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Objective vs. subjective hearing screening measures in schools

Brittany S. Brown

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**OBJECTIVE vs. SUBJECTIVE HEARING SCREENING
MEASURES IN SCHOOLS**

by

Brittany S. Brown, B.S.

A Dissertation Presented in Partial Fulfillment
of the Requirements for the Degree
Doctor of Audiology

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August 2011

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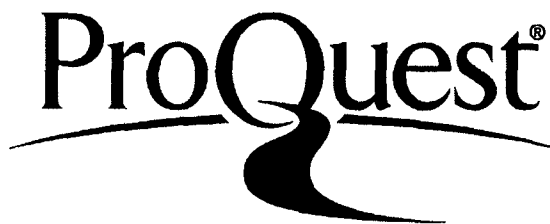
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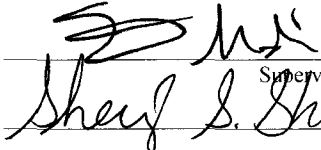
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We hereby recommend that the dissertation prepared under our supervision
by Brittany S. Brown

entitled Objective vs. Subjective Hearing Screening Measures in Schools


be accepted in partial fulfillment of the requirements for the Degree of
Doctor of Audiology



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ABSTRACT

The primary aim of this study was to demonstrate the need for objective hearing screening procedures within traditional school based hearing screenings through literature review. It is believed that objective hearing screenings would provide a better, less-invasive way to screen hearing with minimal participation required from the children, and less interpretation needed from the examiner. A review of the literature suggested that ideal screening measures would include otoacoustic emissions (OAEs) and tympanometry. Currently, the gold standard for school hearing screenings, as described by the American Speech Language Hearing Association (ASHA) (1997), centers on behavioral responses observed by the examiner during a traditional pure-tone audiometry screening. The problems with this behavioral method include uncooperative children, the sensitivity of pure-tone screening to identify effusion, and the overall reliability of subjective hearing screening procedures.

Previous research has shown the advantages of objective screening measures, primarily tympanometry and OAEs. When used in conjunction, these hearing screening measures are more reliable within the school age population. These measures require no behavioral response and provide quicker, as well as more accurate results when used in combination. Therefore, a screening device was identified that addressed the deficiencies of traditional, behavioral pure-tone screening and the advantages of objective hearing screening measures. A 3-in-1 device, the Maico Ero ScanTM Pro, was selected for its

ability to perform distortion product otoacoustic emissions (DPOAEs), transient evoked otoacoustic emissions (TEOAEs), and tympanometry. This device is portable and allows for data storage and printing.

The second purpose of this study was to develop an appropriate grant proposal in order to secure funding for the purpose of obtaining this device. Therefore, further comparison regarding the usefulness of objective hearing screening measures in conjunction with and as opposed to pure-tone audiometry in the school setting could be made. The American Hearing Research Foundation General Research Grant was deemed appropriate. The American Hearing Research Foundation Regular Research Grant awards five to ten \$20,000 grants each year for research in the areas of hearing and balance. The current grant proposal request meets the criteria as described in the proposal guidelines.

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Author Brittany Bona

Date 8-10-11

DEDICATION

For my family and friends, without whose support and prayers this could not have been accomplished.

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CHAPTER I

INTRODUCTION

School hearing screenings have been conducted for many years in order to identify children who have, or are at risk for, hearing impairments. The American Speech-Language-Hearing Association (ASHA) has produced audiological screening guidelines to help audiologists provide the most appropriate services. The ASHA Guidelines for Audiological Screenings provides the most current procedures to be used in the school setting, and they have remained essentially the same for the last three decades (ASHA, 1997).

Current recommended screening procedures are subjective measures and require stringent participation from the child being screened in addition to a conditioned behavioral response (ASHA, 1997). There are constraints to traditional hearing screening procedures when using behavioral techniques. Additionally, hearing screenings are often conducted by someone other than a licensed audiologist such as the school nurse or speech pathologist. Northern and Downs (2002) noted that inexperienced personnel may unintentionally contribute to hearing screening results. Inexperienced examiners can place the headphone incorrectly which can cause up to a 35 decibel (dB) threshold shift, ultimately resulting in a screening failure. Also, examiners may provide instructions that are not easy to understand, influence evaluation results by smiling or making obvious movements, and providing a stimulus that is either too long or too short.

Ambient noise levels are another significant limitation to traditional, behavioral audiometry. This is especially true when screenings are conducted outside the confines of a sound treated booth. Most hearing screenings conducted in the school setting will have some level of ambient noise, which can interfere with screening results. ASHA recommends that unoccupied classroom noise levels should not exceed 30 dB(A). However, the American National Standards Institute (ANSI) is more lenient and allows up to 35 dB(A) of background noise. Unfortunately it has been reported that typical unoccupied classroom noise levels continuously exceed 30dB (A) (Knecht, Nelson, Whitelaw, & Feth, 2002).

Finally, cooperation of young participants can be highly variable and make obtaining accurate responses exceedingly difficult. The use of objective hearing screening procedures would help diminish the number of children who fail hearing screenings due to examiner influences, noise levels, and lack of cooperation. The ease and reliability of objective hearing screening procedures have been evaluated time and again. They have continually been shown to be accurate in the detection of hearing loss, and recommended for infant hearing screening programs.

Early hearing loss identification is critical for appropriate speech, language, and educational development (ASHA, 2008c). Even children with a mild hearing loss are at risk for speech, language, and educational delays. Children with educational delays are significantly at risk for a lower quality of life due to diminished educational abilities especially in the areas of reading, writing, and verbal communication (National Dissemination Center for Children with Disabilities, 2004; McFadden & Pittman, 2008).

Therefore, identification of less than normal hearing and early intervention are fundamental processes to ensure children reach their maximum abilities.

Hearing screenings are designed to detect hearing impairment that has not previously been diagnosed. However, it is unlikely that a child with a severe to profound hearing loss would be initially identified in the school setting. On the other hand, children with minimal or sometimes moderate hearing loss can be missed if instrumentation is not sensitive. Minimal hearing loss includes unilateral hearing impairment, high frequency hearing impairment, and/or hearing impairment that is temporary. The most common cause of transient/temporary hearing loss is otitis media. Otitis media is one of the most common childhood illnesses among school-aged children (Zeisel, Roberts, Neebe, Riggins, and Henderson, 1999). The presence of acute otitis media may allow a child to pass traditional subjective hearing screenings when in fact there is an underlying impairment. Objective hearing screening procedures are available that test the function of the middle ear (i.e., tympanometry), where otitis media occurs, and the inner ear (i.e., otoacoustic emissions). However, to date the only recommendations made are for the use of middle ear analyzers such as tympanometry. The use of hand held screening devices such as otoacoustic emissions (OAEs) are discouraged by ASHA as a screening measure for school aged children (ASHA, 1997).

CHAPTER II

REVIEW OF LITERATURE

Hearing Loss

In order for parents, teachers, and other professionals, to understand the impact hearing loss can have on education and development, they must first understand what it means for a child to have a hearing loss. The two types hearing loss most commonly diagnosed are conductive and sensorineural hearing loss. A conductive hearing loss (CHL), typically affects the low frequency regions, and a sensorineural hearing loss (SNHL) typically affects the high frequency region. A mixed hearing loss is a third possibility and consists of both conductive and sensorineural components. Causes for CHL include such things as otitis media, impacted cerumen, and swelling of the auditory canal. Causes of SNHL include congenital causes, noise exposure, medications, and meningitis. ASHA has established guidelines to help audiologists and parents understand the different types, degrees, and configurations of hearing loss (ASHA, 2008a).

A CHL infers that sounds cannot or do not travel through the outer and middle ear into the inner ear appropriately (CHL affects the ability to hear sound volume). CHL can typically be remedied with medication or surgery. Otitis media is a significant source of CHL and one of the leading causes of illness in young children (Casby, 2001; ASHA, 2008c). In fact, otitis media is one of the most common childhood illnesses and accumulates approximately five billion dollars a year in medical expenses. Children who

are at the greatest risk for otitis media include Native Americans, children enrolled in daycare, and children whose caregivers smoke (Zeisel et al., 1999; Northern & Downs, 2002). Most hearing losses related to otitis media are in the mild to moderate range.

The second type of hearing loss, SNHL, indicates that sounds do not travel from the inner ear to the brain appropriately. SNHL can be cochlear, occurring within the cochlea, or retrocochlear, occurring beyond the cochlea. SNHL causes a decrease in the intelligibility of sounds and is typically not reversible. The third type of hearing loss, MHL, is less common and has both conductive and sensorineural components. Any form of hearing loss can be unilateral, effecting one ear, or bilateral, effecting both (ASHA, 2008a).

The degree of hearing loss is determined by the magnitude of the loss in dB. There are seven categories of hearing sensitivity; normal, slight, mild, moderate, moderately severe, severe, and profound hearing loss. Normal hearing is when thresholds are between -10 to 15 dB HL, a slight hearing loss is thresholds between 16 to 25 dB HL, mild between 26 to 40 dB HL, moderate between 41 to 55 dB HL, a moderately-severe between 56 to 70 dB HL, severe between 71 to 90 dB HL, and profound is 91 dB HL and up (ASHA, 2008a). Hearing loss of greater severity will have a larger impact on a child's ability to develop appropriate speech, language, and educational outcomes.

The configuration of the hearing loss is the appearance of the hearing loss when plotted on an audiogram or a graph of hearing. Certain configurations are associated with certain types of hearing loss. SNHL is seen most often in the high frequencies. CHL is typically associated with low frequency hearing loss. Otitis media is a lead cause of CHL. Otitis media causes stiffness in the middle ear. Due to middle ear stiffness, low

frequencies are attenuated thus creating a low frequency hearing loss. Otitis media is variable and hearing sensitivity may fluctuate between normal and mild to moderate CHL (ASHA, 2008a). In addition, the symmetry of the loss is of importance especially since otitis media does not always occur in both ears (Northern & Downs, 2002).

In summary, a hearing loss is defined by the type, degree, and configuration of hearing sensitivity when plotted on an audiogram. An audiogram is arranged from low frequency or pitch to high frequency. Threshold is plotted by intensities from soft to loud. Thresholds of 20 dB HL or better are considered to be within the normal hearing range. Anything above the 20 dB HL range is considered a hearing impairment for young children according to ASHA guidelines (ASHA, 1997). Hearing loss can range from mild to profound, unilateral or bilateral, symmetrical or asymmetrical, and permanent or temporary.

The type, degree, and configuration of the hearing impairment will be used to determine the appropriate intervention procedures. A mild, unilateral, one frequency SNHL would not warrant the same intervention procedures as bilateral, moderate CHL across the entire frequency range. When evaluating hearing loss, audiologists must examine threshold information closely. A child with a mild, low frequency CHL would likely be referred to a physician for medical treatment before even considering amplification. However, a child with a moderate, high frequency SNHL would almost immediately be fit with hearing aids. When evaluating young children, extra care is given to any thresholds greater than 20 dB HL and often preferential seating is recommended in the classroom even if the hearing loss is temporary because adequate hearing is imperative for normal speech, language, social, and educational development.

Incidence of Hearing Loss in Young Children

The estimated number of children with hearing loss is as high as 6 per 1,000 live births (Cunningham & Cox, 2003). The incidence of pediatric hearing loss has been examined by numerous agencies and authors. The U.S. Department of Education reported, that during the 2003 school year, 79,544 children were receiving special education services under hearing impairment. This number is up from the 70,767 children receiving services for hearing impairment during the 2001 school year (National Dissemination Center for Children with Disabilities, 2004). However, it should be noted that many children from both groups were also receiving services for other disabilities; therefore, this number may not accurately reflect the total amount of children receiving services for hearing loss.

The CDC Early Hearing Detection and Intervention newborn hearing screening survey and follow up survey for 2006 found a total of 4,596 children with hearing loss. Of the children tested 794 children had a mild SNHL, 1,209 children had a moderate SNHL, 656 children had a severe SNHL, 970 children had a profound SNHL, and 63 were SNHL of unknown severity. They also found 322 children had a mild CHL, 400 children had a moderate CHL, 97 children had a severe CHL, and 85 had a CHL of an unknown severity (CDC, 2008). The number of Americans, age three years and up, with hearing loss has almost doubled since the 1990s from 13.2 million to 24.2 (ASHA, 2008c).

