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The effects of background noise on distortion product otoacoustic emissions and hearing screenings

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THE EFFECTS OF BACKGROUND NOISE ON DISTORTION

PRODUCT OTOACOUSTIC EMISSIONS AND

HEARING SCREENINGS

by

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Abstract

Hearing screenings are an important tool for identifying children who have, or are

at risk for hearing loss in the schools. In light of a body of evidence that demonstrates

the effectiveness of objective screening measures, such as otoacoustic emissions (OAEs),

the American Speech Language and Hearing Association (ASHA) recommends

traditional pure tone audiometric screening as the tool of choice for hearing screenings in

the schools. Pure tone audiometric screenings conducted in the schools are problematic

for a number of reasons, but the most significant is the presence of background noise

which is routinely encountered. The main purpose of the present study was to evaluate

the effect of noise levels on two types of hearing screenings, pure tone audiometric

hearing screening and distortion product otoacoustic emission (DPOAE) screening. The

two screening measures were compared in twenty young adults with normal hearing in a

sound treated booth. The results showed that as noise levels (40, 50, and 60 dB SPL)

increased, significant numbers of listeners failed the pure tones but passed the DPOAEs;

indicating that DPOAEs are more resistant to background noise and should be considered

as a more effective screening measure when background noise is present.

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Dedication

This dissertation is dedicated to a number of people. First, I owe my deepest

gratitude to my parents, Tommy and Judy Hollowell. I would not be where I am today

without their unending support and unconditional love. My father has taught me to do

today what others will not so that I may do tomorrow what others cannot; I remembered

this throughout this experience. My mother has been an important role model for me as

her strength of character and integrity has been a driving force in my life. Both my

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person. Lastly, I would like to dedicate this dissertation to my fellow classmates;

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CHAPTER I

Introduction

The prevalence of hearing loss in the United States is significant, with 29 million

Americans having hearing impairment within the speech frequencies (Agrawal, 2008).

Within the pediatric population, statistics indicate that one in every 1,000 live births will

have some hearing impairment (Center for Disease Control, 2009). Due to the incidence

of hearing loss in the United States, measures for early identification have been

implemented and are routinely used. The importance of early identification in regards to

language, cognition, and social development is widely known and well accepted

(Yoshinaga-Itano, Sedey, Coulter, & Mehl, 1998). Early identification typically begins

with newborn hearing screenings performed prior to the infant's discharge from the

hospital. To identify later occurring or acquired hearing loss, or identify children that did

not receive a newborn hearing screen, it is recommended to continue hearing screenings

into the preschool and school aged years. However, there is not a universal gold standard

hearing screening protocol for either preschool or school aged children and currently,

more than one method exists for hearing screenings within these populations (Katz,

2002). The American Speech Language and Hearing Association (ASHA) has a

recommended protocol that relies on pure tone behavioral testing (ASHA, 2006; ASHA,

1990a). This protocol is recommended for both children and adults. However, behavioral

testing within the pediatric population is problematic, and perhaps ill-suited for use

outside the confines of a sound treated booth (Mundy, 2001). Although objective testing,

such as evoked otoacoustic emissions (EOAEs), have been recommended as a screening tool for infants, their use is not listed as the suggested method for school aged screenings (ASHA, 2006).

Evoked otoacoustic emissions (EOAEs) are an accepted, valid, and reliable clinical tool used to aid in diagnostic evaluations, and are currently used as a screening measure outside the confines of a sound treated booth. They are recommended for hearing screenings in infants (Hatzopoulous, et al., 2001; Lonsbury-Martin, McCoy, Whitehead, & Martin, 1993) and are known to have good test re-test reliability yielding accurate results. In addition, EOAEs have been used in diagnostic evaluations for some time (Franklin, McCoy, Martin, Lonsbury-Martin, 1992). Distortion product otoacoustic emissions (DPOAEs) and transient evoked otoacoustic emissions (TEOAEs) are measures of auditory function both as a diagnostic tool and as a screener (Hatzopoulous, et al., 2001; Lonsbury-Martin et al., 1993). Specifically, distortion product otoacoustic emissions (DPOAEs) have been researched in great detail to determine the most efficient parameters to achieve the most accurate results (Lukashkin, Lukashkin, & Russell, 2002; Stover, Gorga, Neely, & Montoya, 1996). Furthermore, DPOAEs have shown resistance to noise and mirror pure tone thresholds (Lee & Kim, 1999; Harris & Probst, 1991).

With any measure of hearing, specifically those used outside the confines of the sound treated booth, the influence of noise should be considered when developing an acceptable screening protocol. Hearing screenings conducted in schools are rarely if ever conducted in a sound treated booth. Ambient noise in educational settings can be significant and can greatly affect screening results (Knecht, Nelson, Whitelaw, & Feth, 2002). Therefore, a screening tool should be used that has the best resistance to noise,

allowing accurate identification in the presence of background noise. The focus of this study was to observe the effect of increasing noise levels on pure tone screenings and DPOAE screenings in young adult listeners with normal hearing. The purpose of the study was to determine which measure could yield accurate results in the presence of noise, at levels that can occur in school settings.

CHAPTER II

Review of Literature

Prevalence of Hearing Loss

Hearing impairment is widely prevalent in the United States. In 2003-2004 approximately 29 million Americans had hearing loss with 8.5 % of those falling into a younger age group (i.e. 20-29 years of age). As suggested by these numbers, hearing loss is not only confined to older populations and the incidence of hearing loss is significant in younger people. In addition, the prevalence of hearing loss in the younger population seems to be increasing due to previously known risk factors such as smoking, noise exposure, and cardiovascular risks (Agrawal, 2008).

When reviewing the prevalence of hearing impairment within the pediatric population, results also indicate hearing loss exists at significant levels in children in the United States. Niskar et al. (1998) sought to find the prevalence of hearing loss in children 6-19 years of age. The purpose of this study was to define the prevalence of hearing loss and socioeconomic status of children in the United States. This study consisted of household interviews and audiometric testing. Audiometric testing was administered in a mobile sound treated examination center. Testing included air-conduction thresholds, with masking if necessary, that were measured at .5, 1, 2, 3, 4, 6, 8K Hz with 1K Hz retested. Otoscopy was not included. Hearing loss was defined as 16

dB or greater and based on low (500-2000 Hz) and high (3000-6000 Hz) pure tone averages. It was found that out of 6,166 children, 5% had both a high and low frequency loss and 15% had one type of loss, either high or low. The majority of the losses were shown to be unilateral. In addition, most of the losses were mild in severity (16-25 dB HL). Niskar et al.'s study is supported by the Center for Disease Control's (CDC) National Health Interview Survey, 1997–2005, which reported that five in every 1,000 children age 3-17 have some form of hearing loss.

Within the pediatric population, statistics indicate that one in every 1,000 live births will have permanent hearing impairment (Center for Disease Control, 2009). However, in 2007 the Center for Disease Control (CDC) reported in the United States, 72,000 children (age 6-21 years) received special education services for hearing impairment. This does not include those with multiple impairments that may receive services under different special education categories, rather than hearing impairment or those who simply do not receive special education services. Therefore, this leads one to believe the total incidence of hearing loss may be higher, such as two or three out of every 1,000 live births (Center for Disease Control, 2009).

These authors indicate that not only is hearing loss prevalent within the United States, it is significant within the pediatric population. Measures have been taken to increase identification; however, there is still inadequacy concerning follow-up measures and identification of progressive or late on set hearing impairment. The prevalence of hearing loss shown in these findings further support that hearing loss, both congenital and acquired, are found in significant proportions and illustrate the need for accurate hearing screening measures.

Early Identification

Audiometric hearing screenings are the primary tool used in early identification. Other identifiers are in the form of "paper" screeners which are high-risk indicator forms. The purpose of hearing screenings are to separate individuals into a "pass" criterion or a "refer" criterion in an attempt to identify individuals who are at an increased risk for hearing loss. It is well documented that if identification and treatment of hearing deficits are not addressed prior to six months of age, language and learning deficits can result (Yoshinaga-Itano et. al, 1998). In addition, the first three years of life have been identified as the most influential in learning language. Hearing impairments which are not identified during this crucial period of development are known to significantly affect social and academic performance in later years (Yoshinaga-Itano et. al, 1998). A significant lack of auditory stimulation during this time can even result in decreased maturation of the auditory structures sometimes referred to as (Central) Auditory Processing Disorder ((C)APD) (Katz, 2002).

The average age of identification in the United States has been reported to be close to three years, with less severe degrees of hearing loss going undetected even longer (NIH, 1993). Taking into consideration the significant lifelong consequences of late identification, it becomes evident that the measures used for early identification must be carefully considered. It would appear that if hearing loss is not identified at birth through newborn hearing screening measures, there is a significant risk that it will not be identified until pre-school or school age. Therefore, hearing screening measures must be accurate so that hearing loss can be detected and the appropriate intervention can begin.

The Role of Objective Testing in New Born Hearing Screening

The National Institute of Health (NIH) addressed early identification of hearing impairment in infants and young children in 1993. It stated that when infants are only screened based on the high risk criteria (HRC) (i.e. "paper" screener) approximately 50% of those with severe to profound hearing loss are missed. Therefore, the NIH suggested that based on data obtained from the neonatal intensive care unit (NICU) all infants in the NICU should be screened for hearing impairment prior to discharge. In addition, it was recommended by NIH (1993) to screen those in the well baby nursery within the first three months of life, however preferably prior to discharge. Furthermore, the NIH suggested that the protocols for screening and follow-up measures be rapid, easily administered, and sensitive to identifying hearing impairment outside a sound treated booth where ambient noise is present. It was also suggested that screening measures should be administered by hearing professionals or supervised personnel (those trained and supervised by hearing professionals).

