whether or not different people could administer the test and get the same results. Inherent frequency and intensity variations in a person's voice need to be taken into consideration when answering this question.

Within subject variability

When subjects repeated each of the Ling Six sounds six times, the intensity of most subjects varied less than 5 dB HL between productions, and all subjects varied less than 10 dB HL. The mean range of intensity differences was less than 5 dB HL for all of the Ling sounds. While statistical analysis indicated that subjects were not consistent overall, the variations that occurred are less significant from a clinical perspective. Some degree of variation is expected when testing people in a clinical setting. For example, 10 dB HL shifts in threshold are considered within test-retest reliability for pure tone audiometry (Franks, 1996; Katz, 2009).

Frequency was more variable than intensity within each subject. For the Ling vowels /a/, /i/, and /u/, the F1 frequency was more consistent than F2, but all frequency variations for vowels ranged less than 500 Hz within each subject. The majority of subjects consistently produced vowels with less than a 200 Hz difference between trials. For consonants, /m/ was most consistently produced, with the most variation being 161

Hz between trials from one subject. Again, while there were statistically significant differences within each subject, this factor may not have an effect on clinical outcomes. For someone who has hearing loss in the 2000 Hz frequency range, for example, one may be unlikely to hear a sound whether it is produced at 2000 Hz or at 2300 Hz. Hearing is tested clinically in octaves and interoctaves, not every 100 Hz.

The fricatives /s/ and /ʃ/ were least consistent within subjects. Most subjects varied less than 400 Hz between productions, but four of 20 subjects ranged 400 to 1000 Hz, and two ranged 1800 to 2000 Hz between productions. With large variations such as these, the outcome of the screening may be affected. For example, if the tester produces the /s/ sound at 3500 Hz once and then at 5500 Hz the next time, a person with high frequency hearing loss may hear the first /s/ and not hear the second /s/. However a normal hearing person should not be expected to miss any sounds, so missing the /s/ sound in one instance and not another may still be considered a screening failure.

Using the Ling Six sounds as a hearing screening with a pass/fail outcome, an increase of intensity by 5 dB HL or less, or a shift in frequency of 500 Hz or less is unlikely to allow someone with hearing loss to pass the screening. Again, someone with normal hearing should be able to hear each of the Ling sounds, even with a decrease in intensity by 5 dB HL or a shift in frequency. If someone failed the screening, a more detailed picture of one's hearing at each frequency could be obtained using diagnostic audiometry.

Gender effects

Research indicates that male and female speakers consistently have differences in frequency characteristics of their speech. Male speakers generally produce lower frequency speech (Kent, 1997; Raphael et al, 2007). Less information about the intensity differences between male and female speakers has been researched.

In this study, male speech was louder for all Ling sounds except /m/; however, the mean intensity difference between the genders was less than 5 dB HL for all sounds. Statistical analysis indicated that there was a significant difference between the intensity of all vowels and of the /s/ consonant, but again the mean differences between male and female intensity was less than 5 dB HL for these four speech sounds. A larger sample size would need to be tested in order to determine if intensity differences between men and women could be generalized to the population outside this study.

For frequency, the mean frequency values produced by the 20 subjects in this study were within 200 Hz of the average vowel formant frequencies referenced by Raphael et al. (2007). There was a statistically significant frequency difference between male and female production of all vowels and the /ʃ/ sound. For /ʃ/, male speakers' peak frequency was 458 Hz lower than female peak frequency on average. Male speech may be easier for people with high frequency hearing loss to understand, as overall male speech was of a lower frequency than female speech. The /ʃ/ sound produced by a male may be more audible for someone with high frequency hearing loss but normal or mild hearing loss thresholds in the mid-frequencies.

Between subjects effects

Statistical analysis indicated that there was a statistically significant difference between the frequency and intensity productions of all sounds between subjects, with the exception of the peak intensity of the /i/ vowel, which was consistently produced by all subjects. The range of frequency and intensity productions among all subjects varied;

however, variation between speakers was expected at the beginning of this study. The one-way ANOVA indicated that within subject variability was significantly lower than between subject variability, so the differences between the participants were greater than the differences within each participant.