Niskar, Kieszak, Holmes, Esteban, Rubin, and Brody (1998) conducted a study to examine the prevalence of hearing loss in children between the ages of 6 to 19 years old. The Third National Health and Nutrition Examination Study (NHANES III) was

conducted from 1988 to 1994 nationwide on 6 to 19 year old children by the National Center for Disease Control and Prevention to examine a wide variety of health related disabilities and disorders. High and low frequency hearing loss was included in this survey and was categorized by sociodemographic characteristics. The NHANES III test group consisted of nearly 40,000 participants that represented the three most prevalent racial and ethnic groups: non-Hispanic Whites, non-Hispanics Blacks, and Mexican Americans. Hearing assessments were conducted on a small portion of the overall participants.

There were 6,908 participants for the hearing-related evaluations. Niskar et al. (1998) conducted tests in a sound treated mobile assessment center, which met clinical calibration requirements, and were conducted by trained examiners. Air conduction thresholds were established for each participant at 500, 1000, 2000, 3000, 4000, 6000, and 8000 Hz with 1000 Hz repeating. If thresholds differed by 40 dB HL or more between ears, masking was performed. Thresholds were accepted between -10 and 110 dB HL unless no response was given, in which case a threshold of 105 dB HL was recorded for statistical analysis (Niskar, et al., 1998). The participant's hearing evaluation results were divided into five categories: age, race, poverty income ratios, household interview results, and questionnaire results.

Age was divided into two groups: 6 to 11 years old and 12 to 19 years old. There were four groups of race: non-Hispanic Whites, non-Hispanics Blacks, Mexican Americans, and "other" races. Other races included Hispanics, Asians and Native Americans. There were three groups based on family income ratios: low, middle, and high. There were 8.6% of participants with no family income data available. Household

interviews were conducted to determine hearing status of participants. Questions were answered by the parents or guardians of children 6 to 16 years old and by the participants themselves, 17 to 19 years old.

Of the 6,908 children and families involved in the evaluations, a total of 6,166 participants' data was used for final statistical analysis. Threshold information was obtained for each participant as well as low pure-tone averages and high pure-tone averages. The low pure-tone average (LPTA) was the average of 500, 1000, and 2000 Hz, and the high pure-tone average (HPTA) was obtained by averaging 3000, 4000, and 6000 Hz. Hearing loss was identified when the LPTA or HPTA were 16 dB HL or worse. LPTAs and HPTAs were categorized by degree of hearing loss. Ears were classified by better or worse ear based on PTAs. The worse ear PTA was compared to sociodemographic information, household interviews, and questionnaire results. The prevalence of hearing loss was determined by comparing the number of children with hearing loss in this study to the total number of children in the U.S. based on the 1991 census (Niskar et al., 1998)

Of the participants tested, 10.8% reported having hearing loss prior to testing. Of the participants who reported normal hearing, 13.8% actually had a hearing loss. Niskar et al. (1998) noted several factors that may have contributed to the under estimate of hearing loss. Such factors included, children who may have been identified with a hearing loss that was transient or temporary at the time of the evaluation or the home interview, which had cleared up by the time of the evaluation. Also, children and parents may not notice a slight hearing loss and may have reported normal hearing. The lack of information available about follow up care may account for the low number of children

identified with hearing loss. The results indicate that a more thorough follow-up procedure should be used when identifying hearing loss in young children.

Questionnaire results were tabulated to look at incidence of low frequency and high frequency hearing loss. The prevalence of specific low frequency hearing loss among U.S. children was 7.1%. Sociodemographics, music, and/or noise exposure had little to no impact on the prevalence of low frequency hearing loss. The prevalence of congestion or tinnitus on the day of testing did affect low frequency hearing loss but not high frequency hearing loss. Also, children with an “ear ache” the week preceding testing or participants with tubes had a higher prevalence of LFHL than children without.

The results of this study found the prevalence of either high frequency or low frequency hearing loss of at least 16 dB HL in one or both ears to be 14.9%. The prevalence of both high and low frequency hearing loss among U.S. children was 4.9%. The prevalence of high frequency hearing loss was 12.7%. Sociodemographics had a significant relation to prevalence of high frequency hearing loss. Children from the low socioeconomic class were more likely to have high frequency hearing loss than children of higher classes. Additionally, males were more likely to have high frequency hearing loss in the 12 to 19 year old group. Mexican American children had a higher prevalence of high frequency hearing loss than any other race. While noise exposure within a 24-hour period prior to testing had no effect on hearing sensitivity, long-term noise exposure is known to cause permanent hearing loss. Optimally hearing evaluations should include both low and high frequencies to identify any potential hearing loss and help prevent possible educational and communicative delays.

Implications of Childhood Hearing Loss

Hearing loss identification is extremely crucial for all age ranges but particularly so for young children since they are acquiring new knowledge and skills daily. As reported by McFadden and Pittman (2008), many children with minimal hearing loss may go unidentified. There are many potential causes for misidentification of hearing loss such as mild, transient hearing losses seen with otitis media. Casby (2001) reported that approximately 80% of children up to age four have had at least one episode of otitis media; in fact, otitis media is the single most common physician findings in office visits among young children. Hearing loss related to otitis media is extremely variable. The hearing loss can range from a transient mild to moderate hearing loss or fluctuate between normal hearing and a mild hearing loss. Hearing loss related to otitis media may even be persistent lasting for several months. Additionally, hearing loss may not be observed in both ears if fluid is only present in one ear (Gravel & Wallace, 2000). The amount of fluid present, in addition to the fluids viscosity, can significantly impact the degree of hearing loss present. Any degree of hearing loss can adversely affect speech, language, and educational abilities.

Hearing loss has considerable impact on a child's communication development, behavior, education, and social skills (Cunningham & Cox, 2003). Casby (2001) performed a meta-analysis using research studies from 1960 to 2001 to evaluate the relationship between otitis media and speech and language delays. The criteria for each study needed to show predictive results related to how otitis media directly affects oral language development in children. The presence of otitis media had to have been evaluated objectively. Additionally, language ability had to have been assessed by either

norm-referenced test and/or descriptive, criterion referenced test measures. Finally, results had to be available in such a way that statistical analysis could be performed and effect size determined. The overall findings suggested that language outcome differences were small between children with and without otitis media with effusion. However, it should be noted that not a single effect size in any analysis was zero; therefore, Casby (2001) suggested that otitis media with effusion can affect language outcomes in young children specifically receptive, expressive, and spontaneous language. It is a safe assumption that language outcomes will vary dependent on the degree and configuration of the hearing impairment.

Gravel and Wallace (2000) conducted a study among 114 children birth to 3 years old to inspect the relationship between otitis media and hearing loss. The authors' study evaluated children at 2.5, 5, 7.5, 10, and 12 months old and yearly until 3 years old. Their goal was to examine the presence of hearing loss linked to otitis media, whether otitis media with effusion that resolved itself with one year had an effect on hearing later, and patterns of otitis media with effusion and hearing loss in relationship to gender, socioeconomic status, and birth risk.

The authors divided children into four groups for each year: bilateral otitis media with effusion (BOME), unilateral otitis media with effusion (UOME), mixed otitis media with effusion (Mixed OME), and infrequent otitis media with effusion (Infrequent OME). Mixed OME was identified when less than 30% of visits were bilateral otitis media but 50% or more of visits were a mixture of unilateral and bilateral otitis media. Infrequent OME was described as more than 20% of visits but less than 50% of visits were a combination of unilateral or bilateral otitis media. The results found that in year one 40%

of the BOME children had hearing loss, 25% of UOME children had hearing loss, 20% of Mixed OME children had hearing loss, and 24% of Infrequent OME children had hearing loss. Second year results found 44% of BOME children had hearing loss, 100% of UOME children had hearing loss (it should be noted there was only one child in this group), 33.3% of Mixed OME children had hearing loss, and no children in the infrequent OME group had hearing loss. In the third year 60% of BOME children had hearing loss, 25% of UOME children had hearing loss, 50% of Mixed OME children had hearing loss, and 22.2% of infrequent children had hearing loss (Gravel & Wallace, 2000). The results clearly show a link between otitis media with effusion and hearing loss.

Wallace and Gravel (2000) further examined the difference in hearing sensitivity as it related to otitis media over time. They divided children into three groups to evaluate times effect on hearing loss. The three groups were: children with normal middle ears in all three years, children with bilateral or mixed OME in year one but normal middle ears in year two and three, and children with bilateral or mixed OME during years one and two but normal middle ears in year three. The authors found a considerable difference between each group. There was also a significant relationship between year of evaluation and group. Furthermore, hearing levels changed noticeable over time. The most noticeable change in hearing sensitivity was seen between year one and year three. The results found that as children aged, the incidence of otitis media decreased and hearing sensitivity improved (Wallace & Gravel, 2000).

Finally, the authors inspected the effect of otitis media and gender, socioeconomic status, and birth risk. The results concluded that females were 15% more likely to be

otitis media free than males; children of lower socioeconomic status were more prone to otitis media with effusion than children of middle socioeconomic status, and children with birth risk such as prematurity had no significantly higher risk of otitis media or hearing loss. The results further showed that when evaluated each year, 30-45% of children had bilateral otitis media with effusion. Chronic otitis media with effusion is known to have a negative impact on speech and language development specifically language development (Gravel & Wallace, 2000). Speech and language development begins in infancy, however, refining these skills continues throughout childhood and any decrease in hearing sensitivity may hinder appropriate development.

Shriberg, Friel-Patti, Flipsen, and Brown (2000) evaluated the relationship between language outcomes and otitis media with effusion with and without hearing impairment. Children in this study were evaluated at 6 to 12 months and 12 to 18 months for otitis media with effusion and hearing loss. Children were then again evaluated at 3 years of age and language samples were taken. Shriberg et al. (2000) found that children who had otitis media with effusion with hearing loss were more likely to have language and educational delays than children who had otitis media with effusion without hearing loss. Language delays were most commonly seen when the hearing loss occurred during the 12 to 18 month age range. Children who had otitis media with effusion and hearing loss were 10 to 21 times higher at risk for later speech disorder. Such problems included decreased speech perception, discrimination, and representation of phonemes. This was particularly true of phonemes that occur in the frequency range most affected by otitis media. The effects of otitis media on language development are extremely variable and may lead to educational delays or disorders. In fact, Blanchfield, Feldman, Dunbar, and

Gardner (2001) reported that children with severe to profound hearing loss are at a higher risk of not graduating high school or college than peers with normal hearing.

Hicks and Tharpe (2002) conducted a two phase study to look at the academic implication of hearing loss and multitasking. Often children are required to perform multiple tasks simultaneously such as writing assignments while being given verbal instruction. For children with normal hearing this may not be a difficult task. Therefore, Hicks and Tharpe (2002) posed the question, “Do children with hearing impairment require extra effort when listening and do they fatigue quicker than their peers with normal hearing?” Fatigue was evaluated based on cortisol levels in the morning and afternoon; in addition, in the afternoons the Dartmouth Primary Care Cooperative Information Project Scales (COOP) was administered. The COOP is a self-assessment in the areas of physical fitness, emotional feeling, schoolwork, family communication, health habits, and social support. Children rated themselves on a 5-point scale. Participants included 20 children, 10 with hearing loss and 10 without.

The results of Hick and Tharpe’s (2002) study revealed that all children had lower cortisol levels in the afternoon when compared to the morning results. On average, children with hearing impairment did have lower cortisol levels than children without hearing loss; however, the difference was not statistically significant. COOP results were similar between the two groups as well.

Hicks and Tharpe (2002) conducted a second study with many of the same participants to evaluate children’s abilities to multi-task with and without hearing loss. Fourteen children with mild to moderate SNHL, and 14 children with normal hearing were asked to perform listening tasks and performance tasks. The listening task consisted

of children repeating words from a phonetically balanced word list (PBK) and calculating the percent correct. Children who wore hearing aids were allowed to wear them during testing. Children were tested in a seated position at a table with a speaker placed 3.5 feet in front of them at 0° azimuth, and at ear level. Words were presented at 70 dB(A) when the speaker was 3.5 feet away. Words were presented in four different test conditions: in quiet, with a +10 signal to noise ratio (SNR), +15 SNR, and +20 SNR. The performance task consisted of children pushing a button whenever a light was seen. The light was introduced during the listening tasks. Children were asked to place their hands on in painted handprints to help control reaction time differences. The light was presented 25% of the time during the repeating word of the listening task, 25% during the carrier phrase, 25% at the end of the carrier phrase and before the repeating word was presented, and 25% of time no light was seen (Hicks & Tharpe, 2002).