The NIH preferred models for hearing screening and follow-up practices within the 1993 statement include auditory brainstem response (ABR) and evoked otoacoustic emissions (EOAEs) as the most probable measures to accomplish a universal newborn hearing screening protocol. They recommend EOAEs to be used as the first screening measure based on the rapid administration and effective identification of infants with normal auditory function. However, due to a high rate of false-positives that occurs from EOAE testing it was recommended to have a second screening consisting of an ABR for those infants that failed the first EOAE screening. This should occur prior to discharge, minimizing the problems that occur with follow-up diagnostic evaluations. If an ABR

screening is warranted, those that pass the ABR screening are to be re-tested in 3-6

months and those that failed the ABR are to have a diagnostic evaluation (NIC, 1993).

Therefore, EOAEs are clearly defined as the suggested protocol for the first line of

screening.

Gorga et.al (2001) evaluated the cost effectiveness of newborn hearing screening.

This study examined screening protocols including ABR, EOAEs, and these used in

combination. It was found that with follow-up cost included as part of the protocol, it was

least expensive to screen newborns with EOAEs first and follow up with an ABR for

those infants that did not pass the EOAE screen. Therefore, not only are EOAEs

suggested for newborn hearing screenings due to their effectiveness, they are also cost

effective for the institution.

As stated above, objective testing is currently recommended and being used for

new born hearing screenings. Prior to EOAEs becoming a routine measure used in

diagnostic evaluations and a recommended method for infant hearing screenings, they

were researched in great detail to determine the parameters needed to obtain the most

accurate results. The following sections detail the recommended specifications for

obtaining EOAEs.

History and Clinical Use of OAEs

Currently, otoacoustic emissions (OAEs) are being used clinically as an objective

measure in combination with other procedures for diagnostic purposes to diagnose

cochlear function. Otoacoustic emissions are sounds produced in response to an acoustic

stimulus delivered to the cochlea that can be measured in those with normal hearing and

mildly impaired ears. There are two types of OAEs: spontaneous otoacoustic emissions

(SOAE) and evoked otoacoustic emissions (EOAE). Spontaneous otoacoustic emissions

(SOAEs) are present without the presentation of a stimulus. However, they are not

present in all normal hearing individuals and therefore are not used as a clinical measure.

Evoked otoacoustic emissions (EOAEs) are elicited by stimuli presented to the ear

through a probe tip inserted into the external auditory canal (EAC) and measured with a

very sensitive microphone. In response to the acoustic stimuli, a responsive sound from

the outer hair cells in the cochlea are sent back through the middle ear system and then

measured in the outer ear. The routine clinical use of EOAEs has led to in depth research

concerning specific testing parameters and support for validity and reliability. The two

main types of EOAEs are transient otoacoustic emissions (TEOAEs) and distortion

product otoacoustic emissions (DPOAEs). Transient otoacoustic emissions are elicited by

a transient stimulus, such as a click or tone bursts; while DPOAEs are produced in

response to the presentation of two primary frequencies (f_1/f_2) at two primary levels

(L_1/L_2), where the nonlinearities of the cochlea are measured by the distortion produced.

The emission frequency is termed by the f_2 frequency. The ratio between f_1/f_2 is 1.2 which

causes the most robust response (Katz, 2002). Signal averaging occurs near to f_1 and f_2 to

obtain an average of the noise; this is termed the noise floor. The responsive sound from

the cochlea is considered a true emission if the level of the DPOAE is a certain level

above the noise floor. The suggested criterion is typically 3 dB for adults, 5 dB for

children, and 10 dB for infants (Katz, 2002; Hall, 2000). Martin and Clark reported in

2006 that with cochlear impairment EOAE responses will decrease in amplitude as

hearing impairment increases to approximately 40 dB HL. Once the impairment has

resulted in a loss greater than 40 dB HL, emissions will have reduced to the extent that

they will disappear and no longer be recordable. It was also reported for emissions to be

elicited, the outer and middle ear pathway must be clear. Once an emission is elicited, it

indicates a normal functioning outer, middle, and inner ear.

Measuring evoked otoacoustic emissions. As mentioned previously, to obtain an

EOAE a probe tip must be inserted into the external auditory canal (EAC) which

occludes it, thus greatly reducing the influence of background noise. The probe tip

typically is made of foam and contains a loud speaker to present the stimulus and a

microphone to measure the response which is converted to an electrical signal for

interpretation. The probe tip used for DPOAEs must contain two ports for presenting two

primary tones as opposed to TOAEs that only requires one port. The responding sound

that is produced by the cochlea is very low in intensity and therefore signal averaging

must be used. Signal averaging is an important aspect of EOAEs. The premise of signal

averaging is to average out unwanted noise. Thus repeated stimulus presentations are

given and responses are averaged so the true OAE signal will remain while the more

inconsistent/random noise artifact is removed (averaged out) from the evoked response.

Signal averaging is used during OAE data collection, thus providing the ability for

accurate OAE results to be obtained in the presence of noise. Specifically, DPOAEs have

been shown to perform better in the presence of background noise and deliver fewer

stimulus presentations resulting in a faster testing time. However, in the presence of very

high noise levels both types of emissions (i.e. DPOAE and TEOAE) can be masked,

resulting in difficulty obtaining a response (Katz, 2006; Martin & Clark, 2006).

Specific clinical applications. It has been accepted that if the outer and middle ear pathways are clear and DPOAEs are unable to be elicited, it indicates a significant cochlear pathology. Therefore, in individuals with cochlear impairment, emissions will be absent or reduced. Previous studies have found that EOAEs are frequency specific and that the emission will only be absent at the impaired frequency region (Katz, 2006).

Research has been conducted that examined the most efficient parameters needed to obtain the most accurate results of OAE testing. Previous research focused on variables such as frequency, relative frequency, level, and relative level which produce the most robust DPOAE. Lonsbury-Martin, McCoy, Whitehead, and Martin (1993) performed a study to evaluate clinical use of DPOAEs. This study evaluated DPOAE testing and their clinical application. This was investigated through two types of DPOAE recordings; audiogram and input/output function. It was found that DPOAEs can be elicited by all normal ears over a wide frequency range, as high as 5K-8K Hz, and are reduced in impaired ears. As previously stated, the ability to obtain OAEs is somewhat dependent on a clear middle ear pathway; thus the absence of DPOAEs might be due to middle ear dysfunction, and not outer hair cell pathology. Otoacoustic emissions can also help determine site-of-lesion; by comparing consistencies and inconsistencies between outer hair cell function and site-of-lesion/disease. When comparing DPOAEs and TEOAEs, it was shown that TEOAEs have the capability to predict hearing function within the frequency range of 1K-4K Hz while DPOAEs were found to extend to 4K-8K Hz and more clearly showed changes in hearing status over time. In addition, DPOAEs were level dependent; indicating those produced by low level stimuli ($\leq$ 60-70 dB SPL) were by an active cochlea while those produced by a high level stimuli ($\geq$ 60-70 dB SPL) were

by a passive/macromechanical property. In summary, DPOAEs provided high frequency information, with the ability to test up to 8K Hz. Distortion product otoacoustic emissions also have high test/retest reliability and a proportional relationship to hearing loss caused by outer hair cell dysfunction. Therefore, DPOAEs were effective in investigating peripheral hearing loss.

Stover, Gorga, Neely, and Montoya (1996) performed a study to asses high (L1/L2= 75/65 dB SPL), moderate (L1/L2= 65/55, 60/50, 50/40 dB SPL), and low (L1/L2= 40/30 dB SPL) level stimuli and their effect on DPOAEs ability to detect normal versus impaired ears. This was achieved through administration of DPOAE input/output functions for nine frequencies. Input/output functions were then converted to DPOAE threshold functions (defined as pure tone estimations extrapolated from DPOAE input/output function). The threshold functions were then compared to DPOAE amplitudes to determine effectiveness of identifying normal verses impaired hearing. A total of 210 subjects participated in the study, which was divided into two groups of normal hearing (n = 103) and impaired hearing (n = 107).

During administration of the nine frequencies, L_1 was held at 10 dB above L_2. The best response of DPOAE amplitude was elicited by moderate level stimuli, allowing a dichotomous decision to be made for all individuals when L_1 equaled 65 dB and L_2 equaled 55 dB, except at 500 Hz. Low level stimulus (L1/L2=40/30) showed a decrease in accuracy of identification. Overall Stover et al. (1996) showed DPOAE threshold functions had high performance in identification of normal verses impaired ears with moderate level stimulus (L1/L2= 65/55).

Test/retest reliability of EOAEs. As stated previously, EOAEs have arisen as a

useful clinical tool with TEOAEs and DPOAEs being the two types used clinically.

Test/re-test reliability of DPOAEs and TEOAEs have been investigated over time to

determine if a change in test results are due to a true cochlear pathology or test error.

Franklin, McCoy, Martin, and Lonsbury-Martin (1992) performed a study investigating

the test/re-test reliability of DPOAEs and TEOAEs. Participants included seven males

and five females between the ages of 19 and 44 years with pure tone thresholds better

than 20 dB SLP. The equipment used to test DPOAEs was a personal micro-based

system, Macintosh IIci and an Otodynamic Analyzer, ILO v1.0 was used to examine

TEOAEs. All EOAEs were tested over four consecutive days (i.e., short term analysis)

and over four successive weeks (i.e., long term analysis).