Limitations and future research

There were several limitations to this study involving the set-up for the recordings. First, despite recording speech in a sound-attenuated booth, ambient noise was picked up by the microphone that may have affected the accuracy of the measurements. Noise reduction was applied using Adobe Audition 6.0 prior to analyzing the frequency of each speech sound. Noise reduction affected the accuracy of the intensity measurements; therefore, intensity measurements were taken using the original samples without noise reduction.

Additionally, the microphone did not have an omnidirectional polar plot (recording sound equally from all directions), as expected. When a 50 dB HL tone was played through the audiometer and soundfield speakers, it was measured at 50 dB HL using a sound level meter at the calibrated point in the booth. But when the recordings of the reference tones were played through the audiometer, the audiometer intensity had to be increased to 72 dB HL in order to accurately read 50 dB HL on a sound level meter. This likely occurred because the microphone used for recording speech was aimed towards the participant, and the reference tones were played from soundfield speakers behind the microphone. Some of the intensity of the reference tone was at the null point of the microphone’s polar plot, making the reference recordings less than 50 dB HL. As a result, intensity differences between productions are accurate, but absolute intensity measurements may not be accurate. The absolute intensity of the Ling sounds was likely inaccurately high.

Because variability was seen among all participants' speech, a larger sample size would be required to determine if the speaker effects observed in this study are true of the general population. Also, the majority of speakers were age 25 years or younger. In order to determine if age could affect the intensity and frequency of one's speech, a wider age range would need to be studied.

Chapter 6

Conclusion

The Ling Six-Sound Test uses the speech sounds /a/, /i/, /u/, /ʃ/, /s/, and /m/, which range across speech frequencies from low to high (Robb et al., 2005). The application of these sounds as a hearing screening could be beneficial in identifying a hearing loss that affects some frequencies and not others, as is often seen with age-related high frequency hearing loss. This screening method could provide a more objective measure of hearing than self-report, and could also refer older adults with presbycusis for diagnostic evaluations.

The results of this study indicate that while there is variation in intensity and frequency within one person's repeated speech productions, the variations may not affect the outcome of the Ling Six-Sound Test used as a hearing screening. Additionally, differences in frequency and intensity were found between subjects, and between men and women. The variations were statistically significant, but it is unclear whether or not these differences would affect the clinical application of the Ling Six-Sound Test. While the Ling Six-Sound Test has potential to be an effective and efficient hearing screening measure, a larger sample of speakers would need to be studied in order to determine if it could be reliably used.

APPENDIX A

TOWSON UNIVERSITY

APPROVAL NUMBER: 14-A041

To: Cecelia Kilcullen
8000 York Road
Towson MD 21252

From: Institutional Review Board for the Proctection 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

TOWSON UNIVERSITY

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.

MPA (for)

Stacy Spaulding, Member
Towson University Institutional Review Board

APPENDIX B

Consent Form for Participation in a Research Project

Principal Investigator: Kelly Burgdorf and Cecelia Kilcullen
Study Title: The Ling Six Sounds as a Hearing Screening Measure

1. Invitation to Participate
You are invited to participate in a study of hearing by Kelly Burgdorf and Cecelia Kilcullen of Towson University. Please read this form and ask any questions you may have before agreeing to be in the research study.

2. Purpose
The purpose of this study is to determine whether speech sounds can be used to screen for hearing loss.

3. Description of Procedures
If you participate in this study, you will be required to listen to a variety of sounds such as tones, speech sounds, and words. You will be asked to repeat what you hear or press a button in response to what you hear. You will also be asked to produce speech sounds. Your speech and language abilities will also be informally assessed. If an unknown hearing or speech, language or voice disorder is indicated during this portion of the study, information will be provided about follow-up and a referral for a diagnostic evaluation will be made. The study will include individuals with both normal hearing and hearing loss. We need to test your hearing to understand whether the tests we perform during the study are valuable in diagnosing hearing problems. You may be excluded from the study if we find an ear infection or other types of conditions that may interfere with the tests. The testing procedure may take from approximately one hour. Breaks from testing will be provided as requested.