The results of the evaluation found all children performed relatively well on the primary task of repeating the words. The authors did find that as SNR became more difficult PBK scores decreased. Children with hearing loss did score significantly lower than children with normal hearing however, the average score was approximately 85% correct which is considered a good word recognition score. Reaction times of children with hearing loss were significantly lower than that of children with normal hearing. Hicks and Tharpe (2002) concluded that children with hearing loss would likely exert more effort when trying to multitask especially in noise due to their inability to hear the words clearly. The best way to maintain good academic achievements is to quickly and accurately identify any hearing impairment.

As previously reported, otitis media is one main cause of hearing impairment in young children. McFadden and Pittman (2008) found that children with even a minimal hearing loss have poor word recognition ability when compared to their peers with normal hearing. The authors defined a minimal hearing loss as either a mild hearing loss, unilateral hearing loss, or a high frequency hearing loss. They found that children with minimal hearing loss were at risk for language delays due to their inability to differentiate sounds, especially in noise. These children's vocabulary ability were as much as three years behind their peers with normal hearing, putting them at an enormous disadvantage for continued academic success (McFadden & Pittman, 2008).

McFadden and Pittman (2008) examined children's ability to multi-task with a minimal hearing loss. The authors examined 21 children ages 8 to 12 years old to determine how they were able to multitask in quiet and in noise. The participants included 10 children with minimal hearing loss and 11 children with normal hearing. Two tasks were established: a listening task and a written task for all participants.

The listening task included a list of 99 nouns commonly used by first graders separated into three categories: people, animals, or food. Words were divided into three 30-word lists with the extra nouns to be used as the baseline stimuli. Nouns were recorded by a female American English speaker at a sampling rate of 22.05 kHz using a microphone with a flat frequency response to 10 kHz. One recording was made in quiet and two were made in noise.

The noise stimulus was created using a 2000 ms broadband noise with a sampling rate of 22.05 kHz. Noise and nouns were mixed and presented to participants. Speech was continuously presented at 65 dB SPL while the noise was presented at 59 and 65 dB

SPL. All testing was performed using headphones and no amplification was provided to children with hearing loss. Children were also provided with labeled pictures of each category (people, food, or animal) and asked to tell the examiner which category each noun they heard went into or if they did not know.

The written task consisted of 18 dot connection games. The numbers of dots in each game were matched as closely as possible, and they were divided into three groups of six. Two booklets were created for participants with a colored page separating each section. The first booklet was used as a baseline and was the same for all participants while the order of arrangement varied for the second booklet. Children were given the first booklet and instructed to play each game in the book while being timed. Participants were informed that they were not in a race, and to complete each game as accurately as possible. They were also given the option to correct mistakes or to continue. Children were told to stop once they reached the colored page. A dot rate was determined for each child. After obtaining listening and written baselines, children were evaluated for their ability to multitask.

Children were given the second dot connection booklet and asked again to connect all the dots while saying which category each word they heard belonged. This was performed in quiet and in noise. Children were instructed to ignore any noise they may have heard. Booklet pages in which accurate dots rates could not be determined were excluded for analysis. If a child did not know what category a noun belonged, it was counted as “no response.”

The results of McFadden and Pittman’s (2008) study were averaged for each listening condition among both groups. A separate analysis was performed to evaluate the

dot rate and noun categorization in quiet and in noise. The results determined that all children's dot rates decreased significantly in noise. However, the children with hearing loss also had a significant decrease in their noun categorization abilities. The results indicate that children with hearing loss have a harder time multitasking, especially in noise when compared to their peers with normal hearing. Therefore, tasks such as note taking have the potential to be more difficult for children with hearing impairment especially in the presence of background noise. The authors noted children with hearing loss should be provided with a note taker, given verbal and written instruction, and be provided extra time to take tests, especially if the instructions are verbal (McFadden & Pittman, 2008).

School Hearing Screenings

ASHA created guidelines for hearing screenings from birth through adulthood. Within these guidelines, there are two sections that are of particular importance for school-aged children: "Guidelines for Screening Infants and Children for Outer and Middle Ear Disorders (birth through 18 years)" and "Guidelines for Screening for Hearing Impairment School-Aged Children (5 through 18 years)." The latter establishes the ASHA requirements for school-based hearing screening programs. ASHA guidelines for screening for outer and middle ear disorders are not required for school hearing screenings; however, it is strongly recommended.

It is the role of the audiologist to perform audiological screenings and identify any disorders or impairments that may be present (ASHA, 2006). ASHA guidelines have been developed for the purpose of identifying such problems through audiological screenings. Audiological screenings are intended to identify auditory disorders,

impairments, and help prevent communication difficulties. Screenings also identify children that are at risk for impairments which can adversely impact communication, health, education, feelings of worth, and social life. Results of audiological screenings help identify the need for rescreening, further assessments or evaluations, and the need for referral to other professionals outside the field of audiology (ASHA, 2006).

According to the ASHA guidelines, children are to be screened upon entry into a school program, annually in kindergarten through 3rd grade, and in the 7th and 11th grades. School-aged children will also be screened when requested, if absent on the day of the initial screening, upon entering a special education program, repetition of a grade, or entering a new school in which previous hearing screening procedures are unavailable. Children who are considered at risk for hearing loss may need to be screened more often to ensure normal hearing sensitivity. At risk children include those whose parents, guardians, or teachers have noticed a decrease in speech and language abilities, those who have concerns about a hearing loss, or a possible learning disability. Children may also be screened at different times if there is a family history of postponed hearing loss, recurrent or chronic otitis media lasting longer than three months, craniofacial abnormalities including the ear, signs of a syndrome that is linked to hearing loss, head trauma, exposure to loud sound, and medication that is known to be damaging to hearing. It should be noted that children who are already receiving services for a hearing impairment do not need to participate in hearing screenings as their hearing status is already being monitored by an audiologist (ASHA, 1997; ASHA, 2008b).

Hearing screenings are to be performed by an audiologist or speech language pathologist (SLP) who has a Certificate of Clinical Competencies (CCC-A or SLP) and

state licensure when required or appropriately trained support personnel. Trained support personnel may include anyone from the school nurse to teachers. Optimally, hearing screenings should be performed in a sound-treated booth with limited if any distraction. The use of sound treated booths is typically not practical. In this case, the American National Standards Institute (ANSI), (1991) makes recommendations for permissible ambient noise levels. ANSI S3.1-1999 recommends that ambient noise levels not exceed 49.5 dB SPL at 1000 Hz, 54.5 dB SPL at 2000 Hz, and 62 dB SPL at 4000 Hz when using a 20 dB HL pure-tone stimulus (ASHA, 1997). Additionally, audiometers should meet all ANSI standards for calibration and limited range audiometers (ASHA, 1997; ASHA, 2006).

Hearing screenings are to be completed with permission of the parent/guardian who will be given a description of the hearing screening protocol, results, and follow-up procedures. Behavioral or conditioned play audiometries and middle ear analyzers (tympanometers) are the only acceptable forms of screening in the school-aged population. Behavioral audiometry is a form of screening in which an observable physical response is given in response to a pure-tone stimulus. The most commonly used approach is asking a child to raise his hand when he hears a sound. Children may also be conditioned or trained to perform a certain action in response to a sound, such as dropping a ball in a bucket. This is known as conditioned play audiometry. Tympanometry evaluates the function of the middle ear, specifically ear canal volume, middle ear pressure, and tympanic membrane mobility. The child does not need to participate or provide any type of behavioral response.

ASHA (1997) recommends behavioral testing were children are be screened using supra-aural headphones at 20 dB HL at the test frequencies of 1000, 2000, and 4000 Hz. A child will be considered a pass if a response is given at every test frequency for each ear. If a child fails to respond for each test frequency, the examiner should check the headphone placement, reinstruct, and rescreen the child. If a child fails to respond again, he will be referred for further evaluation. If a child responds appropriately at each test frequency the second time, it may be counted as a pass (ASHA, 1997).

Only pure-tone stimuli are to be used for hearing screenings. The use of speech stimuli, unorthodox equipment such as hand held screening devices, uncalibrated stimuli, TEOAEs or DPOAEAs are not recommended due to the reported lack of sufficient evidence of their reliability and validity (ASHA, 1997). Children should also be tested individually. Once a fail or referral has been made, children should have their hearing status confirmed within one to three months. It is important to keep records of all hearing screenings for future testing and for parental notifications. Documentation of follow-up procedures should be obtained and recorded. Children with even a mild hearing loss are at an increased risk for educational and communicative disorders and all test results should be recorded (ASHA, 1997).

Presently, pure-tone audiometry and tympanometry are the only ASHA recommended procedures to identify children with potential hearing loss or at risk for possible hearing loss due to middle ear disorders. Children who are referred for further testing should have notification sent home. If hearing loss is confirmed, the teacher needs to be informed and educated about the impact of hearing loss. Teachers and parents that are well informed about hearing loss can help identify children who may be at risk for

hearing impairment (ASHA, 1997). The uses of hand-held devices, such as screening devices or OAE screeners, are not recommended by ASHA due to high false positive rates that can be associated with these tests. TEOAEs and DPOAEs are not recommended due to the reported lack of sufficient evidence of their reliability to screen for hearing disorders in the school-aged population. However, past studies have shown promising results which suggest hand held devices could be extremely beneficial (Sideris & Glatke, 2006). It should be noted that the American Academy of Pediatrics, as cited by Cunningham and Cox (2003) recommended that objective hearing screening procedures be utilized not only for newborn hearing screening but throughout adolescence and adult years (Cunningham & Cox, 2003).

Objective and Subjective Hearing Screening Measures

ASHA recommends the use of subjective pure-tone audiometry to evaluate hearing sensitivity in school-aged children. Recommendations have also been made for the use of middle ear analyzers but, no recommendations have been for the use of objective hearing screening procedures such as OAEs (ASHA, 1997). A subjective hearing screening consists of a pure-tone stimulus that is presented via headphones and where the child must provide a conditioned behavioral response such as raising his hand. An objective screening procedure is one that elicits a measurable physiological response and does not require a behavioral response. It is considered a measure of auditory function and not hearing in the strictest sense. Behavioral or conditioned play audiometries are the only recommended forms of hearing screening for school-aged population. Tympanometry is the only form of objective middle ear analyzer

recommended by ASHA. Currently ASHA makes no recommendations for the use of objective hearing screening devices to test auditory function.

OAEs are an objective screening tool which evaluates the integrity of the inner ear, specifically the cochlea. OAEs are reverberant measurements that are produced in response to a stimulus via the auditory canal from the cochlea. There are two types of OAEs, transient evoked and distortion product. Both examine cochlear function using an audible stimulus; however, the process of measurement is slightly different.

TEOAEs use short duration click or tone-burst stimulus at 80-85 dB SPL with approximately 60 stimuli presented per second. Click stimulus are used for a broader frequency response up to 4 kHz, while tone-burst are more frequency specific, typically between .5 to 4 kHz. TEOAE screenings are safe and quick evaluations of the peripheral auditory system between 1000 to 4000 Hz. TEOAEs are obtained by two stimuli being presented and stored in separate memory banks. The reproducible measures between the two are considered a response while measures that cannot be reproduced are considered noise. TEOAEs can be measured in ears with hearing sensitivity of 40 dB HL or better (Campbell, 2006).

DPOAEs are measured by presenting two pure-tones (f_1 and f_2) at two different intensities (L_1 and L_2) at the same time. When the two pure-tones are close together in frequency, an interaction of the two tones causes a distortion which can be measured via the auditory canal. The most robust distortion in the human ear is noted as $2f_1 - f_2$. For best results, the two tones should be within 1/3 octave of each other. DPOAEs are more frequency specific than TEOAEs and have a higher frequency range, up to 8 kHz. DPOAEs can be measured in ears with a mild to moderate hearing loss (Campbell, 2006;

Lonsbury-Martin & Martin, 1990). In summary, both types of OAEs are sensitive to inner ear damage specifically in the outer hair cells of the cochlea which causes hearing loss.