Distortion product otoacoustic emissions (DPOAEs) were evaluated in two forms.

First, in the form of an audiogram, which investigated the stimulus frequency domain.

Secondly, input/output functions, which evaluated the stimulus level domain. Franklin et

al. (1992) showed DPOAE test/re-test reliability in the form of an audiogram was good

for short and long periods of time. Test/re-test reliability for DPOAEs for input/output

functions had good reliability above inputs levels of 35 dB SLP; these results were

similar for short and long time periods. Frequency related results showed TEOAEs had

good reliability for 1-3K Hz; however, reliability decreased at higher frequencies such as

4000 Hz.

Results of the Franklin et al. (1992) study demonstrated reliability for both

DPOAEs and TEOAEs except at lower frequencies such as 1K Hz for DPOAEs, typically

due to increased subject respiration. Furthermore, the authors concluded that intersubject

variability was high, meaning there were differences in the responses from each individual subject causing a higher chance for measurement error. Overall results support that TEOAEs have high reliability from 1-3K Hz and DPOAEs have reasonable reliability at 1K Hz with excellent reliability from 2-8K Hz. Therefore Franklin and fellow investigators conclude that TEOAEs are suitable for testing speech frequencies and DPOAEs are more suited for higher frequency assessment, thus better for monitoring high risk groups (i.e. otoxicity, premature, hyperbilirubinema, family history, ect.). Overall, EOAEs are a reliable objective measure for early identification of cochlear impairment.

Preferred methods of DPOAE procedures (L1/L2, f1/f2). It has been found that DPOAEs are more sensitive to different cochlear pathologies depending on the level at which they are elicited (Lukashkin, Lukashkin, & Russell, 2002). Level is referred to as the primaries used to elicit the emission. This has led to speculation that primaries (L1 and L2) below 60-70 dB SPL are generated by different structures than those above 60-70 dB SPL. Low level primaries (i.e. below 60-70 dB) reflect an active micromechanical process (nonlinear cochlear amplifier) whereas high level primaries (i.e., above 60-70 dB) reflect a passive macromechanical process. An active process enhances the vibrations of the basilar membrane and is present in a normal functioning cochlea; therefore, enhancement characteristics disappear with cochlear impairment. Passive properties of the basilar membrane are dominant over the active properties at high levels due to the large vibrations caused by high stimulus levels. Therefore, since high levels result in passive emissions and are dominant over active emissions, reduction due to an impaired

cochlear amplifier would not be seen at high level stimuli. Indicating non-linearity would be most evident with the use of low level primaries.

Lukashkin et al. (2002) investigated these issues in a study directed at distinguishing between a "one source" and "two source" hypothesis. If the cochlea is impaired, the passive process would dominate at low level primaries, where in a normal functioning cochlea the active process would be present at low level primaries. Furosemide was used to induce cochlear pathology in guinea pigs, affecting the cochlear amplifier. Results supported that an active source was responsible for low and high level primaries up to 75 dB SPL. This indicated a nonlinear cochlear amplifier (active source) was responsible for emissions at primary levels below 75 dB SPL. Saturation most likely occurred at levels greater than 75 dB SPL when the passive macromechanical properties were dominant. These studies indicate that the primary levels necessary for identifying cochlear pathology (hearing loss) must be below 60-70 dB SPL.

DPOAEs relationship to audiometric pure tones. It is reported that DPOAEs have a strong relationship to pure tone thresholds; and as thresholds improve DPOAE levels increase (Katz, 2002). Harris and Probst (1991) reviewed EOAEs in their regards to audiometric correlation. They were evaluated by comparing screening measures to audiometric thresholds by frequency. Subjects received otoscopic examination, impedance measures, and audiometric thresholds prior to EOAE testing. Subjects then received EOAE testing which included SOAEs, TEOAEs, and DPOAEs.

Results from Harris and Probst showed a sufficient correlation between DPOAE thresholds and audiometric thresholds by frequency; DPOAEs as opposed to TEOAEs seemed to provide the most consistent correspondence to audiometric thresholds by

frequency. Furthermore, as stated Harris and Probst it can be assumed that emissions produced with high level stimuli will not correspond with audiometric thresholds as well as those produced with low level stimuli; this is because, as reviewed previously, high level responses are not results of the cochlear amplifier rather a passive vibration of the basilar membrane. This is attributed to the assumption that it is likely there are differences between the mechanisms that produce emissions at high and low level stimuli. Harris and Probst also indicated threshold DPOAEs may be a better predictor of auditory thresholds at specific frequencies rather than DPOAE amplitude response. However, it was also possible for DPOAE responses to be absent at specific frequencies even when conditions were optimal and hearing was within normal limits. In regards to TEOAEs, if they are present there was a high probability that hearing thresholds were less than 30 dB for at least one frequency. Overall, DPOAEs have the most consistent correspondence to audiometric thresholds. However, at the time of this study there was still much investigation to be done to determine if there was a preferred EOAE procedure for predicting hearing sensitivity by frequency.

Gorga et al. (1993) examined the relationship of DPOAEs with respect to audiometric thresholds in normal and hearing impaired adults by evaluating DPOAE test performance. They showed that DPOAEs obtained between 4000 Hz - 8000 Hz have a strong relationship to audiometric thresholds. Meaning that DPOAEs could accurately indentify normal and impaired hearing individuals within the frequency range of 4000-8000 Hz. At 2000 Hz and 500 Hz, DPOAEs were found to be less accurate, with test performance at 500 Hz being the same as chance responses. Therefore, Gorga et al. showed that DPOAEs have strong correlation to audiometric thresholds and have the

ability to accurately identify normal versus impaired hearing in the higher frequency

range of 4000-8000 Hz.

Resistance to noise. Lee and Kim (1999) evaluated the effects of ambient noise

levels on DPOAE responses as well as signal averaging time while obtaining DPOAEs.

The analysis consisted of viewing the DPOAE: noise ratio (D:N), meaning the

relationship between DPOAE amplitude and noise level where the emission is recorded

(2f1-f2). This is also known as amplitude of the DPOAE response. A baseline result was

obtained for D:N with an ambient noise level of 25 dBA. The authors showed, in

comparison to the baseline, the D:N was significantly affected in the lower frequencies

and at ambient noise levels above 40 dBA. In contrast, higher frequencies were not

affected by ambient noise levels above 40 dBA; for instance 55-65 dBA did not

significantly affect the D:N in the high frequency range. In addition, signal averaging was

affected by low frequency and increased ambient noise level. Therefore, longer time was

needed to obtain a DPOAE in the lower frequency range if increased levels of ambient

noise were present.

Hatzopoulos et al. (2001) performed a study to compare TEOAE protocol with

DPOAE protocol. The study was conducted on 250 infants within a well baby nursery.

Distortion product otoacoustic emissions were elicited using a 75-65 dB SPL protocol

while TEOAEs were elicited using a linear protocol set at 70-75 dB SPL. Cochlear

responses were effectively elicited within a noisy well baby nursery for both protocols at

a similar pass rates. However, it was suggested by the authors that DPOAEs may

outperform TEOAEs due to the nature of the non-linear method/delivery to the cochlea

by the DPOAE stimulus; suggesting that DPOAEs may be more efficient protocol than

TEOAEs for assessment outside the confines of a sound treated booth.

Variability of OAEs.

Subject characteristic can affect the results of both types of EOAEs (TEOAEs and

DPOAEs). Transient otoacoustic emissions have been shown to have larger amplitudes in

neonates when compared to adults. They also have larger response amplitudes when

measured in the right ear and in females (Katz, 2002). Distortion product otoacoustic

emissions are also affected by participant characteristics. Similar to TEOAEs, neonates

have higher DPOAEs than adults and females are found to have larger DPOAEs than

males. In contrast to TEOAEs, some studies have shown that gender only affects

DPOAEs at certain frequencies, rather than affecting the whole frequency range. Aging

effects can also show differences in DPOAE results, specifically reduction in the high

frequencies for older adults with normal hearing (Katz, 2002).

Understanding the necessary components and characteristics in obtaining EOAEs

is important and well understood. Although, EOAEs are recommended as a screening

tool in infants, they are currently not recommended for hearing screenings in school aged

children. The following sections discuss the variety of methods for hearing screenings in

older listeners and the most commonly used protocols.

Methods of Hearing Screening

The United States does not currently have a nationally accepted protocol for

hearing screenings. Without a national protocol it is difficult to assess early identification

due to a lack of information on incidence rate and variability of protocols. Due to the lack

of a national model for hearing screenings, a variety of procedures can be found in the

literature as components of hearing screenings based on the overall goal of the screening. Many states have hearing screenings for school aged children through the Department of Education or Health, but due to the lack of a national model, procedures and referral rates are variable. It should also be noted that no one measure used in isolation is completely accurate in identifying impairment and therefore should be used in combination with other procedures (Katz, 2002).

Hearing screenings can consist of a variety of procedures. These can include: developmental checklist (birth-three years), high risk criteria (HRC) (birth- two years), history (all ages), otoscopy (all ages), auditory brainstem response (ABR) (newborns, infants, toddlers), otoacoustic emissions (OAEs) (newborns, infants, toddlers), pure tone screening (two and half years-adult), immittance measures (six months-older), and behavioral observations (3mo-2yr). The age ranges suggested are the "target populations" for these procedures and these measures can be used at other ages than just the suggested population. In addition to the suggested age ranges for each procedure listed above, any of these measures can be used for difficult to test populations (Katz, 2002).