The experiments will take place at Towson University. An average experiment will take about 1 hour.

4. Risks and Inconveniences
We believe there are minimal risks to you for your participation. No discomfort is associated with the task other than the usual fatigue or boredom related to sitting for an hour.

5. Benefits
You may benefit directly from clinical assessment of your hearing and speech. Additionally, individuals in need of low-cost screening measures may ultimately benefit from the results of this study.

6. <u>Economic Considerations</u>
   You will not be paid nor will you be charged for participation in the study.

7. <u>Confidentiality</u>
   The records from this study will be kept private. In any report published or presented regarding this study there will be no information that will reveal your identity. Records will be kept in a locked room and only researchers will have access to these records.

8. <u>Voluntary Participation</u>
   You do not have to be in this study if you do not want to. If you agree to be in the study, but later change your mind, you may drop out at any time. There are no penalties or consequences of any kind if you decide that you do not want to participate. Your decision as to whether or not to participate will in no way affect any treatment at the Speech and Hearing Clinic or your student status at Towson University.

9. <u>Do You Have Any Questions?</u>
   Take as long as you like before you make a decision. We will be happy to answer any question you have about this study. If you have further questions about this project you may contact the principal investigators, Kelly Burgdorf (kelly.burgdorf@gmail.com) and Cecelia Kilcullen (cbkilcullen@gmail.com), or the faculty advisor, Stephanie Nagle (snagle@towson.edu) If you have any questions concerning your rights as a research participant, you may contact Dr. Debi Gartland, Chairperson, Towson University Institutional Review Board (IRB), at 410-704-2236.

Authorization:
I have read this form and decided that I, ________________________________
(name of subject)
will participate in the project described above. Its general purposes, the particulars of involvement and possible hazards and inconveniences have been explained to my satisfaction.

Signature:__________________________________
Date: ______________________________________

____ ____________________
Signature of Student Investigator Phone

____
Signature of Faculty Sponsor Phone

THIS PROJECT HAS BEEN REVIEWED BY THE INSTITUTIONAL REVIEW BOARD FOR THE PROTECTION OF HUMAN PARTICIPANTS AT TOWSON UNIVERSITY.

APPENDIX C

<u>The Ling Six Sound Test as a Hearing Screening Measure</u>

Instructions for participant:

I will begin recording on the computer, and I will then quietly leave the room. Next, you will hear 4 sounds from the speakers on the wall. This is part of the study, but I don't need any response from you. After those 4 sounds, I will give you a thumbs up.

Once you see my thumbs up, please use the provided page to speak these six sounds using your clearest voice and normal conversational volume:

*/ah/ as in ta-d**a***
*/ee/ as in k**ee**p*
*/oo/ as in sh**oe***
*/sh/ as in **sh**ow*
*/ss/ as in **s**ee*
*/mm/ as in **m**ine*

As you can see, these sounds are repeated eight times on the sheet that has been given to you. Please continue to say each sound on the list until you reach the end.

Do you have any questions?

APPENDIX D

The Ling Six Sound Test as a Hearing Screening Measure

Once you see my thumbs up, please say these six sounds, one at a time, using your clearest voice and normal conversational volume. An example of the sound within a word is provided.