Objective hearing screening procedures are not limited in accuracy by behavioral variables. Children do not need to provide a behavioral response to participate; they merely need to sit still and listen. Studies have shown the usefulness of objective screening procedures (specifically tympanometry and otoacoustic emissions). Objective screening tools have been recognized as a successful way to identify children with hearing loss and/or possible middle ear disorders when compared to traditional pure-tone hearing screenings alone (Eiserman, Hartel, Shisler, Buhrmann, White, & Foust, 2008; Lyons, Kei, & Driscoll, 2004; Sideris & Glatke, 2006; Glatke, Pafitis, Cummiskey, & Herer, 1995; Taylor & Brooks, 2000).

When using objective hearing screening tools, it is not possible for examiners to influence the outcome results. In addition, support personnel, who are trained by audiologists, would require less training time for the use of objective screening measures. While probe tips can be placed incorrectly in the ear canal, repeating test procedures would take minimal time and screening instructions are easy to follow. Objective hearing screening tools have been reported to provide reliable results in up to 70 dB SPL of noise; however, whenever possible, background noise should be limited (Etymotic Research INC., 2009).

Tympanometry is an objective screening tool which evaluates the functionality of the middle ear. Tympanometry is a measure of acoustic immittance using a low frequency tone (226 Hz) with positive and negative pressure sweeps via a probe tip placed in the auditory canal. A 226 Hz tone is used to assess the stiffness qualities of the

middle ear. The negative and positive pressure sweeps evaluate the mobility or compliance of the tympanic membrane or eardrum. A tympanogram is the pictorial representation of tympanometry results. There are five types of tympanograms, type A, A_s, A_d, B, and C. The type of tympanogram is determined based on ear canal volume, compliance, and pressure. Normative ranges are available for each type for children and adults (Northern & Downs, 2002).

Type A, A_s, and A_d are all considered normal tympanometry, indicating normal middle ear function. A Type A_s tympanogram is used to denote an ear with a stiffened compliance which may be seen with scar tissue on the eardrum. A Type A_d tympanogram indicates a deep or flaccid compliance often associated with disarticulation of the ossicular chain. A Type B tympanogram or flat has a flat compliance and can have either normal or large ear canal volumes. Type B tympanograms with normal ear canal volumes are commonly seen with those who have otitis media with effusion. Type B tympanograms with large ear canal volumes are seen with ruptured tympanic membranes or pressure equalizing tubes. A Type C tympanograms have near normal compliance and high negative pressure in the middle ear. Type C tympanograms may be seen in ears with fluid in which the eardrum still has some mobility or eustachian tube dysfunction. The type of tympanogram observed aids in determining if the middle ear is functioning normally or if there is a possible disorder (Northern & Downs, 2002).

Subjective hearing screening measures are obtained via supra-aural headphones using a pure-tone stimulus. Screenings are obtained at 20 dB HL at 1, 2, and 4 kHz for each ear separately. Children are required to provide a behavioral response either by raising their hand or providing a conditioned response such as dropping a toy in a bucket

when a sound is heard. A child is considered to have passed if he responds appropriately two out of three times to the stimulus at each frequency tested. A child can pass for just one or both ears. Pure-tone screenings are the only true test of hearing in the hearing screening protocol. Subjective screening measures require strict participation from the child being tested (ASHA, 1997).

There are many limitations when using subjective hearing screening procedures alone. Young children are not always cooperative and do not always provide accurate behavioral responses to pure-tone audiometry. Children who are shy or scared may not provide accurate behavioral responses. These children would be considered having failed their hearing screening. Children with disabilities, like mental retardation, may not be able to provide appropriate behavioral responses and would also be counted as having failed (Taylor & Brooks, 2000).

Under the ASHA guidelines, trained support personnel like school nurses or speech language pathologist, are allowed to perform screenings under the supervision of a licensed audiologist (ASHA, 2006). However, not all support personnel have been adequately trained, and there is an increased risk for tester-related referrals. Improper placement of earphones can cause up to a 35 dB threshold shift thus causing a child to fail his hearing screening. Support personnel may try to position the headphones so that the child is comfortable or not adjust headphone placement when a child manipulates it himself.

Behavioral factors, such as visual cues unknowingly made by inexperienced examiners, can affect screening outcomes. Children who can see the tester adjusting the dial on the audiometer or if the examiner looks to the child when it is time to respond

may cause an increase of false positive responses. Additionally, presenting prolonged or shortened stimulus may cause the child to give inaccurate responses resulting in a referral (Northern & Downs, 2002). While most audiologists are aware of such distractions, support personnel may not be aware. They may not realize they are persuading the child to respond to a stimulus he does not hear, or to become uncooperative because test procedures are taking too long. Support personnel can be properly trained to obtain accurate tests; however, due to the subjectivity of pure-tone screenings, they should only be done under the supervision of an audiologist.

In addition to child participation, traditional pure-tone hearing screenings can be difficult to obtain in settings that are noisy. Pure-tone audiometry for the purposes of screening hearing outside the confines of a sound treated booth is problematic, specifically in school-aged children. Since the majority of school hearing screenings are not conducted in sound treated rooms, but rather a classroom with elevated noise levels, obtaining accurate results can be challenging (Northern & Downs, 2002; Allen, Stuart, Everett, & Elangovan, 2004). While using a sound treated booth would be optimal, it is not practical and therefore noise levels should be continuously monitored and adjusted.

Knecht, Nelson, Whitelaw, and Feth (2002) conducted a study to evaluate background noise levels and reverberation times of unoccupied classrooms. Background noise is the level of undesired noise that hinders what children are trying to hear. Reverberation is the continuation of a sound within a confined area as the sound waves rebound off hard surfaces, often referred to as an echo of the sound. Reverberation time is the amount of time it takes for reverberant sounds to reduce to a set level. The authors examined background noise levels and reverberation times of 32 classrooms in eight

different schools and then compared their measurements to the ASHA and ANSI recommended tolerances. ASHA recommends that unoccupied classroom noise level should not exceed 30 dB(A) and reverberation times should be less than 0.4 seconds. ANSI S12.60–2002 recommends that unoccupied classroom noise levels not exceed 35 dB(A) and reverberation times should be less than 0.6 seconds. Each classroom was evaluated the same manner with exception of heating, ventilating, and air conditioning systems (HVAC) which could not be controlled (Knecht et al., 2002).

The first step was to obtain each classrooms volume by measuring the height, length, and width of each room. Five different measurement points were marked in each room to ensure no measurements were made in any standing wave patterns. A sound level meter was positioned above each point and an amplifier and speaker were place in the front left corner of each room. Speakers were placed on the floor facing upward to mimic an omin-directional speaker system. Measurements were made with a sound level meter which had a programmable start so that no one would be in the rooms when measures were taken. Background noise was measured first and then reverberation times were taken.

The noise levels of the 32 classrooms ranged from 34.4 dB(A) to 65.9 dB(A). Only four classrooms had noise levels that were less than the ANSI recommendation of 35 dB(A) and only one had noise levels below the ASHA recommended 30 dB(A). Rooms with HVAC systems on had an average noise level of 49.7 dB(A) and an average of 39.8 dB(A) when turned off. Reverberation times ranged from 0.2 second to 1.27 seconds. Thirteen classrooms surpassed the 0.6 seconds recommended by ANSI and six were less than the ASHA recommended 0.4 seconds. Classrooms with larger volume had

longer reverberation times. It should be noted that only one classroom met ASHA recommendation. The lowest background noise levels and reverberation times were noted in the newest schools (Knecht et al., 2002). The results of this study illustrated the need for continued noise level monitoring to ensure appropriate hearing screening results.

The Importance and Significance of Objective Screening Information

The question of whether objective hearing screening equipment should be used as a supplemental resource or as a replacement of traditional pure-tone hearing screening has been brought to light by multiple authors (Lyons et al., 2004; Eiserman et al, 2008). The differences between objective and subjective screening procedures are substantial; however, each has a valid role in early hearing loss identification.

Each procedure has many advantages and disadvantages. The fact that pure-tone audiometry is a true test of hearing is an obvious advantage. While OAE will likely be absent in a child with hearing impairment, it is not a test of hearing but rather a test of the inner ear function (ASHA, 1997; Northern & Downs, 2002). Additionally, tympanometry is also a test of function in regards to the middle ear. Pure-tone audiometry is also the “gold standard” for hearing evaluations and most support personnel are somewhat aware of what the child should do (ASHA, 1997).

Time is a key factor when performing school based hearing screening. Objective screening procedures are often quicker to teach, administer, and perform than subjective screening procedures (Taylor and Brooks, 2002). Training of support personnel to use tympanometers and OAE screeners would likely take less time than training for pure-tone audiometry. Also, the time it takes for a child to condition for objective screening procedures would be diminished. Children may have to be re-instructed about how to

respond to pure-tone stimuli (Eiserman et al., 2008). In addition to time, objective screening tools can be easier to use since the majority have clear pass/refer results or the normal range is highlighted (Sideris & Glatke, 2006). The results of tympanometry and OAE screenings, in addition to pure-tone audiometry, will ultimately identify more children with a possible hearing loss than one or other alone.

Extensive information about the use of objective hearing screening tools for identification of hearing loss and middle ear disorders has been widely reported (Taylor & Brooks, 2002; Sideris & Glatke, 2006; Eiserman et al., 2008). Otoacoustic emissions and tympanometry are the most commonly used objective screening tools during hearing evaluations or screenings. The current ASHA guidelines do not require the use of objective inner ear hearing screening tools during traditional school based screening programs (ASHA, 1997).

Taylor and Brooks (2000) designed a study to investigate the sensitivity and specificity of TEOAE screening procedures when compared to traditional pure-tone hearing screenings and tympanometry. The sensitivity and specificity of TEOAEs has been used to evaluate the validity of test results. Vohr et al. (1998) as cited in Taylor and Brooks, reported study results in which the sensitivity and specificity of TEOAEs were at 95% and 87%, respectively. The purpose of Taylor and Brooks' (2000) study consisted of 150 children between the ages of three to eight years old; three ears were excluded from the final analysis due to a lack of cooperation during the screening procedures for a total of 297 ears. The children in this study were referred from local speech and hearing centers, ear nose and throat doctors, early intervention programs, children's rehabilitation

services, and some daycare programs. Eight children in the study had known hearing loss, but no threshold information was provided to examiners.

All screening procedures were performed by two ASHA certified audiologists. There were three phases of the hearing screenings: pure-tone screening, tympanometry, and TEOAE screenings. Pure-tone audiometry was conducted in a sound treated room. Air conduction screenings were conducted at 20 dB HL for 1000, 2000, and 4000 Hz. A child passed pure-tone screenings if a response was given at 20 dB HL at all test frequencies for each ear. If a child did not respond at 20 dB HL, audiometric thresholds were determined in an effort to eliminate over referral for nonparticipant children.

Tympanometry was conducted using a 226 Hz probe tone. If a child did not fall within the ASHA recommended normative ranges, they were referred for further testing. A child did not pass tympanometry if his static admittance was less than 0.3 mmho, ear canal volumes were greater than 1.0 cm³, or tympanic width was greater than 200 daPa.

OAEs were obtained using a manufacture default filter, intensity ranged from 75 to 85 dB SPL at a rate of 50 clicks per second. A total of 260 averages were made, the noise rejection level was set at 47 dB SPL. To determine if a response was present or absent, average noise levels of the ear canal and average OAE responses were recorded together at the center frequency bands of 1000, 2000, 3000, 4000, and 5000 Hz. A response was considered valid if it was at least 3 dB above the noise floor at any frequency band. At least three of the frequencies had to be valid in order for a child to pass. To pass, individual frequency bands and whole-wave reproducibility had to be at least 40% when specificity and sensitivity goals were at 90-95% (Taylor & Brooks,

2000). The whole wave and the individual frequency band had to be reproduced within 40% of the original.

The results of the screenings were divided into two sections; TEOAE and pure-tone results, and TEOAEs and tympanometry results. Results of children who passed TEOAEs and pure-tone screenings were compared for sensitivity and specificity. Sensitivity of TEOAE and pure-tone screenings were at 81% and specificity was at 95%. In other words, the sensitivity of TEOAEs and pure-tone audiometry to identify a hearing loss had a hit rate of 81% and with 95% accuracy to identify children with normal hearing. The screening results found 251 of 297 ears that passed pure-tone screenings also passed TEOAE screenings. Only six ears passed TEOAE screenings but failed pure-tone screenings, while 14 failed TEOAE screenings but passed pure-tone screenings. The results of the TEOAE and pure-tone analysis found a high correlation between the numbers of children who fail TEOAE screenings and the number failing pure-tone screenings. Suggesting that passing TEOAEs is a strong predictor of normal hearing sensitivity. Therefore, the number of children who failed TEOAEs is directly related to the number who failed pure-tone audiometry.