Currently, pure tone screening is the most popular method used, as suggested by ASHA (1990a; 2006). This consists of presenting pure tones at frequencies ranging from 500 to 4000 Hz at 20 (for children) and 25 (for adults) dB HL. Pass criteria requires a response at all of the test frequencies and referral is made if the participant fails to respond at any of the testing frequencies. This procedure is relatively quick to administer and can be conducted by non-professionals. However, screening procedures are usually administered outside a sound treated booth and noise levels within these environments are likely to cause difficulty obtaining accurate results, especially in the lower

frequencies (500 Hz). It should also be noted that middle ear disorders can be overlooked unless hearing loss is present resulting in impairment greater than 20 or 25 dB due to middle ear pathology.

Otoacoustic emissions are a recommended screening measure for infants, difficult to test populations, and as a diagnostic measure to determine site-of-lesion (Katz, 2002). It is a test of cochlear function; specifically, this measure assesses outer hair cell function of the cochlea. As stated previously, the outer hair cells are stimulated via a probe tube that is inserted into the external auditory canal (EAC). In return a sound is emitted in response to acoustic stimuli that can be measured in the EAC (Katz, 2002). This is an objective measure, meaning it does not require a behavioral response from the patient, which is possibly more suitable for younger populations due to limited behavioral responses sometimes obtained in the pediatric population. Otoacoustic emissions require minimal contact with the patient and have proven to be an efficient measure over time (Katz, 2002).

While there are many studies on different hearing screening measures, the American Speech Language and Hearing Association (ASHA) has put forth a suggested protocol for hearing screening. As stated, ASHA's protocol is currently the most widely used for preschool and school aged hearing screenings. Below, the screening guidelines are outlined for different populations.

American Speech Language Hearing Association protocol. The American

Speech Language and Hearing Association (ASHA) has suggested preferred practices for

audiologic screenings. The protocol was designed for large populations to be separated

into two groups: normal hearing and impaired hearing. The two guidelines that will be

discussed are Guidelines for Audiologic Screening (i.e. screening guidelines for pure

tones) (ASHA, 1997) and Guidelines for Screening Hearing Impairment and Middle Ear

Disorders (i.e. Screening Guidelines for Immittance) (ASHA, 1990a). The first consists

of the pure tone hearing screening procedures to detect hearing impairment. It suggests

when screening children to administer pure tones at 500, 1000, 2000, and 4000 Hz at 20

dB for each ear. This measure is appropriate for ages three to approximately third grade.

However, it can be given to high-risk children in higher grades and even up to age 40 if

applicable. A referral is received if the participant fails to respond at any of the presented

frequencies. In this case, a rescreen is suggested within the same session or at the most

within two weeks.

The second set of guidelines mentioned above refers to otoscopy and immittance

measures that are suggested in order to identify middle ear disorders. Immittance

measures are viewed as abnormal if ear canal volume is too large, no mobility of the

tympanic membrane is present, or if visual examination shows drainage, blockage, or ear

pain. If the gradient of the tympanogram is not within normal limits, it is suggested that

the participant be rescreened in four to six weeks. The American Speech Language and

Hearing Association does have recommended practices for otitis media with effusion in

young children consisting of optional case history, visual examination, and acoustic

immittance testing. These results should then be compared to normative data for the population being screened.

It should be noted for ASHA's pure tone screening guidelines, 500 Hz may be disregarded if ambient noise levels are too high. This suggest that pure tone screening results are not optimal for obtaining accurate results in the presence of noise. Furthermore, issues concerning personnel, instructions, time, acoustic environment, and equipment are to be taken into consideration in combination with the results obtained (ASHA, 2006; 1990a).

Preschool and school-aged hearing screening. It is known that hearing impairments can readily occur in early childhood and therefore school age screenings should be implemented in an effective universal manner (NIH, 1993). However, there is not a universal accepted guideline for this early age group. Some state funded programs provide screenings for 3 to 5 year olds, but this comes with varying guidelines and personnel requirements to administer the measures. As stated, the American Speech Language and Hearing Association (ASHA) has also put forth a suggested screening protocol for this age group. While many measures exist that can be used as components of a screening protocol, currently ASHA's protocol has been the most widely used for preschool and school aged hearing screenings. It is common for screenings to be administered to public school kindergarteners and first graders within the educational setting because this is the first opportunity a large group of children can be targeted at the same time. Unfortunately, if state and federal funding is not available, procedures, referrals, and follow-up criteria can vary greatly (Katz, 2002). It is important for a screening program to have the ability to effectively identify those with impairment,

without over identification resulting in a high referral rate because this can increase cost and decrease effectiveness of the screening due to follow-up evaluations.

Allen et al. (2004) evaluated the pass/refer rates of middle ear pathology and hearing loss in children aged 3 to 4 years enrolled in a Head Start program using ASHA Guidelines for Audiologic Screening (ASHA, 1997). Specifically, Guidelines for Screening Infants and Children for Outer and Middle Ear Disorder, Birth through 18 Years (i.e. Screening Guidelines for Immittance) and Guidelines for Screening Hearing Impairment-Preschool Children, Three to Five Years (i.e. Screening Guidelines for Pure Tones) were used. A primary focus of this study was to investigate pass/refer rates of middle ear status while closely following ASHA guidelines. The participants included 1,462 three to four year old children enrolled in one of seven Head Start programs in eastern North Carolina from 1998 to 2002. Otoscopy, tympanometry, and pure tone screenings were administered using the procedures described in the ASHA Guidelines for pure tone and immittance screenings. Children who did not pass were re-screened within two to four weeks in accordance with Head Start screening protocol which is more conservative than the ASHA guidelines which recommend that rescreening occur six to eight weeks after initial screening. Those who were referred after both screenings were sent for a follow-up diagnostic evaluation.

The authors found that 53.8% of all children passed the initial screening, which required passing otoscopy, tympanometry, and pure tone testing. This was consistent over a four year period. An additional, 58.7% passed the re-screen yielding a pass rate of approximately 80% (75.9%). However, after the re-screen and the diagnostic evaluation, only six children had a confirmed hearing loss. Based on these results, the authors

concluded that when using ASHA's protocol, concerns lie with a high initial referral rate and a low incidence of identified hearing loss. It should be noted that it is still undetermined whether the high initial refer rate was due to the common middle ear disorder at this age or an inefficient protocol, bearing in mind that pass rates were based on passing all three components of the screen including otoscopy, tympanometry, and pure tones.

In Allen et al.'s study the age of the children screened should be considered as a possible reason for the false positive rate, as well. The young age of the subjects can affect the accuracy. It has been previously shown that pure tone pass rates increase with age (Mundy, 2001); suggesting behavioral testing such as audiometric screening would be more suitable for older age groups while an objective measure may yield improved results within younger populations (Allen et al., 2004). Therefore, pure tone testing may not be suitable for the pediatric population and may elicit limited responses from children (Katz, 2002).

Viktor, Monika, Cornelia, and Kunigunde (2004) also evaluated hearing screenings of pre-school children. Their study consisted of 2,199 children from 47 pre-schools. The screening was performed using pure tone testing at 500 Hz (25 dB), 1000, 2000, 4000 Hz (20 dB). Of the 2,199, 1,832 children were screened. The screening resulted in 390 children failing, with only 217 receiving a follow-up evaluation from an ear, nose, and throat (ENT) specialist. A positive result was found in 139 children indicating a hit rate of 64%. Of those, most losses were due to middle ear pathology and only four children were identified with a permanent sensorineural hearing loss, with three

being bilateral. Again, with reliance on pure tone screening measures alone, a high initial referral rate was seen.

Lyons, Kei, and Driscoll (2004) examined DPOAEs incorporated with pure tones and typanometry as a means to contribute to school screenings. Participants included 1,003 children with a mean age of 6.2 years. Distortion product otoacoustic emissions efficiency was examined through true positive rates and false positive rates when compared to pure tone results. It was suggested to avoid the use of fixed signal-to-noise-ratio (SNR) as a pass criterion for all DPAOE frequencies combined; this is because of the variability between each frequency. Therefore, DPOAE results were obtained with DPOAE SNR (DPOAE amplitude minus mean noise floor for each participant) criterion for each frequency, which include 4 dB, 5 dB, and 11 dB for 1.1 (1K Hz), 1.9 (2K Hz), and 3.8 (4K Hz) Hz respectively. True positive rates were 86%, 89%, and 90% while false positive rates were 52%, 29%, and 22% for 1K Hz, 2K Hz, and 4K Hz respectively. Lyons et al. found when DPOAEs were compared with pure tones plus tympanometry, DPOAEs were not sufficient. Meaning when DPOAEs were used alone they were not as accurate as pure tones plus tympanometry. However, when DPOAEs were used in combination with tympanometry, test performance was improved in comparison to pure tone screening plus tympanometry. This suggested that DPOAEs, when used alone, may miss children with subtle middle ear dysfunction; yet, when used in combination with tympanomtery shows high performance indicating the promise of a useful tool for school aged screening protocol.

As mentioned, many procedures exist to evaluate hearing impairment and all can be used as a part of a hearing screening protocol. When choosing the components to

comprise a screening protocol one should take into consideration the environment in which the screenings will take place. Many screenings are conducted in the educational setting where noise cannot be controlled. Researchers have evaluated the levels of noise that occur in schools and compared them to the suggested criteria for ambient noise levels. The following literature sheds light on the amount of ambient noise that can occur during hearing screenings in a school setting.