/ah/ as in ta-d***a***
/ah/ as in ta-d***a***
/ah/ as in ta-d***a***
/ah/ as in ta-d***a***
/ah/ as in ta-d***a***
/ah/ as in ta-d***a***
/ah/ as in ta-d***a***
/ah/ as in ta-d***a***

/sh/ as in ***sh***ow
/sh/ as in ***sh***ow
/sh/ as in ***sh***ow
/sh/ as in ***sh***ow
/sh/ as in ***sh***ow
/sh/ as in ***sh***ow
/sh/ as in ***sh***ow
/sh/ as in ***sh***ow

/ee/ as in k***ee***p
/ee/ as in k***ee***p
/ee/ as in k***ee***p
/ee/ as in k***ee***p
/ee/ as in k***ee***p
/ee/ as in k***ee***p
/ee/ as in k***ee***p
/ee/ as in k***ee***p

/ss/ as in ***s***ee
/ss/ as in ***s***ee
/ss/ as in ***s***ee
/ss/ as in ***s***ee
/ss/ as in ***s***ee
/ss/ as in ***s***ee
/ss/ as in ***s***ee
/ss/ as in ***s***ee

/oo/ as in sh***oe***
/oo/ as in sh***oe***
/oo/ as in sh***oe***
/oo/ as in sh***oe***
/oo/ as in sh***oe***
/oo/ as in sh***oe***
/oo/ as in sh***oe***
/oo/ as in sh***oe***

/mm/ as in ***m***ine
/mm/ as in ***m***ine
/mm/ as in ***m***ine
/mm/ as in ***m***ine
/mm/ as in ***m***ine
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/mm/ as in ***m***ine

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Cecelia B. Kilcullen

[redacted]

EDUCATION

Doctor of Audiology Candidate Anticipated: May 2015
Towson University: Towson, Maryland
Current GPA: 3.95

B.A. Communicative Disorders *Summa cum laude* May 2009
West Chester University: West Chester, Pennsylvania
Cumulative GPA: 3.9; Major GPA: 3.97

CLINICAL EXPERIENCE

Audiology Student Clinician

Ear, Nose, and Throat Associates, Baltimore, MD Feb. 2013 – present

- Perform adult and pediatric diagnostic audiological evaluations
- Conduct adult hearing aid evaluations, fittings and troubleshooting
- Perform and interpret vestibular evaluations, including VNG and calorics
- Perform and interpret auditory brainstem response testing
- Perform and report newborn hearing screenings using OAE and ABR equipment

Baltimore City Public Schools, Baltimore, MD Sept. 2013 – Dec. 2013

- Perform pediatric diagnostic audiological evaluations and school-based hearing screenings
- Program and troubleshoot hearing aids and FM systems
- Perform cochlear implant troubleshooting
- Plan and conduct aural rehabilitation

ENTAA Care Audiology, Glen Burnie, MD May 2013 – July 2013

- Performed adult and pediatric diagnostic audiological evaluations
- Conducted adult hearing aid evaluations, fittings and troubleshooting
- Performed and interpreted vestibular evaluations, including ENG and calorics
- Performed and interpreted auditory brainstem response testing and electrocochleography

Kennedy Krieger Institute, Baltimore MD Feb. 2013 – May 2013

- Performed pediatric and adult diagnostic audiological evaluations using conventional, behavioral observation, visual reinforcement, and conditioned play audiometry according to the patient's age and abilities
- Conducted pediatric hearing aid fittings, adjustments and troubleshooting
- Completed Central Auditory Processing evaluations and reports

Towson University Speech, Language, Hearing Center, Towson, MD
Feb. 2012 – Dec. 2013

- Performed diagnostic audiological evaluations

- Conducted adult hearing aid evaluations, fittings and troubleshooting

EMPLOYMENT EXPERIENCE

Special Education Teacher Feb. 2010 – June 2011

High Road School of Prince George's County, Capitol Heights, MD

Seventh/Eighth grade classroom teacher for students with emotional, behavioral and learning challenges

- Created, implemented, and modified daily lesson plans according to curriculum guidelines, student IEPs and student ability for all subjects
- Supervised the classroom teacher's assistant and one-to-one aide
- Managed behaviors in the classroom following Therapeutic Aggression Control Techniques

SERVICE EXPERIENCE

Towson University Student Academy of Audiology, *Secretary* 2012 – 2013
Towson University Student Academy of Audiology, *Member* 2011 – present
Center on Hearing and Deafness, Inc., *Volunteer* 2007 – 2009
Autism Alliance of Chester County, PA, *Volunteer* 2006 – 2008