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Value of Otoacoustic Emissions Testing in Pre-school Hearing Screenings: A Literature Review

Paige Stabrawa
pastabr@ilstu.edu

Scott E. Seeman PhD
Illinois State University

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Capstone Project Submitted by:

Paige Stabrawa, B.S.

Advisor:

Scott Seeman, Ph.D., CCC-A

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Abstract

Unidentified hearing loss in children can have a potential effect on their speech and language, educational, cognitive, and social development. The goal of early detection is to minimize the effects of hearing loss through the appropriate referral for diagnosis and treatment. Hearing screenings throughout the preschool and school-age years are vital for the detection of a late-onset, late identified, or acquired hearing loss. Three influential organizations known as The American Academy of Audiology (AAA), The American Speech-Language-Hearing Association (ASHA), and The National Center for Hearing Assessment and Management (NCHAM), have considered behavioral pure tone screening as the “gold standard” for hearing screening protocol across a range of age groups. Although ideally this gold standard would be implemented in all cases, there may be some instances in which the recommended protocol is not appropriate. Performing a pure tone hearing screening may not be plausible for large groups of children, or those who are not capable of conditioning to the task. In these cases, the use of Otoacoustic Emissions (OAEs) has been suggested as an alternative. The aim of this literature review is to discuss the purpose of preschool and school-age hearing screenings, which screening tools are effective in identifying hearing loss in children, and what the appropriate protocol should be for those screening tools. If OAEs were to be substituted for pure tone screenings, the selection of the pass/fail criteria and specific protocol should maximize the number of children being correctly identified with a hearing loss.

Introduction

The purpose of performing early childhood hearing screenings is to provide a quick and cost-effective way to identify those who are at risk of hearing loss (Hall, 2017). Hearing loss is one of the most common developmental disorders identifiable at birth, with increasing prevalence throughout school-age children. According to Grote (2000), universal newborn hearing screening programs would not detect 10-20% of cases of children with permanent childhood hearing loss detected later in life. Recent research has confirmed that the prevalence of hearing loss almost doubles from the neonatal years to the early school years. Fortnum et al. (2001) found that 50 to 90% more children who initially passed their newborn hearing screening were found to later acquire a permanent childhood hearing loss by the age of 9 years.

Performing hearing screenings during the preschool years is just as critical as screening newborn infants. The preschool years are an important time for speech and language acquisition, social development, development of emotional and psychosocial status, and early pre-academic skills. There are many negative impacts an unidentified hearing loss can have on a child's education. Hearing loss can interfere with the reception of speech, especially in a noisy and reverberant classroom environment. Children with hearing loss often present symptoms that are similar to other attention deficit disorders, learning disabilities, or language processing problems. Behaviors can often include difficulty with reading, spoken, and/or written language, difficulty attending to spoken or other auditory information, frequently asking for repetitions, and appearing isolated from their peers. In a survey of parents whose children were identified with hearing loss, 3 out of 4 parents reported that their children experienced problems related to their hearing loss. The most commonly reported problems included impaired social skills, impacted grades in school, language development, and impacted emotional health (Kochkin et al., 2007). Even a mild hearing loss can have a potential impact on a child's education, impede cognitive growth, and can even delay social skills. Children with a minimal or mild hearing loss have demonstrated lower educational test performance, greater dysfunction in terms of behavior, stress, and self-esteem. It has been reported children with a minimal hearing loss were at higher risk for academic struggles, with 37% of children having to repeat a grade. These children are also four times more likely to have speech-language deficits and difficulty communicating (AAA, 2011). This population of children with a mild hearing loss may initially pass their newborn hearing screenings, and many do not follow up for rescreening. Hearing loss can also be progressive, meaning there is development of a hearing loss over time, or late onset during infancy or childhood. Screening preschool aged children can detect a progressive or delayed-onset hearing loss that was not present or detected during infancy.

Childhood hearing screenings can be used to detect a hearing loss in those children who were lost to follow-up after their newborn hearing screening, those who developed a delayed or late-onset hearing loss during the preschool years, and to identify those children at risk for speech/language or academic-related delays in school. Early identification of hearing loss by age 6 months combined with early intervention services is associated with speech and language development that is at or near the typical rate of development (AAA, 2011). Proper identification and appropriate management of hearing loss during the early childhood years can have broad effects and potential impact on a child's education, cognitive and social development, and speech/language skills. It has been shown that earlier identification of hearing loss can lead to a greater likelihood of preventing or reducing the negative effects that can result from the loss (AHSA, 1997). One goal of early detection through hearing screenings is to maximize the perception of speech, which could result in the achievement of linguistic-based skills and academic success throughout the early school years.