Noise Levels in Educational Settings

The American Speech Language and Hearing Association (ASHA) has guidelines for ambient noise levels in an educational setting. These guidelines were published in 1995 and confirmed in 2002. They are as follows: background noise levels in classroom should not exceed 30 dBA, reverberation times not to exceed 0.4 seconds or less, and an overall signal-to-noise ratio (SNR) should be a minimum of +15 dB. The ASHA position statement contains the guidelines that confirm these criteria which occurred in 2002 when American National Standards Institute (ANSI) published the information concerning noise levels in schools. Recommendations from ANSI included noise levels not to exceed 35 dBA, reverberation time not to exceed 0.6–0.7 seconds, and a SNR should be a minimum +15 dB; this shall be based on room size. However, if these standards are not met there is little that can be done to improve them; if they are even checked.

Knecht, Nelson, Whitelaw, and Feth (2002) evaluated background noise in schools by measuring the levels of noise in 32 different unoccupied elementary classrooms in eight public schools. A Bruel & Kjaer 2260 Investigator sound level meter (SLM) was used to obtain measurements. The SLM was calibrated internally and externally before each measurement. The results showed background noise in schools ranging from 34.4

dB (A) to 65.9 dB (A) ; with only 4 classrooms being in accordance with the less

stringent ANSI recommendations of noise levels below 35 dB (A). Furthermore, only one

classroom had a level of 30 dB (A), which met the more conservative guideline suggested

by ASHA. Twenty seven classrooms did not meet either of the suggested guidelines,

ranging from 5-15 dB over the suggested level for ambient noise.

Statement of the Problem

In the United States, hearing impairment widely exists in the pediatric population

in significant proportions. Due to the lifelong consequences unidentified hearing

impairment can have on language, cognition, and social development, it becomes evident

that that the measures used for early identification must be carefully considered. Thus,

objective diagnostic measures, such as EOAEs, have been researched in depth to

demonstrate the ability to aid in early identification screenings of hearing impairment.

Newborn hearing screenings have taken advantage of these findings by using objective

measures such as EOAEs and shown success in increasing identification rates. Late onset

or progressive hearing impairments should be identified during school based screenings

using measures that are effective; however, hearing losses are being missed possibly due

to inadequate screening protocols for this age group and inappropriate testing

environment.

The efficacy and appropriateness of school hearing screenings can be investigated

through evaluating the screening in the presence of noise. As stated, the most common

screening measure being used is audiometric pure tones, even though EOAEs have been

shown to be an effective screening tool in infants when noise is present. The performance

of these two screening components in the presence of noise may show which screening

tool more accurately identifies normal hearing individuals under comparable conditions in which school screenings are performed. Therefore, the focus of this study was to obtain pure tone and DPOAE information in the presence of various levels of background noise to asses hearing status. This information was then compared to pass/fail criteria for pure tone and DPOAE hearing screenings to determine which method more accurately identified normal hearing adults in the presence of noise.

CHAPTER II

Methods

Participants

This experiment consisted of 20 adult listeners, 18-28 years of age who were recruited from undergraduate and graduate classes in the Department of Speech on a volunteer basis. The participants received no compensation for inclusion in the study, aside from a free hearing screening. The inclusion criteria was as follows: (1) normal hearing sensitivity, defined as pure tone thresholds of 25 dB HL or better for octave frequencies 500-4000 Hz and a pass result on DPOAE screening in quiet, bilaterally; (2) no known neurological, cognitive, or central auditory processing symptoms; and (3) all other otologic history to be unremarkable. Participants who did not meet the defined criteria for hearing were referred to the Louisiana Tech University Speech and Hearing Center for a free audiological examination. The inclusion criterion was assessed with a pure tone screening, DPOAE screening, and brief case history prior to the experimental procedures.

Materials

All experimental procedures were conducted in a sound treated booth located in Woodard Hall on the Louisiana Tech University campus. The sound treated IAC test booth met ANSI specifications for ambient noise levels (ANSI S3.1-1991). Experimental equipment used consisted of a Grason Stadler GSI 17 portable audiometer (AR079374) with TDH-39 headphones to obtain audiolocial pure tone data. This instrument was

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calibrated prior to testing, met ANSI standards (ANSI S3.6-1969), and daily calibration

checks were administered throughout experimental testing. A Bio-logic Systems Corp

otoacoustic emissions screener (06L8497A) was used to elicit DPOAEs. Grason-Stadler

GSI sound field speakers located within the sound treated booth were used for the

presentation of varying degrees of background noise. The noise was presented through

Tascam CD-160 CD player, routed through a GSI 61 audiometer. A Quest Electronics

sound level meter (SLM) Model 1700 (HT6040004) was used to verify noise in dB SPL

that was routed through the audiometer in dB HL (ANSI S1.4-1971). Background noise

used during experimental testing consisted of cafeteria noise obtained from Auditec

recordings. The cafeteria noise was routed through the GSI 61 audiometer via Tascam

CD-160 and presented in the sound treated booth through the GSI 61 sound field speakers.

Test Procedures

Prior to data collection the Quest Electronics SLM was used to measure noise

levels in SPL within the sound treated booth. This was done to obtain noise levels in dB

SPL that were routed through the audiometer in dB HL. It was found presenting noise

from the right sound field speaker at 25, 35, and 45 dB HL through the audiometer equals

40, 50, and 60 dB SPL respectively within the sound treated booth at a distance of one

meter from the speaker. These noise settings on the audiometer were used for the noise

conditions for each participant.

Each participant had the Human Participants Consent Form (Appendix A) read

aloud to them by the examiner, had any questions pertaining to the experiment answered,

and signed the consent form. Participants completed an audiological case history form

provided by Louisiana Tech University Speech and Hearing Clinic (Appendix B). Each

participant was escorted into the sound treated booth and screened per inclusion criteria. If

all inclusion criteria were met the experimental portion of the test began. To assure each

participant met inclusion criteria a pure tone screen and DPOAE screen were

administered. The a pure tone screening was presented at 25 dB for 500-4000 Hz and a

DPOAE screen for 3000- 5000 Hz bilaterally in quiet. If the inclusion criterion was met

the screening was used as data for the quiet condition of the experimental portion. Pure

tones and DPOAEs were obtained bilaterally in the quiet condition and in the noise

conditions at the levels mentioned previously: 40, 50, 60 dB SPL. Screenings were

obtained in an alternating manner to counter-balance the data obtained, i.e. pure tone

screenings and DPOAE screenings were alternated in order of which screening was

administered first for each participant.

Before administration of pure tone testing with the portable audiometer the patient

was seated in the center of the booth facing the left sound field speaker. The examiner

and portable audiometer were located to the right of the participant where stimulus

presentations were out of the participant's line of sight. The participant was instructed to

sit quiet and listen for different tones in each ear. The participant was told to indicate

when the tone was heard by raising their hand. They were notified that this will be done

in quiet and then in different levels of noise. The examiner placed TDH-39 headphones

on the participant and performed the screening by presenting a 25 dB signal from the

portable audiometer at octave frequencies 500-4000 Hz first in the right ear in the quiet

condition. The same procedure was then repeated in the left ear. After obtaining pure tone

screen bilaterally in the quiet condition, pure tone screens were obtained in the noise

conditions. This was done in the same manner as the quiet condition with the exception

of presenting cafeteria noise routed through the GSI 61 audiometer from the right sound

field speaker at 40, 50, and 60 dB SPL while the participant was seated in the center of

the booth facing the left sound field speaker. During the pure tone screening, if the

participant indicated hearing the presentation tone a "pass" was marked on the data sheet.

If the participant failed to respond a "refer" was indicated on the data sheet.

Distortion product otoacoustic emissions (DPOAE) screening began by

instructing the participant to continue facing the left sound field speaker and sit still and

quiet. The participant was told they would hear different tones but they did not need to

respond. They were notified it would be performed in quiet and in different levels of

noise. The foam insert was then placed in the right ear canal to obtain DPOAEs at 3000,

4000, and 5000 Hz in the quiet condition. The same procedure was repeated in the left

ear. After the DPOAE screening was completed bilaterally in the quiet condition, it was

administered within the noise conditions. This was performed in the same manner as it

was in quiet with the exception of presenting cafeteria noise routed through the GSI 61

audiometer from the right sound field speaker at 40, 50, and 60 dB SPL.

During DPOAE screening, the emission (DP), noise floor (NF), and the difference

between the emission and noise floor (DP-NF) was recorded for each frequency. The

DPOAE screening parameters included: L1 to equal 65 and L2 to equal 55 for each

frequency. F_2 frequencies obtained were 3000 Hz, 4000 Hz, and 5000 Hz with an f_1/f_2

ratio of 1.22. A DP response was recorded as a true emission on the Bio-logic Systems

Corp screener if the DP-NF was 6 dB or greater. This is the Biologic Systems Corp

otoacoustic emission screener default protocol pass/fail criteria. It should be noted

different age groups have different criteria for determining if the result is a true emission.