The result of TEOAE screenings and tympanometry screenings had a sensitivity of 60% and specificity of 91%. The results indicated that 241 of 297 ears passed tympanometry and TEOAE screenings. There was a higher incidence of ears that failed tympanometry but passed TEOAEs (10 of 297) and of ears that passed tympanometry but failed TEOAEs (24 of 297). It should be noted that there are many other studies that have found a correlation between Type B and Type C tympanogram and reduced TEOAE responses. In addition, pressure equalizing tube placement can affect the outcomes of

TEOAEs (Glattke et al., 1995). Regardless, there was a significant statistical correlation between identification of abnormal tympanometry and TEOAEs that showed a direct relationship between children who failed tympanometry and children that failed TEOAEs.

In summary, results determined the sensitivity to be 81% and specificity to be 95% for pure-tone and TEOAE comparison. This suggests TEOAEs can be used as a reliable tool for identifying children with hearing impairments. However, the use of TEOAEs as a screening tool for middle ear pathologies is less reliable, but still significant. Taylor and Brooks (2000) were discouraged by the low sensitivity of TEOAEs and pure-tone testing. They hypothesized that this may be due to lack of sensitivity of TEOAEs pass/refer criteria to identify low frequency hearing losses. They also suggest that the 20 dB HL screening criteria for pure-tones may be too conservative since some children with a 20 dB HL hearing loss will pass TEOAEs. The authors' suggested that the criteria for TEOAEs to identify hearing loss needs to be approximately 30 dB or higher. They also suggested if they had set high response amplitudes in combination with the TEOAE signal to noise ratio of 3 dB, the sensitivity may have improved (Taylor & Brooks, 2002). Overall, the sensitivity and specificity were considered to be acceptable for pure-tone and TEOAE screenings, and the use of TEOAEs can substantially reduce the amount time and effort it takes to test mass quantities of young children. Of the total children tested, only 2% could not be tested due to lack of cooperation. Young school-aged children can be exceedingly difficult to test and quick accurate test procedures can make hearing screenings more agreeable for everyone (Taylor & Brooks, 2000).

Sideris and Glatke (2006) examined 200 children ages two to five years old to scrutinize the usefulness of immittance (tympanometry) testing and TEOAEs over that of or in addition to, traditional pure-tone audiometry. They hypothesized that since tympanometry and TEOAEs are objective measures, accurate screening results could be obtained without children's participation. Unlike pure-tones, children were not required to provide a behavioral response in any way. The results of this evaluation identified 43 children with a possible hearing impairment using pure-tone audiometry and 42 using TEOAEs. Of the 43 children who failed the pure-tone screening, 40 also failed TEOAEs and/or tympanometry. The authors also noted that 27 of the 43 children who failed pure-tone screening did so because they were uncooperative while only 4 of 42 children failed TEOAEs because they would not cooperate. It is clear that pure-tone audiometry requires certain competencies to obtain responses appropriately and in a timely manner.

Allen, Stuart, Everett, and Elangovan (2004) conducted a study among three and four year olds enrolled in North Carolina Head Start centers in three counties from 1998 to 2002. The purpose was to examine the pass/refer rates for middle ear disorders and hearing loss. A total of 1,462 children participated in this study. Participants who were tested at three years were not retested at four years old for this study. Participants were of lower socioeconomic status, which is known to have a higher incidence of middle ear pathologies, and many children had disabilities or delays such as speech and language disorders. The majority of participants were four years old and included slightly more boys than girls.

Participants were tested in quiet rooms which met ANSI standards (ANSI S3.1-1999) for permissible ambient noise levels. Testing areas were assessed using a precision

sound level meter prior to each test session. Pure-tone audiometry was obtained using portable audiometers and supra-aural headphones. Otoscopy and tympanometry were also performed in accordance with ASHA guidelines. Pure-tone audiometry was acquired at 1000, 2000, and 4000 Hz using a 20 dB HL pure-tone through conditioned play audiometry.

Audiological screenings were performed by ASHA and North Carolina licensed audiologists and/or supervised graduate students in speech language pathology or audiology. Participants were screened within the first 45 days of each school year. Participants were considered to have passed if they responded appropriately, two out of three times at all frequencies for each ear. A refer was noted as unilateral, bilateral, and if one or multiple frequencies were missed (Allen et al., 2004).

Participants who did not pass were retested between two to four weeks in compliance with Head Start guidelines. Participants were considered to have passed if he or she passed otoscopy, tympanometry, and pure-tones screenings. A participant was referred if he or she did not pass one or more screening test for either ear (Allen et al., 2004).

The results of this study found that approximately 46% of participants failed the initial screening in one of three areas. Of the participants who did not pass, 38% were referred for audiological evaluations and nearly 7% were referred for medical evaluations or both. Approximately 10% of participants failed the otoscopy screening and the majority of participants who did not pass were referred for structural anomalies. Seventy-one percent of participants passed the pure-tone screening. The most common reason for referral from pure-tone screenings was a one frequency unilateral loss. The largest

amount of participants who could not be tested, due to cooperation problems, were seen during pure-tones screenings. Seventy one percent of participants also passed the tympanometry screening. The most common reason for tympanometry referral was due to decreased static acoustic compliance and increased tympanic width. Decreased acoustic compliance is often seen in ears with otitis media with effusion. If participants did not pass all three screening protocol, they were referred to be rescreened at a later date (Allen et al., 2004).

A total of 675 children were referred for rescreening, medical evaluation, or both. Approximately 71% of the participants referred received the suggested evaluation. Of the total 1,462 children screened, 80% passed the audiological screening either at the first or second screen. Nineteen children were seen for diagnostic audiological evaluations. The results identified one child with a sensorineural hearing loss, four children with conductive hearing losses, and one child that could not be tested using behavioral testing procedures. Fifteen children were seen for medical evaluation. Eleven of the 15 had abnormal findings including, otitis media and cerumen impaction. Six children were seen for both medical and audiological evaluation. The results found that four children had otitis media and one had impacted cerumen. Of the total children tested, six had confirmed hearing losses and 18% had unconfirmed hearing sensitivity because they did not continue with follow-up procedures. Undoubtedly, more children would have been identified with hearing loss had they been fully evaluated as the incidence of otitis media is increased among this population (Allen et al., 2004).

The demographics of the test group may have affected pass/refer rates. The children in this study were from impoverished, rural, medically disadvantaged areas, of

lower socioeconomic status, putting them at an increased risk for middle ear disorders. Furthermore, the children who participated in this study were younger than participants in other studies which may affect pass rates since pass rates increase as children age. The results of this study found that nearly half of all four year olds will be referred from the initial screening when using the ASHA hearing screening guidelines. The rate of referral could be related to middle ear pathologies, in addition to, limited participation of young children (Allen et al., 2004).

In summary, the goal of this study was, to examine the pass/refer rate of children using the ASHA guidelines for birth to 18 years for middle ear screenings and three to five year olds for pure-tone screenings. There were several factors that affected the outcome of this study. First, the reason children were referred from the initial screening should be further examined to determine if it is related to middle ear disorders or if the screening procedure needs to be changed. For example, the ASHA recommend guidelines for tympanometry are the same for children one to 18 years. In a study conducted by DeChicchis et al. (2000), as cited by Allen et al. (2004) the authors found that the use of age specific norms yielded better pass/refer rates, especially for children three to four years old. This study found, that when using age appropriate ASHA guidelines, nearly half of three to four year olds will be referred, suggesting the current ASHA guidelines are not specific enough for young children. Secondly, the amount of children who participated in the follow-up procedures was limited. This could be attributed to many factors such as limited or no insurance to pay for follow-up care and absence on the day of follow-up testing. Screening techniques as well as test population demographics should be considered when testing young children (Allen et al., 2004). The use of

objective screenings tools will most likely increase the number of children identified with hearing loss and children at risk for hearing loss due to middle ear disorders.

Lyons, Kei, and Driscoll (2004) conducted a study to examine the performance of DPOAE as a screening tool for school-aged children when compared to the pass/refer rates of pure-tone audiometry and tympanometry. A total of 1,003 school-aged children took part in this study. There were 528 boys, 475 girls, and the mean age of participants was 6.2 years old. Children with short attention spans, mental retardation, physical disabilities, learning disabilities, or children who could not understand the test procedures were not included in this study. In keeping with the ASHA recommended hearing screening protocol, these children would have been included in traditional screening results. A trained audiologist performed all testing. Participants were tested in a quiet room, in a seated position, with ambient noise levels ranging between 34 and 51 dB A. If the ambient noise level exceeded 50 dB A the test procedures were terminated and continued when the noise had settled. Pure-tone audiometry, tympanometry, and DPOAEs were performed on each participant.

Pure-tone audiometry was performed at 20 dB HL at 500, 1000, 2000, and 4000 Hz. Currently ASHA does not require 500 Hz to be evaluated during hearing screenings. If participants failed to respond, at any frequency, to the 20 dB HL tone two out of three times, a threshold was determined. A child was considered to have failed the pure-tone screening if his thresholds were greater than 25 dB HL; which is higher than the recommended 20 dB HL made by ASHA.

Tympanometry was performed using a 226 Hz probe tone to identify potential middle ear disorders. Tympanometry was classified using a modified version of Jerger's

classification system. A participant was considered to have failed if the tympanometry results were Type B or C₂ tympanograms. DPOAEs were obtained with the f₂ frequencies at 1.1, 1.9, and 3.8 kHz to closely match pure-tone testing at 1000, 2000, and 4000 Hz. The f₁ and f₂ frequency intensities were at 65 dB SPL and 55 dB SPL, respectively. The results of the DPOAE screening were plotted on a receiver operating characteristic (ROC) curve to examine hit rates and false positive effectiveness. The ROC curve showed a high hit rate and low false alarm rate for 1.9 and 3.8 kHz.

Of the 1,003 children (2,006 ears) tested, all children were successfully examined in all three areas. The results of the pure-tone and tympanometry screening found that 265 ears failed tympanometry. Of these, 140 had Type B tympanograms, and 125 had Type C₂. Of the ears with Type B tympanograms, 78 passed the pure-tone audiometry screening and 93 ears passed with Type C₂ tympanograms. Distortion product amplitude (DP-amp; the amplitude between the DPOAE and the noise floor) for children with normal hearing and normal tympanograms ranged from 6.2 to 8.3 dB SPL for 1.1, 1.9, and 3.8 kHz. Ears that failed tympanometry had negative DP-amp values. The noise floor decreased as frequency increased for children with normal hearing and tympanograms; suggesting that noise had less of an effect on DP-amp in the higher frequencies. While the DP-amp decreased with abnormal tympanograms and hearing loss (Lyons et al., 2004).

The results of the current study found that 265 of 2,006 ears did not pass tympanometry; however, 171 of the 265 ears that failed tympanometry did pass the pure-tone screening. This suggests that children with middle ear dysfunction may still pass pure-tone screenings. This number is alarming since the incidence of middle ear

pathologies is a leading cause of childhood illness. The authors recommend, based on these findings, that tympanometry should be included in all hearing screening programs to identify children with middle ear dysfunction. The authors also examined the difference between pure-tone screenings, tympanometry, and DPOAE screening results. Test results found, that DPOAEs were most sensitive to high frequency information, which was likely due to the level of background noise canceling out the low frequency response. The authors recommend when using DPOAEs in school hearing screenings that 1.1 kHz be examined carefully, due to the influence of background noise.

The use of DPOAEs as a screening tool was examined against the gold standard of pure-tone audiometry and tympanometry. The test results showed a lower hit rate (0.62 to 0.68) than expected when using DPOAEs alone. The results propose that the use of DPOAEs alone would be not be effective, suggesting they would pass between 32 to 38% of children who would otherwise fail pure-tone audiometry and tympanometry. It should be noted that the low frequencies are affected most by middle ear dysfunction and the DPOAE is most sensitive to high frequency responses. The authors recommend the use of pure-tones, tympanometry, and DPOAEs in order to thoroughly examine a child's hearing sensitivity and middle ear function (Lyons et al., 2004).