There are three primary organizations that support the implementation of childhood hearing screenings. The American Academy of Audiology (AAA), The American Speech-Language-Hearing Association (ASHA), and The National Center for Hearing Assessment and Management (NCHAM) have developed thorough guidelines and recommended protocols for infant, preschool, and early childhood hearing screenings. Typical recommended protocol includes otoscopy, tympanometry, and a pure tone hearing screening using conditioned play audiometry for test frequencies 1000, 2000, and 4000 Hz at an intensity level of 20 dB HL. Many professionals, including Hall (2012) have recently been questioning the effectiveness and practicality of pure tone hearing screenings. Pure-tone hearing screening results in young children can be confounded by factors such as skill and experience of the tester, the cognitive abilities of the child, and the amount of noise in the test setting. It has been demonstrated that a high proportion of preschool children are not able to be reliably screened with pure-tone screenings (Hall, 2012). The use of Otoacoustic Emissions (OAEs) in early childhood hearing screenings can provide a quick and objective measure of auditory function. It is important to determine the appropriate screening protocol, including the criteria used to define pass/refer outcomes, and the sensitivity and specificity of the screening tool when evaluating which screening method is the most effective.

The primary aim of this literature review is to discuss the purpose of early childhood hearing screenings, and the use of OAEs while screening this population. The recommended protocols for AAA, ASHA, and NCHAM will be discussed for the preschool and school-aged populations. The use of pure-tone hearing screenings and OAEs will be evaluated in terms of the sensitivity and specificity of each. The three topics we would like to address are: what screening tools should be included in early childhood hearing screenings, what information can OAEs provide during screenings, and what protocol should be used for OAEs. This discussion will include both Distortion Product OAEs (DPOAEs) and Transient Evoked OAEs (TEOAEs).

Methodology

Database searches using key search terms (Table 1) revealed approximately 140 related papers and books. Roughly 70 literature sources were selected for review. Of the 70 articles and books reviewed, 33 were selected as appropriate resources for the purpose of this literature review. We evaluated each of the resources in terms of inclusion and exclusion criteria (Table 2) to determine which resources were appropriate.

Table 1: Database search including search terms that were used and number of articles chosen for review.

Database Used	Search Terms
PubMed	Preschool hearing screening; otoacoustic emissions; screening protocols; speech and language delays; hearing loss in children
Milner Library Database	Preschool hearing screenings; pure tone hearing screenings; otoacoustic emissions; newborn hearing screenings

Google Scholar	Preschool hearing screenings; distortion product otoacoustic emissions; transient evoked otoacoustic emissions

Table 2: Inclusion and Exclusion criteria for choosing appropriate resources.

Inclusion Criteria	Exclusion Criteria
Published between years 1980 to present	Published before the year 1980
Studies involving children ages birth to 18	Studies involving adults ages 19 and older
Studies examining otoacoustic emissions in hearing screenings	Studies excluding otoacoustic emissions in hearing screenings
Studies examining pure tone hearing screenings in school age children	Studies examining hearing screenings in healthcare settings
Studies that included normative data	Studies that did not include normative data

Hearing Screening Protocols

When a hearing loss is suspected, a full diagnostic audiological evaluation should be performed to determine the type and severity of the hearing loss. However, this is not realistic for all individuals with hearing loss. Universal newborn hearing screenings (UNHS) are typically performed after birth before the infant is discharged from the hospital. In some cases, an infant may not pass the hearing screening, and it is recommended that the infant receive a diagnostic evaluation to determine the reason for the outcome of the screening. There is a widespread and serious issue of loss to follow-up (LTFU) where parents do not follow-through with these recommendations. The Centers for Disease Control and Prevention (CDC) estimated a LTFU rate of 32.1% for diagnostic assessment in 2013 (Hall, 2016). This estimate provides further support for the need for preschool and school-aged hearing screenings especially to identify these infants who failed their newborn hearing screening yet did not receive a full diagnostic audiological assessment. The occurrence of delayed onset hearing loss and LTFU, along with the high costs of not identifying and treating hearing loss underscores the imperative of screening all children.