The suggested criterion is typically 3 dB for adults, 5 dB for children, and 10 dB for

infants. Therefore, the Biologic Systems Corp default criterion (6 dB) is more

conservative than the suggested adult criterion of 3 dB for adults and children. The

Biologic Systems Corp screeners default protocol evaluates 3000- 5000 Hz; however, if a

"refer" was received on the first two frequencies tested (i.e. 5000 Hz and 4000 Hz), the

third frequency (3000 Hz) is not tested and an overall "refer" is received. If the

equipment could not obtain an emission due to elevated background noise, the frequency

being tested was labeled as "noisy" and resets down to 2000 Hz to obtain an overall

result. For example, if a participant passes 5000 Hz and 4000 Hz, but the screener was

unable to obtain 3000 Hz, which was labeled as "noisy", the equipment would test 2000

Hz. If 2000 Hz passed the result was an overall "pass"; however, if background noise was

still too elevated to obtain an emission at 2000 Hz it was also labeled as "noisy" and the

overall result was a "refer". The signal-to-noise-ratio determined if the emission was

couldn't be recorded due to elevated background noise.

CHAPTER III

Results

The present study examined the effects of various levels of background noise on

DPOAE screenings and ASHA recommended pure tone screenings in young normal

hearing adults. The purpose of this study was to determine at what noise levels are

DPOAEs and pure tone hearing screening results unable to be measured, or unlikely for

the listener to pass the screening as a result of background noise level. The following

research questions were addressed in the present study:

1. At what background noise levels do DPOAEs fall below the pass criteria in

normal hearing adult listeners?

2. At what background noise levels do pure tone screening responses fall below

the pass criteria in normal hearing listeners?

3. Which screening measure is more resistant to the effects of background noise?

All testing was completed in a sound treated IAC test booth (ANSI S3.1-1991)

using a portable audiometer (ANSI S3.6-1969) and a portable OAE screener. Both

DPOAE and pure tone screening results were recorded for right and left ears

independently in quiet, and with 40, 50, and 60 dB SPL of cafeteria noise. Background

noise levels were verified with a Quest Type I Sound Level Meter.

Participants

Participants for the present study were 20 normal hearing adults (2 males and 18 females) which ranged in age from 18 – 28 years (mean age of 22.5) who denied any history of ongoing audiological problems or any symptoms associated with auditory processing problems. This was determined through completion of audiologic case history form (Appendix B). Normal hearing was defined as thresholds that were 25 dB HL or better for the octave frequencies 500- 4000 Hz bilaterally. The participants received no compensation for inclusion in the study, aside from a free hearing screening. Participants were recruited from various undergraduate and graduate classes in the Department of Speech at Louisiana Tech University. Prior to the experimental testing, each participant was read aloud the informed consent (Appendix A) and signed it as verification of their willing participation. Participants who did not meet the inclusion criteria for the study were referred to the Louisiana Tech Speech and Hearing Center for a free audiological evaluation.

Experimental Methods

Each participant was seated approximately one meter from the right sound field speaker at a 0 degree azimuth in an IAC sound treated test booth (ANSI S3.1-1991). DPOAE screening measures were recorded for right and left ears by the examiner, with the participant instructed to remain still and quiet. No subjective response was required by the participant.

The pure tone audiometric screening, as recommended by ASHA, was conducted for both right and left ears in quiet by the examiner. The screening was conducted using a portable audiometer (ANSI S3.6-1969). Results for the pure tone screening were

recorded as either a "pass" or a "fail". A pass indicated that the participant responded to the frequencies of 500, 1000, 2000, and 4000, Hz at an intensity level of 25 dB HL for each ear, independently. A failure to respond to any of the frequencies for either ear resulted in a failed result. Pure tone screening procedures were conducted in accordance with ASHA guidelines. Participants responded by raising either hand in response to the pure tone presentations, and the screening was conducted with the examiner beside the participant with a screen in front of the audiometer hindering the participants view from the signal presentations.

The sequence of testing consisted of the examiner recording both DPOAE screenings and pure tone screenings in quiet, and then at 40 dB SPL, 50 dB SPL, and 60 dB SPL of cafeteria noise. All participants were tested individually with no breaks between each condition. Approximate testing time was ten minutes for each participant.

DPOAE Screening Results

DPOAE descriptive data analysis. Figure 1 shows the means for right ear screening results. The reported DPOAE results are the emission (DP) with the noise floor (NF) subtracted, for the screening frequencies which were 3000, 4000, and 5000 Hz. The screening DPOAEs were recorded in quiet and then at 40, 50, and 60 dB SPL of background noise. As expected the graph illustrates that as background noise was increased, the DP-NF values decreased. The graph also demonstrates that the greatest effect was seen at 3000 Hz.

Figure 1. Right ear DP-NF averages of all participants at each frequency tested as a function of background noise level of 0, 40, 50, and 60 dB SPL

Figure 2 shows the means for left ear screening results. Again, the reported DPOAE results are the DP with the NF subtracted, for the screening frequencies which were 3000, 4000, and 5000 Hz. As with the right ears, screening DPOAEs were recorded in quiet and then at 40, 50, and 60 dB SPL of background noise. The graph illustrates that as background noise was increased, the DP-NF values decreased nearly identical to the right ears, and that 3000 Hz demonstrated the greatest effect. However, one unique observation of interest was that the effect of 60 dB SPL of background noise on 3000 Hz for the left ear was visually less significant than the right.
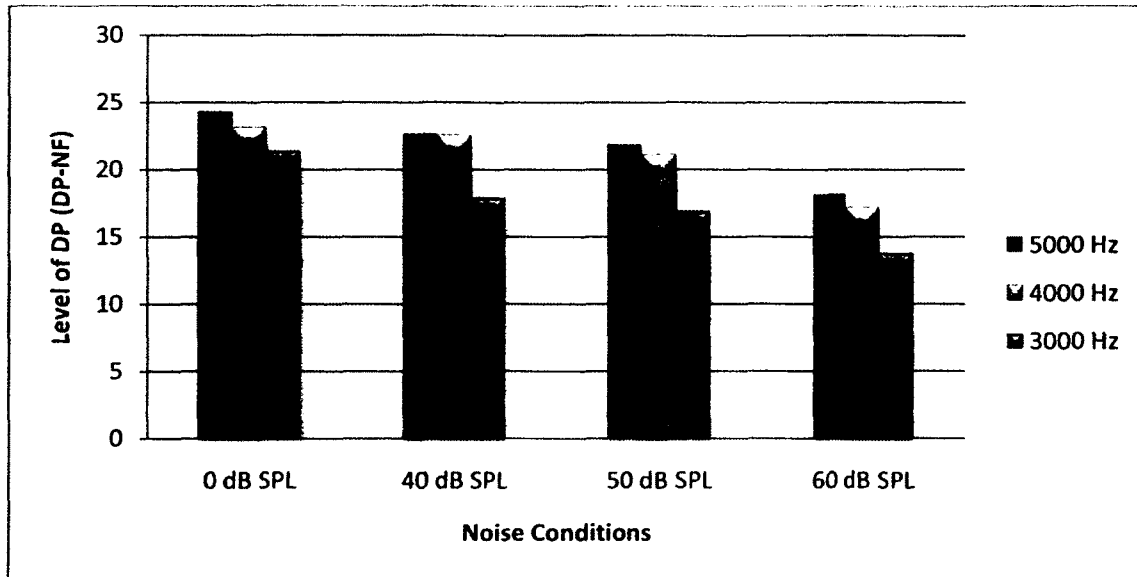
Figure 2. Left ear DP-NF averages of all participants at each frequency tested as a function of background noise level of 0, 40, 50, and 60 dB SPL