Eiserman et al. (2008) conducted a study in which they examined the use of an objective screening tool in daycare settings to evaluate hearing sensitivity in young children. The authors made use of DPOAEs to screen young children's hearing. The aim of this study was to provide evidence that objective measures could be used to produce the same, if not better, hearing screening results.

The authors' study consisted of 4,519 children under the age of three that were enrolled in a Head Start program in four different states (Kansas, Oregon, Washington, and Utah). The hearing screenings were conducted by trained support personnel with whom access to audiological technical support was readily available. The screenings took place in the class play area and in the home. The hearing screening consisted of three procedures. First, otoscopy was performed and any children with abnormal otoscopic findings were referred to a physician. Second, DPOAE screenings were conducted up to three times, to ensure reliability of refers, passes, and children who could not be tested. Finally, diagnostic evaluations were performed by a physician or an audiologist to rule out a potential hearing loss or medical problem.

DPOAEs were obtained at 5000, 4000, 3000, and 2000 Hz. The intensity level for F1 was 65 dB SPL and F2 was 55 dB SPL. The results were displayed as pass/fail, and in order to pass overall, three of four frequencies had to pass. The equipment used had the ability to alert testers to too much internal or external noise. Children's hearing sensitivity was to be evaluated in a timely manner, and children who did not have medical or audiological follow-up information after six months were counted as leaving the study (Eiserman, et al., 2008).

The results for the individual screening procedures were recorded and analyzed. Analysis found, of the 4,519 children evaluated, eight had abnormal otoscopic results and were referred to their health care provider for follow-up. Of the 4,511 children that passed otoscopy, 3,412 passed the initial DPOAE screening and required no further testing. Eight hundred and nine children were referred for further evaluation, and 290 children could not be tested. Children who did not pass the initial DPOAE screening

could either be retested or referred to their health care provider for follow-up procedures. The option to refer or retest was left up to the examiner in regards to history of hearing related pathologies, such as otitis media. Of the 1,099 children who did not pass OAEs or could not be tested, a total of 44 children were referred to health care providers.

A total of 257 children needed to be referred for audiological or medical follow-up following re-screening. Only 159 children received the necessary follow-up care. Of these children, 52 had normal hearing and required no additional follow-up care while 107 were identified with a hearing loss and/or a disorder that required further care. Of the 107 with hearing loss, only seven had permanent hearing loss, 83 had otitis media, two had occluded pressure equalizing tubes, and 15 had excessive earwax or congestion. Children who were referred for further evaluation in which no follow-up care was available were considered to have left the program.

Follow-up assessment was not obtained for children who passed the screening; therefore, it was not possible to assess the sensitivity of the test procedures. Nonetheless, the information available was used to determine the positive predictive value (the percentage of which a test with a positive result will yield a disorder such as hearing loss) and estimate the negative predictive value (the percentage of which a test with a negative results will not yield a disorder such as hearing loss), 67.3% and 98.8% respectively. Children were correctly identified with hearing loss 67.3% of the time and correctly identified with normal hearing 98.8% of the time. These values provided necessary evidence that over-referral was not happening. This may not be the best representation of the positive predictive value, since many outer and middle ear abnormalities may clear up on their own before diagnostic evaluations can be performed.

In summary, the previous study successfully demonstrated the effectiveness of OAEs to identify early childhood hearing loss (Eiserman et al., 2008). The authors suggested that through the use of objective hearing screening procedures, such as DPOAEs, it could be estimated that of the 98 children who were lost to program closure or leaving the Head Start program, 66 children may have a hearing disorder, or hearing loss. Additionally, the authors' hypothesized that roughly four of the 98 children lost to program closure could have had a permanent hearing loss. The best way to help identify young children with hearing loss is effective hearing screening programs, in addition to, appropriate follow-up procedures that reduce the risk of children getting lost in follow-up procedures. When OAEs are used in a multi-step program, such is the case here, more children with hearing loss can be identified and therefore, reduce the impact of hearing loss on education, language, and social abilities. The decision to use OAEs as an objective measure of hearing is ultimately up to program coordinators; however, it should be highly recommended and encouraged.

Statement of the Problem

The previous research has thoroughly shown a link between hearing loss and speech, language, and educational delays (Hicks & Tharpe, 2002; Cunningham & Cox, 2003). Additionally, the current hearing screening procedures may inadvertently allow up to 50% of young children with hearing loss to go unidentified (Allen et al., 2004). Objective procedures have been shown to be an effective tool for the identification of hearing loss and middle ear pathologies (Taylor & Brooks, 2004). Throughout the literature review, objective hearing screening tools have continuously been shown to be less timely, accurate, and easy to administer (Eiserman et al., 2008). Hand held objective

screening devices would allow multiple schools to be serviced under one program (Allen et al., 2004). Objective screening procedures are also appropriate for the use of identifying children with hearing loss and middle ear pathologies as accurately as subjective hearing screening procedures (Sideris & Glatke, 2006; Lyons et al., 2006).

Currently there are no recommendations for the use of OAEs in school based hearing screening programs. The use of OAEs would provide valuable information about inner ear function, alert testers to potential hearing loss, and help minimize over referral due to children's cooperation and tester errors. The use of tympanometry in combination with OAEs screeners would significantly enhance school based screening programs.

Tympanometry is currently the only recommended objective screening tool; and it can only be used to identify abnormal middle ear function, such as otitis media not hearing status. Otitis media is one of the most commonly diagnosed illnesses in young children potentially causing mild transient conductive hearing loss (Northern & Downs, 2002; ASHA, 2008d). The use of objective hearing screening tools can identify potential hearing loss related to middle ear pathologies as well as hearing loss related to abnormal cochlear function quickly and accurately (Taylor & Brooks, 2000; Allen et al., 2004; Lyons et al., 2004; Sideris & Glatke, 2006; Eiserman et al., 2008). An extensive comparison, of subjective and objective hearing screening protocol, needs to be examined in order to determine the most effective hearing screening procedures for school-based hearing screening programs. This study attempted to evaluate objective screening tool available for use in school-based hearing screenings. In addition to evaluating objective screening tools, a request for proposal was identified to further research the efficiency

and feasibility of using a hand held device for the purpose of screening hearing among school-aged children.

CHAPTER III

REQUEST FOR PROPOSAL SELECTION

Currently ASHA has no recommendation about the use of objective hearing screening techniques they do make recommendation for objective screening for middle ear function, in addition to traditional pure-tone audiometry during mass hearing screening procedures. The literature review in the previous chapter confirmed that the use of objective hearing screening tools could be both reliable and sensitive to hearing loss in young children. Therefore, a grant proposal was developed to secure funding for the purpose of examining the usefulness of objective hearing screening measures in conjunction with pure-tone audiometry in school hearing screenings. The American Hearing Research Foundation regular research grant was the grant chosen. Criteria for the American Hearing Research Foundation grant request for proposal funding includes research that relates to the hearing or balance functions of the ear. The grant allows for basic and clinical studies to be projected with particular deliberation given to new research.

The American Hearing Research Foundation awards five to ten \$20,000 research grants each year. There were no applicant restrictions provided in the grant application guidelines. All applications are reviewed by the research committee each year in January. The American Hearing Research Foundation provides funding for studies related to

hearing and balance. Awarded funds help to expand knowledge in the field of audiology directly related to hearing or balance.

Intended Audience

As previously addressed in Chapter One, it can be increasingly difficult to obtain behavioral responses from young children. This is especially true of uncooperative children including but not limited to, children who are shy, refuse to respond, and children who may have some type of disorder or disability in which they are unable to respond appropriately. The intended audience would include these children, in addition to, cooperative and well behaved children. Children enrolled in school (daycare or elementary) which utilizes the Louisiana Tech University Speech and Hearing Clinic will be screened to identify potential hearing loss or middle ear complications. Both objective and subjective screenings will be performed.

The use of noninvasive objective hearing screenings will include tympanometry and otoacoustic emissions on all children when possible. The use of tympanometry and OAEs will help to determine if an uncooperative child has normal middle ear and cochlear function. As stated in Chapter One, young children are more prone to otitis media than any other population and the presence of fluid can hinder appropriate speech, language, and educational development.

Device Selection

In order to obtain the best objective hearing screening equipment available the requirements for hearing screenings were examined. Areas of greatest concern when selecting the best equipment included, size, portability, screening options, on screen results, cleanliness, time, and printing options. A device that was small and easily moved

was needed so screening could be conducted in many different locations. The ability to perform tympanometry and OAEs was required, specifically the ability to perform both TEOAEs and DPOAEs. The on screen display needed to be easy to understand and read. The evaluation process will be performed many times so the use of disposable tips was considered the best way to maintain proper infection control. The device needed to have quick screening options, optimally less than two minutes. Finally, a device that had portable printing options was required so results could be printed in various locations.

There were many devices that meet the criteria stated for appropriate screening evaluation. However, one device was superior over the rest. The Maico Ero Scan™ Pro three in one hand held objective screening device was selected. The Ero Scan™ Pro met and exceeded all of the desired requirements. This device has the capabilities of performing screening tympanometry, TEOAEs, and DPOAEs all in one portable device. This device is small and easy to operate, screenings can be performed in under a minute. Diagnostic evaluations are available if a child does not pass the screening procedure, and results are clearly displayed as Pass/Refer. There is also a portable printer is available. Additionally, this device has the ability to store data collected so data can be retrieved at a later date. Maico also reports this device has reliable test results in up to 70 dB SPL of noise, which is critical for school hearing screenings.

Previous literature review noted the importance of objective hearing screenings in all hearing screening programs. The device was selected based on its ability to perform screening tympanometry, TEOAEs, and DPOAEs. This will allow for the most thorough screening procedures available. This device will help to determine the function of both the middle and inner ear.

Methods and Procedures

A grant proposal was developed in accordance with the American Hearing Research Foundation guidelines (see Appendix A). The format of the grant proposal contains the following information:

1. Title Page: Include title of project, principal investigator(s), mailing address, phone number, and e-mail address of the individual or institution that is applying for the funding. Be sure this information is on the FIRST page of your proposal. Please state which grant you are applying for: AHRF Grant, Derlacki Grant, Harrison/CORE Grant, or Birtman Grant. Make sure the award you are applying for is being given that year. Please indicate whether you are a Ph.D. or M.D. Be sure to include the name and ALL contact information (including address, phone and e-mail) of the financial officer to whom we should send a check should your proposal receive a grant.
2. Description: Include a brief description of the project. Also include performance site and key personnel.
3. Table of Contents: Include all first-level headings with page numbers.
4. Detailed Budget: Provide a one-year budget (or two-year budget if you are applying for a special grant that spans two years) that includes salary for support staff (students, post-doctorate fellows, etc.), equipment, and supplies. Do not include salaries for principal investigator(s) or overhead; the AHRF does not fund these costs. Your

budget should include the total amount asked for (the total) somewhere on the budget page.

5. Biographical Sketch (One For Each Principal Investigator): Please include your contact information (at least phone and e-mail) on the biographical sketch page. List all publications (maximum, two pages), current funding, pending funding, and requested funding. Please indicate what you will do if you receive overlapping funding. Also include letters of support from collaborators, if appropriate.
6. Main Body: Include specific aims of the project; background and significance; methods; and what type of subjects (human or animal), if applicable. The body should be no longer than 10 pages (12-point type, standard margins).
7. Progress Report (For Renewal Projects): Include preliminary data and any relevant progress.

Research from the previous chapter in combination with additional information was used to compile the grant proposal.

Appendix B consist of the grant proposal that was constructed for the American Hearing Research Foundation grant. Guidelines for the American Hearing Research Grant were strictly followed with no exceptions made.

CHAPTER IV

DISCUSSION AND CONCLUSION

The aim of this dissertation was to evaluate the usefulness of objective hearing screening devices in conjunction with traditional pure-tone hearing screening in the school age population through an extensive literature review. The objective hearing screening device to be used was selected through careful and precise literature reviews. In addition to determining which screening devices would be most advantageous, a proposal for funding was drafted in order to examine potential benefits.

Request for Proposal

The grant proposal was created to obtain objective hearing screening equipment and to show a clear and defined need to include such screening tools in traditional school based hearing screening programs. The goal of the American Research Hearing Foundation grant is to explore new technologies and ideas in the field of audiology directly related to hearing and balance. Award of the grant proposal would allow for exploration of the most cost and time efficient objective hearing screening measures to be used with the school-aged population.