Otoacoustic Emissions

OAEs are low amplitude signals that are reflected from the inner ear back to the ear canal that are generated by the outer hair cells within the cochlea. These are technically not a test of hearing, but rather a physiological measure of outer hair cell function and the integrity of cochlear function. In a healthy ear, the stimuli generated by the screening are transmitted through the middle ear to reach the inner ear, where the outer hair cells of the cochlea produce a response, or emission. These emissions are picked up by a microphone in the probe and analyzed, producing an automated pass or fail response. Data is collected and averaged in terms of the reproducibility of the emission, as well as the difference value between the emission and the noise floor (NF) amplitude. The presence of OAEs indicates that the pre-neural cochlear receptor mechanism, as well as the middle ear mechanism, are able to respond to sound in a normal way. OAEs are frequency specific and frequency selective, meaning they give information about different parts of the cochlea simultaneously (Kemp et al., 1990). TEOAEs are generated when clicks or tone bursts are used to stimulate the ear. The use of a click stimulus has been found to stimulate a majority of the basilar membrane. DPOAEs are generated by two pure tones, or primaries, with f1 being lower in frequency primary and f2 being higher. OAEs are said to be measurable in ears with normal hearing sensitivity, and in ears with abnormal hearing sensitivity of up to 30 to 40 dB HL, providing no conductive pathology is present (AAA, 2011). The response obtained by OAEs is dependent on the integrity of the outer hair cells and normal middle ear function. OAEs have been found to be sensitive to both sensorineural and conductive hearing losses, so there is potential for OAEs to be an effective screening tool for the school-aged population.

DPOAEs

DPOAEs are recorded by using two pure tone signals, known as the primary tones, to stimulate the cochlea. In response to the simultaneous tones, the cochlea will generate additional tones at frequencies that are related to the stimulus tones. The theory behind DPOAEs is that there are two pure tones, primary tone f1 being low frequency and primary tone f2 being higher in frequency. When these two pure tones are presented to the human ear at the same time, the distortion product emission will occur at 2f1-f2. Unlike TEOAEs, DPOAE responses are recorded during cochlear activation. DPOAEs are typically recorded from 1000 to 6000 Hz, with some reaching up to 10,000 Hz depending on the manufacturer. Screening results will produce a value for the difference between the distortion product emission and the noise floor amplitudes, represented as DP-NF. For the emission to be present, the DP-NF value must often match a minimum value determined by the manufacturer. An acceptable recording is typically 5 to 6 dB above the noise floor. DPOAEs are expected to be present if all pure tone thresholds are better than 25 dB HL, and absent if the pure tone thresholds are worse than 40 dB (Ramos et al., 2013). Hall (2000) recommends DPOAE screenings are most efficient for frequencies 2000 to 5000 Hz in order to avoid contamination from excessive noise levels in the lower frequencies (1000 Hz and below).

TEOAEs

TEOAEs are evoked by using a click stimulus and are recorded during the silent intervals between the brief, transient clicks which activate a wide portion of the basilar membrane. The typical latencies for TEOAEs range from 5 to 15 milliseconds. TEOAEs may offer a quick and objective way to evaluate the function of the peripheral auditory system for frequencies 1000 through 4000 Hz by looking for the presence or absence of a response. TEOAEs have been found to be sensitive to the presence of hearing loss, but do not give information related to the magnitude of the loss. TEOAEs are typically present in those who have normal cochlear function and a healthy middle ear. Screening results will produce a value to represent the dB difference between the transient evoked emission and the noise floor amplitudes, which is represented as TE-NF. An acceptable TEOAE response is typically 3 to 6 dB above the noise floor and is reproducible. TEOAEs are absent when the hearing thresholds are equal to or worse than 30 dB HL for frequencies 1000 through 4000 Hz (Taylor & Brooks, 2000). Research by Prieve et al. (1993) showed that once the hearing thresholds exceed 20 dB HL, the amplitude of the TEOAE emissions will decrease rapidly. Robinette et al. (2007) found that when pure-tone hearing thresholds are better than 20 dB HL, TEOAE responses are present 99% of the time, and when thresholds are greater than 40 dB TEOAE responses are always absent.