Figure 3 illustrates the mean DPOAEs of both ears combined for 3000, 4000, and 5000 Hz in quiet and with the addition of 40, 50, and 60 dB SPL of background noise. Again, the amounts indicate DP with the NF subtracted. As expected the graph is almost identical to that of the right and left ears.
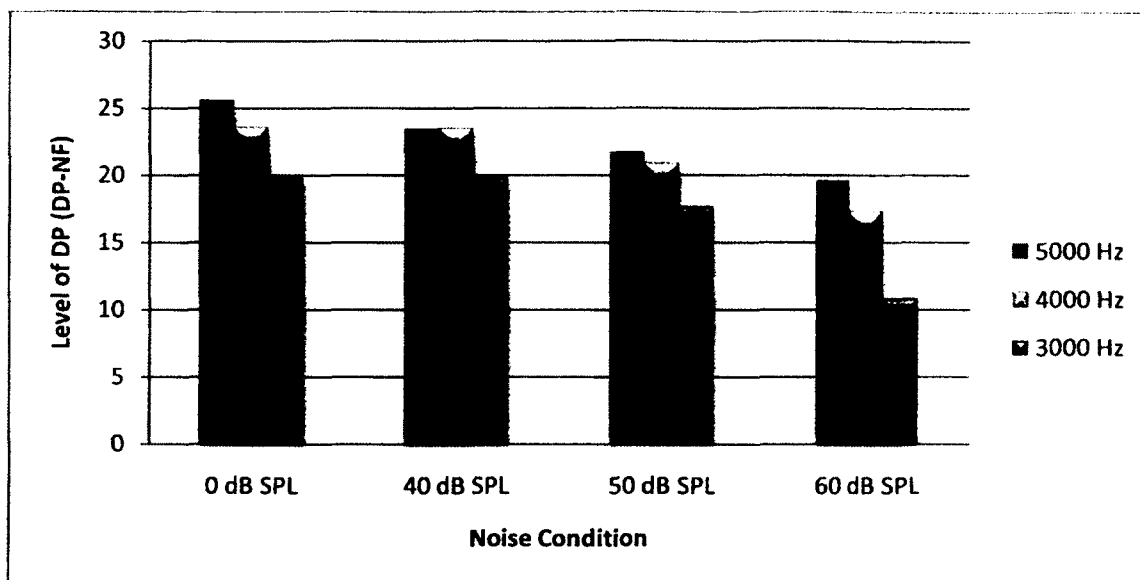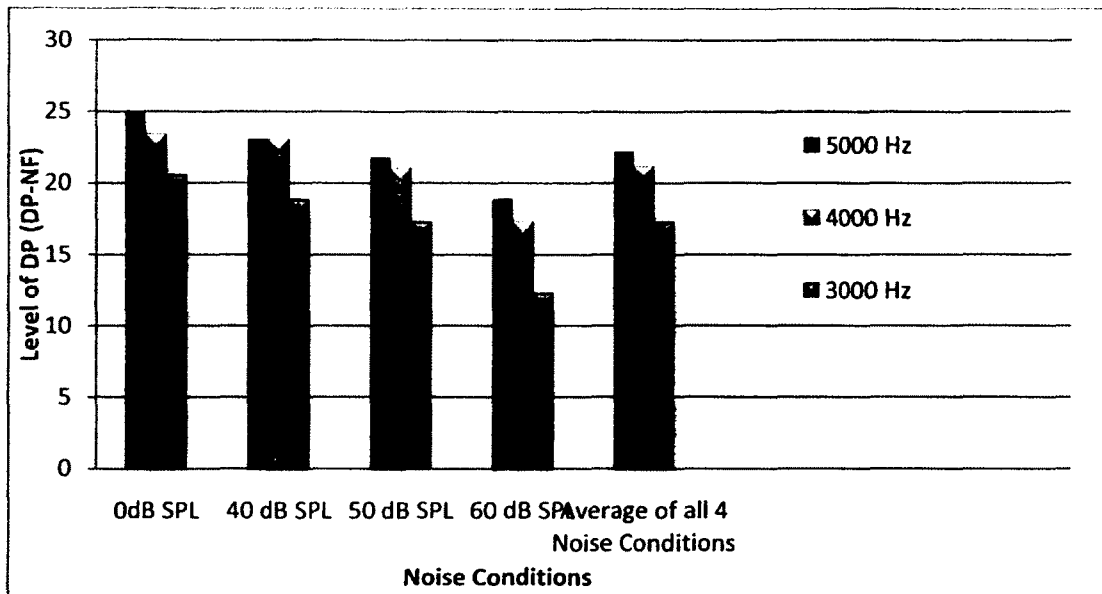
Figure 3. Binaural DP-NF averages of all participants at each frequency tested as a function of background noise at levels of 0, 40, 50, and 60 dB SPL

DPOAE inferential data analysis. To better understand the relationship between the cafeteria noise levels of 40, 50, and 60 dB SPL used in the present study and its effect on the DPOAE frequencies of 3000, 4000, and 5000 Hz, paired t-tests were conducted. The following comparisons were made for right and left ears independently and for all of the frequencies measured in the experiment. Paired t-tests consisted of: quiet to 40 dB SPL, quiet to 50 dB SPL, quiet to 60 dB SPL, 40 dB SPL to 50 dB SPL, 40 dB SPL to 60 dB SPL, and 50 dB SPL to 60 dB SPL. Overall results can be seen in Table 1 and Table 2.

Table 1. Values plotted for right ear paired t-test comparison of 0-40, 0-50, 0-60, 40-60, and 50-60 SPL for all frequencies tested (3000, 4000, 5000 Hz)

Right Ear Paired Comparisons:	Frequency:		
	3000 Hz	4000 Hz	5000 Hz
0-40	1.0	.962	**.011**
0-50	.094	.058	**.014**
0-60	**.000**	**.000**	**.000**
40-50	.064	.076	.140
40-60	**.000**	**.000**	**.000**
50-60	**.000**	**.005**	.075

Note. Bolded results indicate significant values (< .05). Shaded values indicate significance consistent for all three frequencies tested.

Table 2. Values plotted for left ear paired t-test comparison of 0-40, 0-50, 0-60, 40-60, and 50-60 SPL for all frequencies tested (3000, 4000, 5000 Hz)

Left Ear Paired Comparisons:	Frequency:		
	3000 Hz	4000 Hz	5000 Hz
0-40	**.003**	.439	**.047**
0-50	**.002**	.106	**.031**
0-60	**.000**	**.001**	**.001**
40-50	.391	.205	.465
40-60	**.000**	**.001**	**.013**
50-60	**.000**	**.001**	**.005**

Note. Bolded results indicate significant values (<.05). Shaded values indicate significance consistent for all three frequencies tested.

Right ear results revealed significant differences (< .05 significance level) for all three frequencies when comparing quiet to 60 dB SPL and 40 dB SPL to 60 dB SPL.

Left ear results also showed significant differences (< .05 significance level) for all three frequencies. The significant differences were seen when comparing quiet to 60 dB SPL, 40 dB SPL to 60 dB SPL and additionally 50 dB SPL to 60 dB SPL.

DPOAE Pass/Fail Results

A specific research aim of the present study was to determine at what background noise levels are screening DPOAEs unable to be measured, or fail to yield accurate results. The results of this study indicate that young normal hearing adult listeners do not fail the DPOAE screening until 60 dB SPL of cafeteria noise was introduced. At background noise levels of 40 and 50 dB SPL, all of the participants had passing results for screening DPOAEs. When 60 dB SPL of cafeteria noise was introduced; only two participants failed the screening.

Pure Tone Screening Results

A second research aim of the present study was to determine at what background noise levels are pure tone screenings inaccurate in young adult normal hearing listeners. Pure tone screenings were conducted at octave frequencies of 500, 1000, 2000, and 4000 Hz. In order to be considered a pass, the participant had to respond at 25 dB HL for each frequency. Right and left ears were screened independently in quiet and then in the presence of 40 dB SPL, 50 dB SPL, and 60 dB SPL of cafeteria noise.

Results for right and left ear screenings, as well as overall pass/fail screening results as a function of background noise can be seen in Table 3. The pure tone screening results indicated that as background noise increased, passing rates decreased as expected. Specifically, at background noise levels of 50 dB SPL, sixteen participants passed. When the background noise level was increased to 60 dB SPL, only six participants passed.

Table 3. Total number of participants identified as passing the pure tone screening shown in reference to each noise condition (0, 40, 50, and 60 dB SPL)

Level of Background Noise:	0 dB SPL	40 dB SPL	50 dB SPL	60 dB SPL
Number of Passing Participants: (Total Participants= 20)	20	20	16	6

DPOAE versus Pure Tone Screening Pass Rates

The last research aim of the present experiment was to observe which screening measure was least affected by background noise. The data clearly indicates that DPOAEs are more resistant to the effects of background noise in young adult normal hearing listeners and can be seen in Figure 4. No participant failed the DPOAE screening until 60 dB SPL of cafeteria noise was introduced, and then only two participants failed. In contrast, levels of 50 dB SPL of cafeteria noise added to the pure tone screening condition resulted in four participants failing, and at 60 dB SPL fourteen participants failed.

Pass/Fail Screening Results

	0 dB SPL	40 dB SPL	50 dB SPL	60 dB SPL
◆ Pure Tone Screen	20	20	16	6
■ DPOAE Screen	20	20	20	18

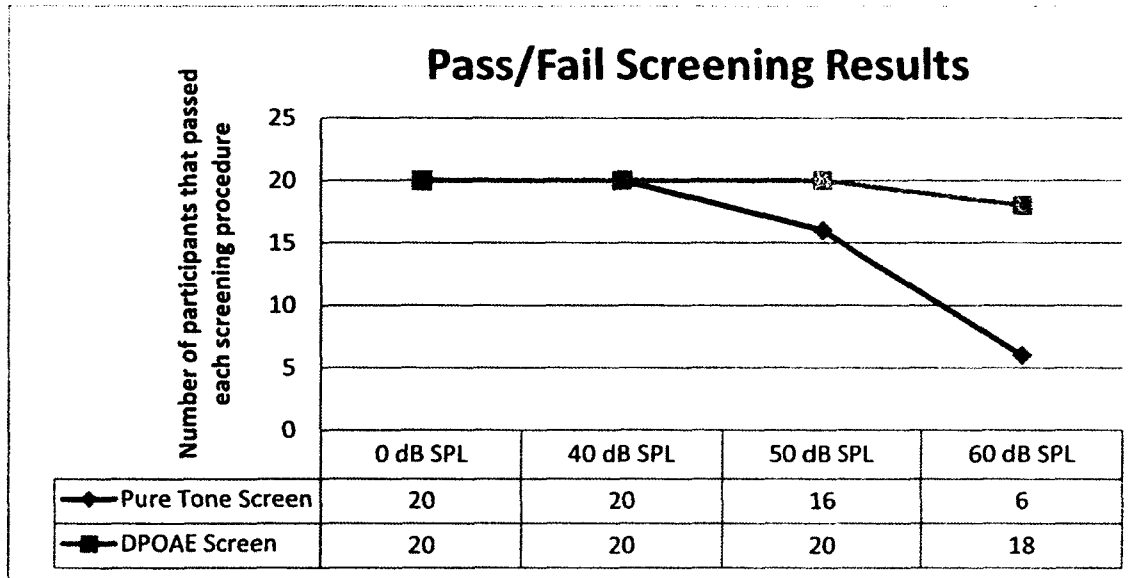*Y-axis: Number of participants that passed each screening procedure*

Figure 4. Total number of participants identified as passing the DPOAE screening and pure tone screening as a function of background noise.