Currently there are no recommendations made by either ASHA or the American Academy of Audiology in regard to the use of objective hearing screening devices. In

fact, ASHA has deemed such devices as inappropriate procedures for the purpose of screening hearing in the school-aged population. The literature review clearly reveals that such a statement is no longer valid. Therefore, the guidelines should be re-evaluated and proper objective hearing screening recommendations added.

Device Selection

Throughout the literature review, the use of objective hearing screening equipment was determined to be noninvasive, reliable, and sensitive to middle ear and inner ear disorders or pathologies. The use of a hand held device was chosen due to its convenient size and portability. Additionally, data collection could be stored and reviewed at a later time. The use of disposable tips allowed for proper infection control in numerous settings. The continued use of objective hearing screening devices with the school-aged population will likely show an improvement in the amount of children identified with hearing loss, transient or otherwise. It is hopeful that such results will prompt the required inclusion of objective hearing screening measures in school-aged hearing screenings procedures.

APPENDIX A

AMERICAN HEARING RESEARCH FOUNDATION GENERAL

GRANT APPLICATION GUIDELINES

The American Hearing Research Foundation funds 5 to 10 research grants each year, with an average funding level of \$20,000 per research project. Grant applications are reviewed by a Research Committee and awards usually begin in January. Research Grants should relate to the hearing or balance functions of the ear. Both basic and clinical studies may be proposed. Priority is given to providing startup funds for new projects. To apply for a Research Grant, please adhere to the following guidelines. Applications are due no later than noon on August 1 of the previous year. The Grant Applications should contain the following parts:

Part	Description
Title Page	Include title of project, principal investigator(s) and mailing address of the individual or institution that is applying for the funding.
Description	Include a brief description of the project. Also include performance site and key personnel.
Table of Contents	Include all first-level headings with page numbers.
Detailed Budget	Provide a one-year budget that includes salary for support staff (students, post-doctorate fellows, etc.), equipment, and supplies. Do not include salaries for principal investigator(s) or overhead; the AHRF does not fund these costs.
Biographical Sketch (One For Each Principal Investigator)	List all publications (maximum, two pages), List current funding, pending funding, and requested funding. Please indicate what you will do if you receive overlapping funding. Also include letters of support from collaborators, if appropriate.
Main Body	Include specific aims of the project; background and significance; methods; and what type of subjects (human or animal), if applicable. The body should be no longer than 10 pages (12-point type, standard margins).
Progress Report (For Renewal Projects)	Include preliminary data and any relevant

APPENDIX B
GRANT PROPOSAL

Grant for Objective Hearing Screening Equipment

Investigators: Steve Madix, Ph.D., CCC-A/SLP

Brittany Brown, B.S.

306 Robinson Hall

Louisiana Tech University

Ruston LA, 71270

(318) 257-4764

Grant Applicant: smadix@latech.edu

bsb021@latech.edu

Applying for the AHRF Grant

Financial Office: Louisiana Tech University

Name: Joseph R. Thomas, Jr.

Address: P.O. Box 7924

Ruston LA, 71272

Phone: 318-257-4325

E-mail: jthomas@latech.edu

DESCRIPTION

The primary objective of this application is to receive a grant in which to purchase an objective hearing screening device to be used in elementary schools by school personnel. Specifically, this hand held hearing screening device will be a combination unit that assesses middle ear function (screening tympanometry) and inner ear hair cell function (otoacoustic emissions). It will address many of the problems associated with the traditional “raise your hand when you hear the beep” pure-tone audiometry screening and lead to better accuracy in identifying hearing loss. It will also be used to collect research data on the efficiency and feasibility of using this hand held device as the recommended manner of screening hearing in school-aged children. Pilot data recorded from 48 young students comparing the results of screening tympanometry and otoacoustic emissions to traditional pure-tone audiometry screening has indicated significant discrepancies between the two measures. Specifically, the traditional pure-tone screening has been observed to be: unreliable with even low levels of background noise, which are usually present in the schools; difficult to administer to very young children and children who do not poses English as their primary language; and not sensitive to slight levels of hearing loss which can impact academic development. The following data and explanations will indicate the incidence of hearing loss in young children, its significance and consequence, the importance of early identification, the current recommendations for identification and where it falls short, and the need for a more precise and objective manner of hearing screening in this population.

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BUDGET

Agency: American Hearing Research Foundation

Due: August 1, 2011

Project Title: Grant for Objective Hearing Screening Equipment

Proposed Budget	Support Requested	Institution Match
<i>A. Personnel</i>		
1. Research Faculty		
<i>Name: Louisiana Tech Speech and Hearing Clinicians</i>	\$ 0	\$ -
<i>Name:</i>	\$ -	\$ -
2. Staff		
<i>Clerical</i>	\$ -	\$ -
<i>Post Docs</i>	\$ -	\$ -
3. Subtotal	\$ -	\$ -
4. Fr. Ben. (32.4%, 35.4%, 23.3%)	\$ -	\$ -
5. Graduate Assistants	\$ -	\$ -
6. Undergraduate Students	\$ -	\$ -
7. Subtotal A	\$ -	\$ -
<i>B. Supportive Expenses</i>		
1. Travel	\$ -	\$ -
2. Operating Services	\$ -	\$ -
3. Supplies	\$ 500	\$ -
4. Software	\$ -	\$ -
5. Equipment	\$ 6,095	\$ -
6. Consultants	\$ -	\$ -
7. Other Expenses		
a. O/S Tuition Waiver	\$ -	\$ -
b. Lab Use Fees	\$ -	\$ -
8. Subcontracts	\$ -	\$ -
9. Subtotal B	\$ 6,595	\$ -
<i>C. Overhead</i>		
State: 22% of TDC	\$	\$ -
TOTAL	\$ 6,595	\$ -

Total LA Tech Direct Costs \$ 6,595 \$ -

Funding if awarded will be used to purchase one Maico Ero Scan™ Pro three in one hand held objective screening device and supplies. The supplies would include disposable tips in ten different sizes and printer paper.

PRINCIPAL INVESTIGATOR

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Publications

- Plyler, P.N. & Madix, S.M. (2007) *Contribution of high-frequency information to the acceptance of background noise in listeners with normal and impaired hearing*. American Journal of Audiology, 16 (2): 149 – 157.
- Hedrick, M.S. & Madix, S.M. (2009) *Effect of vowel identity and onset asynchrony on concurrent vowel identification*. Journal of Speech Language and Hearing Research, 52, 696 – 705.
- Hedrick, M.S. & Madix, S.M. (2009) *Perceptual Anchoring in Concurrent Vowel Perception by Listeners with Hearing Impairment*. Journal of Speech Language and Hearing Research, In Review.

Presentations

- Madix, S.G., Thelin, J.W., Plyler, P.N., Hedrick, M., & Malone, J., (2005). *The effects of age and context on phonemic restoration in young adult females*. American Academy of Audiology Annual Conference, Washington D.C., Poster Presentation.
- Madix, S.G., Plyler, P.N., Burchfield, S., & Hedrick, M., (2005). *The effects of notch filtering and low-pass filtering on the acceptance of background noise in normal hearing listeners*. American Academy of Audiology Annual Conference, Washington D.C., Poster Presentation.
- Madix, S.G., (2005). Acceptable Noise Level (ANL). Speech Pathologists and Audiologists in Louisiana Schools (SPALS); Invited Speaker, Annual Convention, Shreveport Louisiana.
- Madix, S.G., (2005). Acceptable Noise Level (ANL). Speech Pathologists and Audiologists in Louisiana Schools (SPALS); Invited Speaker, Annual Convention, Shreveport Louisiana.
- Madix, S.G., Thelin, J.W., Plyler, P.N., Hedrick, M., & Malone, J.C., (2006). *Components of Auditory Closure*. American Academy of Audiology Annual Conference, Minneapolis, Minnesota. Poster Presentation.
- Madix, S.G., (2006). Acceptance of Background Noise. College of Liberal Arts Research Symposium. Speaker; Louisiana Tech University.
- Madix, S.G., (2006). Acceptable Noise Level (ANL). Louisiana Speech and Hearing Association (LASHA) Annual Convention, Lafayette, Louisiana.
- Alworth, L.N., Plyler, P.N., & Madix, S.G., (2007). *Effect of personality type on the acceptance of background noise*. American Academy of Audiology Annual Conference, Denver, CO., Poster Presentation.

- Madix, S.M. and Freyaldenhoven, M., (2008). The effect of listener fatigue on the acceptance of Background noise in full time hearing aid users. American Academy of Audiology Annual Conference, Charlotte, NC, Poster Presentation.
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- Chatelain, M.A. and Madix, S.M. (2008). *Subjective versus objective hearing screening results of school-aged children*. American Academy of Audiology Convention, Dallas, TX, Poster Presentation.
- Chatelain, M.A. and Madix, S.M. (2008). *Subjective versus objective hearing screening results of school-aged children*. American Speech and hearing Association Schools Conference, Orlando, FL, Round table discussion.
- Madix, S.M. (2009). *Subjective versus objective hearing screening results of school-aged children*. Louisiana Speech and Hearing Association Convention, Lafayette, LA, Presenter.

Current Funding:

None

Letters of Support from Collaborators:

None

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Current Funding/Pending Funding/ Requested Funding:

None

Letters of Support from Collaborators:

None

SPECIFIC AIMS OF THE PROJECT

The importance of identifying hearing deficits is crucial in young school-aged children to ensure proper academic development. Unidentified hearing losses early in life can lead to significant and perhaps permanent deficits. To identify children who have hearing impairment, ASHA has a recommended procedure for the screening of hearing in the school setting using behavioral pure-tone audiometry. However, due to the omission of low frequencies being screened for this procedure, and the often less than ideal ambient noise levels present during the screening, it is believed that a significant number of children are not being identified or are being misidentified.

The literature will establish a better manner in which to conduct hearing screenings in young children, which is to use objective screening measures such as OAEs and tympanometry. These two screening measures used in conjunction are significantly more accurate in identifying hearing impairment, specifically mild transient hearing impairment associated with middle ear fluid. As well as being more sensitive to less than normal auditory function, these screening measures are simple to interpret and are within the scope of practice of personnel who routinely conduct hearing screenings.

A grant award will allow us to collect further data that will support our own pilot data as well as the results of objective and subjective hearing screenings reported in the literature. Our results will demonstrate the superiority of objective auditory screening measures, specifically when conducted outside of a sound treated test room, in the school-aged population. To this end, a grant award will be used to obtain a DPOAE and tympanometry screener to be placed in a rural public elementary school for the purposes of furthering data collection on this topic.

BACKGROUND AND SIGNIFICANCE

Incidence and Type of Hearing Loss in Young Children

The incidence of hearing loss in America and its impacts has been widely documented in both peer-reviewed journals as well as more popular mainstream media outlets. There is a segment of the population with hearing impairment for which hearing loss is certainly of more severe consequences, pre-school and young school-aged children.

The number of Americans, age three years and up, with hearing loss has almost doubled since the 1990's from 13.2 million to 24.2 (ASHA, 2008c). These numbers may reflect wider screening efforts rather than an actual increase in the number of children with hearing loss. The inception and implementation of newborn hearing screening programs and aggressive follow-up protocols for children at risk for hearing loss has significantly contributed to the number of children identified with hearing loss. However, some children's hearing loss may not be present at birth, or children who are at risk for hearing loss may not be identified. When this occurs, it is not uncommon for hearing impairment to not be identified until school age (ASHA, 2008c).

Regardless of the age of identification, approximately 75,000 children between the ages of 6 to 21 were receiving special education services under the category of hearing impairment during the 2003 school year (National Dissemination Center for Children with Disabilities, 2004). This number is up from the nearly 70,000 children receiving service during the 2001 school year (US Dept. Ed, 2002). Additionally, it has been estimated from studies conducted through the Third National Health and Nutrition Examination Survey (NHANES III) from 1988-1994 that approximately 3 million

children between the age of 6-19 will have either mild to severe hearing loss (NIDCD, 2005). Specifically the NHANES III examined a sample of 6,166 children between the ages 6-19 years for hearing loss. The survey found that 14.9% of children tested had hearing loss in either one or both ears (Niskar, 1998). Overwhelmingly, mild hearing losses were more numerous for these school-aged children than other more severe degrees. Regardless of the severity, hearing loss should be identified as early as possible to prevent communication, developmental, or academic difficulties (ASHA, 2008b).