Neonatal and Infant Population

It is recommended by the Joint Committee on Infant Hearing (JCIH) that all infants receive a hearing screening no later than 1 month of age. Since 2012, 44 states have legislation involving newborn hearing screenings, with 28 of those states requiring a hearing screening on every infant before they are discharged from the hospital. The two types of technology used to screen newborns are OAEs and auditory brainstem response (ABR). Both are automated screenings that provide a pass or fail result that does not require interpretation. With the OAE screening, the infants will receive a refer result if there is any middle ear fluid/dysfunction, or blockage. With the automated ABR screening, a click sound is used to stimulate an electrical response that is picked up by electrodes that are placed on the infant's head. The ABR screening is analyzed and recorded on the computer software as a pass or refer result. OAE and ABR screenings are found to be highly reliable and effective tools to screen newborns in an objective manner that do not require any response from the infant. Some hospital screening programs implement a combined protocol using both OAEs and ABR to improve the overall effectiveness of the screening. Multiple studies have found that the combined screening protocol led to a refer rate of <2% and a false-positive rate of <2.0% (Hall et al., 2004). This low refer rate results in the need for fewer diagnostic follow-up assessments. Other hospitals implement a two-stage protocol for newborn hearing screenings. The infants are first screened using OAEs, and if they receive a pass result, no additional testing is performed. If the infant fails the OAE screening, they are next screened with an automated ABR protocol. Those infants who pass the automated ABR are at low risk for hearing loss, and do not require further assessment. Infants that receive a fail result are referred for diagnostic testing to determine if a hearing loss is present. The Early Hearing Detection & Intervention (EHDI) program collects data from newborn hearing screenings to determine which infants require follow-up testing or early intervention services. This is to ensure those infants receive their follow- up services and diagnosis no later than 3 months so they can receive individualized care and early intervention.

OAE screenings should be conducted in a quiet environment, with the infant resting quietly. The stimulus level is calibrated in each ear based on each manufacturer's specifications. Once the stimulus level requirements are met, the OAE screening begins and will end once stopping criteria is met. TEOAE screenings are performed using a high-level click, typically around 80 dB SPL, and a minimum of 50 averages should be collected before the screening is stopped. The recommended SNR (TE-NF) for TEOAE test screenings is 6 dB, with 70% reproducibility. DPOAEs are often recorded using mid-level stimuli (f1 primary = 65 dB SPL, f2 primary = 55 dB SPL). The recommended criteria for an appropriate DPOAE recording is a 6 dB SNR (DP-NF) with a minimum absolute DPOAE level of -5 dB SPL (Gorga et al., 1997). DPOAE screenings are typically terminated based on the SNR rather than a number of averages. It is suggested to test infants at least 11 hours after birth to prevent false positives due to vernix and other fluids from the birthing process. If the infant fails the initial OAE screening, they should be tested once more before discharge to confirm the results (ASHA, 1997).

Preschool Children

This group includes children ages 3 to 5 years of age. The goal of screening for this age group is to identify the possibility of a permanent hearing loss that could interfere with the development of speech-language/communication skills, social development, or impede future academic performance. The procedure for preschool hearing screenings is a pass-refer technique to determine children who require diagnostic audiologic evaluation or other assessments.

According to ASHA (1997) a hearing impairment for this age group is either unilateral or bilateral hearing loss greater than 20 dB HL from frequencies 1000 through 4000 Hz. The first part of the screening process is a visual inspection and tympanometry with a low frequency probe tone. If the child is able to reliably participate in the task, conditioned play audiometry (CPA) should be completed under headphones for frequencies 1000, 2000 and 4000 Hz at 20 dB HL. Pass criteria according to ASHA (1997) is if the child responds correctly 2 out of 3 times at the specified decibel level at each frequency, in each ear. Refer criteria is if a child does not respond 2 out of 3 times at the specified decibel level at any frequency in either ear, or if the child could not condition to the task. If the child is not able to condition and complete CPA, ASHA recommends completing visual reinforcement audiometry (VRA) in sound field. AAA (2011) follows the guidelines recommended by ASHA closely, stating that children chronologically and developmentally 3 years of age or older should undergo a pure tone screening. When discussing the use of OAEs in screening, AAA (2011) recommends the use of OAEs only for children who are younger than the age of 3 years, or those where a pure tone screening is not developmentally appropriate given the child’s cognitive and skill levels. Recently, NCHAM a well as J. Hall have investigated the use of OAEs in screening younger populations rather than completing a pure tone screening. Hall (2017) recommends including OAEs in screening protocols as a quick and reliable way to screen a large number of children in a short amount of time.

The AuDX Bio-Logic system by Natus Medical is a common screening tool used by health care professionals and audiologists to complete TEOAE and DPOAE hearing screenings. This system comes preprogrammed with DPOAE or TEOAE protocol, including collection parameters and pass/refer criteria. TEOAE screening protocol tests frequencies 1286-3536 Hz at an intensity of 80 dB pe SPL. For the response to be acceptable, the TE amplitude needs to be 0 dB SPL or greater, with TE-NF being 6 dB or greater. The NF should be -10 dB SPL or lower to be an acceptable response. TEOAEs must have a reproducibility of 70% or greater. DPOAE screening protocol tests frequencies 2000-5000 Hz, with f1= 65 dB SPL and f2= 55 dB SPL. The DP frequency is represented by 2F1-F2, with a noise calculation average amplitude of 100 Hz above and 100 Hz below the DP frequency. For the response to be acceptable, the minimum DP amplitude must be -10 dB SPL with a minimum DP-NF amplitude of 8 dB and noise amplitude of -17 dB SPL. Children screened with these protocols will receive a pass result when three out of four of the test frequencies meet the passing response conditions defined above (Bio-Logic, 2002). The pass/refer criteria used by the AuDX Bio-Logic system is taken from data published by Gorga et al. (1997). These are often described as the “Boystown norms”. They also include another set of norms known as the “Vanderbilt norms”.