CHAPTER IV

Discussion and Conclusion

The purpose of the present study was to determine the effects of various levels of background noise on DPOAE screenings and ASHA recommended pure tone screenings in young normal hearing adults in a sound controlled environment. The experiment was designed to determine at what intensity levels of background noise renders DPOAE and pure tone screenings useless. In other words, how much noise was needed before listeners with normal hearing failed to pass the screening? Specifically, the present experiment attempted to observe at what background noise levels did DPOAEs and pure tones fall below the pass criteria, and which screening measure was more suited to be used in potentially noisy environments.

Pure tone hearing screenings for young school aged children outside the confines of a sound treated environment, conducted per ASHA recommendations (ASHA, 1997) appear to be ill suited for detecting those at risk for hearing impairment. The problems that exist for subjective hearing assessment in this young age group are many. The most significant problem encountered with pure tone hearing screenings in the schools is background noise levels. Simply put, ambient noise levels cannot be controlled and even small amounts of background noise can have significant masking effects on listeners using standard headphones. This problem becomes more evident in listeners who are very young, inattentive, do not understand how or when they are to respond, or simply

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refuse to respond. Additionally, there are better screening procedures, namely objective measures, available which are used in other populations routinely and effectively.

It is not uncommon for the personnel who conduct the hearing screenings in the schools not to be an audiologist. The ASHA recommendation is that they are properly trained by an audiologist. Although conducting hearing screenings does not appear to be a difficult or complicated task on the surface, it does require certain skills and caution in order to obtain accurate and reliable results. Any subjective assessment requires a certain amount of judgment from the examiner in regards to the administration of the measure, as well as the interpretation of the measure. Previous studies have been cited that point out the potential draw backs of pure tone screening in the schools, and recommendations for objective testing in young children (Allen et al., 2004; Katz, 2002; McClure, 2010; Mundy, 2001).

The current study was conducted to specifically observe the reactions of DPOAE and pure tone screenings to background noise. DPOAEs were chosen because they are an objective measure of peripheral auditory function that when recorded with inserts, are somewhat resistant to the effects of background noise. Inserts as opposed to headphones provide a certain amount of attenuation allowing for more accurate results to be obtained. The DPOAE screening high pass rates may largely be due to the transducer used. The current study was designed to compare commonly used screening measures used in their traditional manner. Differences between transducers should be compared in future studies.

Distortion product otoacoustic emissions are routinely used in newborn infant hearing screening programs, and require no more expertise to collect than pure tone

screening data. Cafeteria noise was chosen as the background noise due to its similar

frequency bandwidth to noise that occurs in schools, as well as the lack of commercial

background noise that is representative of an elementary school. The examiner concedes

that the two measures observed are representative of different frequency regions (pure

tone screenings were recorded at 500, 1000, 2000, and 4000 Hz, and DPOAEs were

recorded at 3000, 4000, and 5000 Hz) and therefore the reported results are not intended

to be interpreted as a justification to substitute one screening for the other. However, the

results of the current study are intended to point out that DPOAEs yielded more accurate

screening results at higher noise levels than pure tones recorded in the traditional manner;

and they are used as an indicator of hearing status in populations that are unable to

respond behaviorally.

In young adults with known normal hearing status, DPOAE screenings were

reliably recorded at background noise levels that reached 60 dB SPL, with only two

participants out of 20 referred as "fail". Conversely, 14 participants "failed" the pure

tone screening at the same level. At 50 dB SPL of background noise, all 20 participants

passed the DPOAE screening as opposed to only 16 with the pure tone screening. That is

a 20% false positive rate at 50 dB SPL, a level that has been reported during school

hearing screenings (Knecht et al., 2002; McClure, 2010).

The results of the present study are intended to demonstrate the reliability of a

commonly used objective measure in the presence of background noise levels which

yield pure tone screenings unreliable. The sole use of DPOAEs as a hearing screening

measure in the schools for young children is not being recommended; as DPOAEs are a

test of peripheral auditory function while pure tone behavioral results are a true test of

hearing. However, results from this study clearly show that at the very least should be examined in conjunction with other objective measures and compared to pure tone screening results. Future studies should include more balanced distribution of gender, incorporation of TEOAEs and middle ear screeners, as well as young children in the sound room to determine what the potential limits are in terms of accurate results in the presence of noise. To administer the current study on children rather than adults, it would be predicted that DPOAEs would remain the same if not increase in pass rates considering emissions amplitudes are higher in children. Pure tone pass rates would be expected to decrease considering the already discussed problems that coincide with behavioral testing in children.

APPENDIX A

Human Subjects Consent Form

HUMAN SUBJECTS CONSENT FORM

> **The following is a brief summary of the project in which you are asked to participate. Please read this information before signing the statement below.**

TITLE OF PROJECT: Effects of Background Noise on Distortion Product Otoacoustic Emissions and Pure Tone Thresholds

PURPOSE OF STUDY/PROJECT: To determine the effect, if any, of background noise on distortion product otoacoustic emissions (DPOAEs) and pure tone thresholds.

PROCEDURE: If you agree to participate in this study, you will have your hearing tested and listen to various levels of background noise while audiometric measures are obtained. Audiometric measures include a DPOAE screening and pure tone threshold testing. This consists of placing insert earphones and headphones on both ears. You will be asked to sit quietly while your hearing is screened with insert earphones and asked to respond, by raising your hand, to pure tone stimuli using headphones while background noise is present.

INSTRUMENTS AND MEASURES TO INSURE PROTECTION OF CONFIDENTIALITY/ANONYMITY: Your identity will not appear on any of the forms used in the experiment or analysis of the data. Only numerical data such as averages will be used in the presentation of results.

RISKS/ALTERNATIVE TREATMENTS: There are no known risks associated with these procedures and participation is voluntary, all information regarding the study will be reviewed and signed during informed consent procedures. These procedures do not vary from routine audiometric measures. The experimental aspect of the study consists of evaluating the effect of background noise on clinical audiometric measures.

BENEFITS/COMPENSATION: free hearing evaluation

I, _____, attest with my signature that I have read and understood the following description of the study, "Effects of Background Noise on Distortion Product Otoacoustic Emissions and Pure Tone Thresholds ", and its purposes and methods. I understand that my participation in this research is strictly voluntary and my participation or refusal to participate in this study will not affect my relationship with Louisiana Tech University or my grades in any way. Furthermore, I understand that I may withdraw at any time or refuse to answer any questions without penalty. Upon completion of the study, I understand that the results will be freely available to me upon request. I understand that the results of my survey will be confidential, accessible only to the principal investigators, myself, or a legally appointed representative. I have not been requested to waive nor do I waive any of my rights related to participating in this study.

_____   _____
Signature of Participant or Guardian   Date

CONTACT INFORMATION:The principal experimenters listed below may be reached to answer questions about the research, subjects' rights, or related matters.
Steven G. Madix, Ph.D, Department of Speech, 216 Robinson Hall, 318-257-4764
Matthew D. Bryan, Au.D., Department of Speech, 214-A Robinson Hall, 318-257-4764

Members of the Human Use Committee of Louisiana Tech University may also be contacted if a problem cannot be discussed with the experimenters:
Dr. Les Guice (257-3056)   Dr. Mary M. Livingston (257-2292 or 257-4315)

APPENDIX B

Audiologic Case History

LOUISIANA TECH UNIVERISTY SPEECH AND HEARING CENTER

DEPARTMENT OF SPEECH
LOUISIANA TECH UNIVERSITY
RUSTON, LOUISIANA 71272

AUDIOLOGY CASE HISTORY: ADULT

PURPOSE OF TODAY'S VISIT: _____

_____

PREVIOUS HEARING TEST ELSEWHERE:_____

_____

EVERYDAY LISTENING ENVIRONMENTS:_____

_____

_____

HEARING DIFFICULTY: Onset_____   Progression_____

_____

       Cause_____   Other_____

DESCRIPTION OF HEARING PROBLEM: _____

_____

_____

Phone_____   Individuals_____   T.V. Radio_____
Groups_____   Church_____   School_____
Home_____   Quiet_____   Localization_____
Work_____   Noise_____   Movies_____

Ear Aches
RE   LE   Number _____ Duration_____ Treatment_____ Last
Occurrence_____

Surgery T&A_____ Mastoidectomy _____Stapes Mobilization_____

Myringotomy_____ Fenestration_____ Tympanoplasty _____Other__

MEDICATIONS:_____

_____

TINNITUS: RE LE   Description_____ Frequency _____Duration

_____

VERTIGO: Description_____ Duration_____ Frequency_____
Nausea_____
Hearing Change_____ Gait Disturbance _____
Precipitating Factors_____
Related to Head Movement: Yes No   Rising/Standing Yes No
Spinning _____

SERIOUS ILLNESSES/HOSPITALIZATION:_____

_____

FAMILIAL HEARING LOSS: NONE_____

_____   Relation to Client_____Age of Onset_____Etiology.

_____

TRAUMA Noise Exposure _____ Type of Noise_____

_____   Number of Hours_____ Protection Used_____

_____   Head Injury/accident _____

HEARING AID USE OR TRIAL
RE   LE   Hearing Aid Type_____ Results _____

_____   Hearing Aid Usage: Full-Time_____ Part-time_____

_____

PREVIOUS AURAL REHABILITION: When _____ Where _____
Duration _____
Purpose _____

_____
Outcome _____

_____

EXPECTED OUTCOMES OF HEARING EVALUATION: _____
_____

_____

Observations _____

_____

_____   _____
Graduate Clinician   Supervisor

                                                    _____
_____
                                                    Date

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