The Center for Disease Control (CDC) has further classified by type, the nature of the hearing losses which include sensorineural, conductive, and mixed (CDC, 2008). A sensorineural hearing loss (SNHL) is defined by the American Speech Language Hearing Association (ASHA) as damage to any portion of the cochlea or higher that results in a permanent hearing loss. A conductive hearing loss (CHL) is defined as deterioration of the acoustic signal between the outer ear to the middle ear and any portion of the middle ear space. Typically, CHLs are transient and can sometimes be surgically or medically remedied. Finally, a mixed hearing loss (MHL) is the combination of conductive and sensorineural mechanisms (ASHA, 2008a).

The CDC Early Hearing Detection and Intervention newborn hearing screening survey and follow up survey for 2006 found a total of 4,596 children with hearing loss. Of the children tested 3,629 children had a SNHL ranging from mild to profound and 63 with unknown severity. They also found 819 children had a CHL ranging from mild to severe and 85 children if unknown severity (CDC, 2008).

The ASHA Hearing Screening for School-Aged

School hearing screenings play a major role in earlier identification of hearing losses that may not have been present at birth or have recently developed. ASHA (2006) has recommend hearing screenings be done upon entering a new school, yearly in kindergarten through third grade, in the seventh and eleventh grade, entering into special education, and when a child repeats a grade. The purpose of hearing screenings is to determine if there is a need for further audiological testing and to prevent or remediate any communication, health, educational, and psychosocial functioning (ASHA, 2006).

ASHA (1997) recommends hearing screenings be done by an audiologist, speech language pathologist, or support personnel. The testing should be done in a sound treated room when available, or in quiet setting if not. Children should be screened at 20 dB HL at the frequencies of 1000, 2000, and 4000 Hz for each ear separately (ASHA, 1997). If a child fails a hearing screening they should be referred to an audiologist for further assessment.

Hearing screenings should be conducted on pass-fail criteria. As mentioned earlier, the screenings should be conducted in a sound treated booth if available. However, most school hearing screenings are conducted in the least noisy room in the school. There are recommended standards for permissible background or ambient noise levels when the testing is conducted in a sound treated booth as set forth by the American National Standards Institute (ANSI), ANSI S3.1-1999. It is recommended that noise levels in the test setting should also follow ANSI standards, but this is rarely if ever checked.

When noise exceeds recommended specifications, it would be necessary to find an appropriately quiet setting to ensure accuracy and reliability of screenings. Moderate levels of ambient noise, that exceed ANSI standards, make it difficult to impossible to hear lower frequencies at 20 dB HL for even the most trained listener, much less a young child. In this scenario if the ASHA recommended hearing screening is followed exactly, there would be a tremendous number of failed screenings due to the inability to hear at the lower frequencies. It is our suspicion that rather than actually fail the majority of the children screened, one of two events probably occur; either the pass criteria is raised above 20 dB HL, or lower frequencies are deleted from the screening protocol. Both alternatives would allow for the presence of middle ear fluid to go undetected.

A second potential threat to the accuracy and validity of the traditional behavioral pure-tone hearing screening is the manner of the child's response. Typical hearing screenings consist of pure-tone audiometry where the child raises his or her hand or points to the ear in which they hear the tone after each presentation (ASHA, 2008b). Potential threats can arise if the child does not fully understand the task, becomes accustomed to a pattern of the tones and indicate a response when it is not really heard, or if the child is unable to be conditioned to the task. These threats can potentially lead to a significant number of false positives (children who have no hearing loss but fail the screening) or false negatives (children who have hearing loss but were able to pass the screening). In the event a child does not pass the hearing screening they should be instructed and re-screened. If they do not pass again they should be referred to an audiologist for a full evaluation. The full evaluation and hearing sensitivity thresholds

should be completed within one month but no more than three months following the screening (ASHA, 2008b).

Importance of Low Frequency Input and Conductive Hearing Loss in Children

The previously cited studies illustrate the significant number of children that have some form of hearing loss. While congenital hearing loss is typically sensorineural in nature, children ages three and up whom experience transient hearing loss are typically the result of a CHL that ranges from mild to moderate (Northern & Downs, 2002). In young children, the most common form of acquired hearing loss is CHL which is usually the result of a malfunctioning Eustachean tube which does not allow for the drainage of the mucous secreted by the mucosal linings of the middle ear space. Otitis media (OM) is an inflammation or infection of the middle ear as a result of this stagnate fluid and is typically treated medically by antibiotics.

CHL is associated with a deficit that is primarily confined to the lower frequencies 1000 Hz and lower. Hearing loss in this frequency region is perceived as a reduction in loudness to the listener and makes difficult to hear what is being said. Children with a history of OM especially those that are considered chronic, OM lasting three months or longer, are more likely to have a low frequency CHL that extends past the timeframe normally considered transient (Niskar et al., 1998). Niskar and colleagues (1998) found that children with OM were three times more likely to have a low frequency hearing loss than children who were OM free.

The ASHA recommended hearing screening is a subjective measure of hearing which relies on the truthfulness and accuracy of the child's response. Only subjective measures are true tests of "hearing" in the strictest sense. However, children can be

screened with objective measures to determine auditory function. An objective measure is one that does not rely on the observation of a behavioral response. The results of objective measures are not used to diagnose hearing loss, they assess auditory function. However, auditory functions are consistent with hearing and for the purposes of a screening, are an acceptable form of hearing acuity evaluation. Universal infant hearing screening programs are an example of using objective measures for the purposes of assessing hearing auditory acuity.

The purpose of any screening measure is to identify problems that pose a potential threat. For hearing screenings, the most common threat is in the form of a transient, low frequency CHL. Hearing loss of this nature is typically manifested by a decrease in low frequency hearing (250 – 1000 Hz). The ASHA hearing screening does not test 250 or 500 Hz and it is possible for a child with middle ear fluid to pass a hearing screening at 20 dB HL for the remaining higher frequencies. Additionally, testing outside of a sound treated booth, it is difficult for any listener to hear low frequency tones at 20 dB HL. Given the importance of low frequency information when assessing hearing and the difficulty of accurately acquiring it outside of the sound treated booth, it would appear that the ASHA recommended hearing screening protocol is not an ideal method of separating normal from impaired hearing. Specifically, it would appear to be a poor tool for identifying the most common and probably most overlooked hearing deficit which is CHL.

Objective auditory screening tools can be very useful when attempting to detect less than normal hearing. One form that is used routinely as both a screening tool as well as a diagnostic measure is otoacoustic emissions (OAEs), specifically transient evoked

otoacoustic emissions (TEOAEs) and distortion product otoacoustic emissions (DPOAEs). TEOAEs are an objective test of the peripheral auditory system which extends to the outer hair cells of the cochlea and analyzes auditory function between approximately 1000-4000 hertz (Hz). DPOAEs are able to examine auditory function up to 8,000 Hz. OAEs are conducted by placing a probe tip in the ear that produces one or two tones and creates an echo in the inner ear. The intensity of the echo is measured. Both OAE measures are quicker to administer than a traditional pure-tone screening and can be conducted by the same personnel who administer the pure-tone screenings. Additionally, OAEs are more sensitive to middle ear disorders than the ASHA recommended hearing screening protocol.

There are many limitations to traditional pure-tone screenings; however, the literature does not recommend a gold standard or best practices for screening school-aged children in light of these findings. More importantly, ASHA has not modified their recommendations for screening school-aged children. The information available demonstrates the need for change in how hearing screenings are conducted in the schools. In addition, the literature also shows that tympanometry and OAEs can be conducted more quickly with results that require less interpretation and examiner responsibility than pure-tone audiometry (Lonsbury-Martin & Martin, 1990; Eiserman et al., 2008, Sideris & Glatte, 2006; Allen et al., 2004).

Depending on the screening criteria, a child with mild middle ear effusion could also potentially pass an OAE screening. Due to this a second objective measure should be conducted in addition to the OAE screening. Tympanometry is an objective measure of auditory function from the ear canal to the middle ear space. As a screening measure, it

has great sensitivity for detecting even mild middle ear fluid and can be conducted and interpreted by the same personnel conducting the ASHA recommended hearing screening. The method of screening OAEs and tympanometry can be used to distinguish normal from abnormal auditory function, and thus hearing acuity.

Serious potential threats to accuracy and validity exist when pure-tone screening audiometries are used to assess hearing outside of the sound treated booth. The most common form of hearing impairment for this population can be readily missed with the ASHA recommended screening protocol. Due to the importance of identifying children with even mild hearing impairments in the school setting, it is essential to investigate the efficiency of other screening measures. It would seem logical to use objective measures of auditory function that are more sensitive to the hearing disorders associated with this age group.

In a study conducted by Taylor and Brooks (2000) they examined the sensitivity and specificity of TEOAEs, tympanometry, and pure-tone audiometry. They examined 297 ears in children aged three to eight years old. Pure-tone, tympanometry, and TEOAEs were obtained for each ear in varying orders. TEOAEs were obtained between 1000 and 5000 Hz for each ear. To be counted as a pass TEOAE had to be at least 3 dB above the noise floor, or the level of ambient noise, in at least three of the frequencies tested. The results of this study found that of the 297 ears used, 14 ears passed the pure-tone screening but failed the TEOAE screening. If only pure-tones had been used; which is typically the case in most hearing screening programs, 14 ears would have gone undiagnosed with a hearing loss or possible middle ear pathology which was identified through further screening procedures. This study shows evidence that there are children

who pass the traditional ASHA recommended hearing screening, yet may still have a slight hearing impairment.

Furthermore, Lyons, Kei, and Driscoll (2004) conducted a study on 1003 children comparing DPOAEs, tympanometry and pure-tone testing looking at hit rates (children correctly identified with a hearing loss) and false alarms (children identified with a hearing loss but did not actually have a hearing loss). The results of this study found that 171 of 2006 ears passed pure-tones but failed tympanometry. DPOAEs were obtained at 1.1, 1.9, and 3.8 kHz and were compared to the pass/fail criteria of the closest pure-tone frequencies, 1000, 2000, and 4000 Hz. When comparing the DPOAE results to the pure-tone screening results hit rates were 0.86 for 1.1 kHz, 0.89 for 1.9 kHz, and .90 for 3.8 kHz. These results were considered adequate for pure-tone screening; however when looking at tympanometry and DPOAEs, the hit rates were 0.62 for 1.9 kHz and 0.68 for 3.8 kHz, the hit rate for 1.1 kHz was not provided due to a masking effect from ambient noise. These results show DPOAEs cannot be used alone due their lack of sensitivity to middle ear disorders. However, they are very useful when used in combination with pure-tone and tympanometry (Lyons, Kei, and Driscoll, 2004).

The Importance of Identification of Hearing Loss in Young Children

Hearing loss can adversely affect a child's performance in school. Decreased performance is the result of insufficient volume and clarity, the severity of which is dependent of the type and degree of the hearing loss. Hearing loss can affect speech perception, learning, self-image, and social skills (Niskar et al., 1998). It is harder for children with a hearing loss to learn aspects of verbal communication such as idiomatic expression, word order, vocabulary, and grammar (National Dissemination Center for

Children with Disabilities, 2004). Fortunately children with a hearing impairment are included in the Individuals with Disabilities Act (IDEA) and can receive special education or other services through this program.

IDEA describes a hearing impairment as “an impairment in hearing, whether permanent or fluctuating, that adversely affects a child’s educational performance” (US Dept. Ed, 2002). A child’s ability to hear can be distorted by noise and other sounds of everyday life. Children with even a slight hearing loss can have difficulty hearing and may require special services. Hearing loss can also affect speech perception putting children at a greater risk for learning difficulties because they are missing auditory information. This is especially true if the child is not aware of any hearing loss, which is often the case with slight hearing losses (Niskar et al., 1998).

The slight, mild to moderate CHL is known to be the most common type of hearing impairment in school-aged children. Even so, it is also the most overlooked form of hearing impairment and the most underestimated in relation to the young listener’s academic development. The name itself, “slight”, “mild”, implies an insignificant consequence. Additionally, the transient nature of the CHL adds to the under appreciation of the potential harm it may have on academic development. Most young children are unaware of mild CHL and may not report any difficulties. This makes the role of the hearing screening all too important for identifying this hearing impairment.

METHODS AND PROCEDURES

A grant proposal will be developed in accordance with the American Hearing Research Foundation guidelines in order to secure funding for and objective screening

device, specifically OAEs and tympanometry all in one device. Please see the attached budget for equipment details.

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