ECHO has a recommended OAE screening and follow-up protocol for preschool and school-aged hearing screenings. The child will undergo an initial OAE screening. If the child passes the initial screening, the screening is complete and the child receives a passing result. If the child fails the initial screening, they will undergo an OAE rescreening two weeks following the initial screen. If they pass the second OAE screening, they receive a passing result and the screening is complete. If the child fails the first and second screening, they must be referred to a physician to receive medical clearance. After medical clearance, a third OAE screening should be conducted. If the child fails the third OAE screening, they should be referred to an audiologist for a full diagnostic evaluation.

School-Age Children

This group includes children aged 5 years through 18 years. An unidentified hearing loss throughout these years can lead to many negative effects on the child's education, development, and communication skills. ASHA's school-aged screening protocol recommends annual screenings for all children 3 years of age or older, in any public or private educational program or licensed child care facility. AAA (2011) recommends screening children at ages 4, 5, 6, 8, and 10 years of age to detect those children not identified by newborn hearing screening, and those with a progressive or late-onset hearing loss. It was found that around 90% of new hearing losses will be identified if screenings are complete for preschool children through grade 3. For this age group, ASHA (1997) recommends completing CPA for the younger children, and a conventional audiometry screening for the older children who are capable of raising their hands in response to the tones. The screening should be conducted at 1000, 2000 and 4000 Hz at a presentation level of 20 dB HL. If the child fails the screening in either ear, they should be rescreened in 14 to 21 days. If the child continues to fail the rescreening, they should be referred for further evaluation by an audiologist. According to Early Childhood Hearing Outreach (ECHO), 20% of children ages 3 to 5 years of age are unable to complete pure tone hearing screenings due to the complexity of the task. For children whose age, cognitive levels, or language skills may affect the results of a pure tone hearing screening, OAEs may be an appropriate substitute. The pass/fail criteria for DPOAE and TEOAE screenings are the same as the criteria used in the Preschool Children section.

The Use of OAEs in Early Childhood Hearing Screenings

When selecting a screening tool for young children, there are many factors to consider. The age and developmental level of the child, as well as their ability to participate in the screening, should be considered. When used to screen preschool and early childhood aged children, OAEs can provide a quick and efficient way to measure auditory function. OAEs are an objective measurement, meaning they are not influenced by the many listener variables that young children may present. There is no behavioral response needed from the child, so cognitive level, language skills, and age do not confound the results. OAEs are not influenced by subjective interpretations, which makes them highly reproducible and more precise than pure tone audiometry. When comparing OAE screenings to pure tone screenings, pure tone screenings require a higher level of cognitive functioning for the child to appropriately respond to the task. This is problematic for the pediatric population, and children who are developmentally delayed and unable to provide the correct response. OAEs are useful for children who are too young to test, or those where a pure tone hearing screening is not appropriate for their developmental and cognitive skills. Typically, an audiologist is not present during school screenings, and the screenings are carried out by volunteers, nurses, or other trained personnel. OAE devices are easy to use and portable, with the outcome being presented on a display with a clear pass or fail result. This reduces the risk of misinterpretation of results. OAE screenings are quick to administer, with a time of about 30 seconds to 1 minute per ear. Since OAE screenings have been found to take significantly less time to complete than pure tone screenings, personnel would be able to screen more children in a given day.

Abnormal OAE results are likely to be found in children with cochlear hearing loss involving outer hair cell dysfunction, or in those with middle ear dysfunction. OAE screenings are likely to refer ears with impaired cochlear function, which is associated with permanent hearing loss, and in ears with a middle ear disorder such as otitis media or effusion that can interfere with the child's hearing. The detection of and valid measurement of OAEs is significantly dependent on the status of the middle ear. Studies have shown that approximately 90% of all children experience some type of otitis media between six months and four years of age. Further studies have shown that approximately 50-60% of preschool children experienced a middle ear pathology during the school year, and 25% of school-aged children had a middle ear pathology during the year. Acute otitis media (AOM), or otitis media with effusion (OME) can serve as a barrier to sounds reaching the tympanic membrane and can cause a mild fluctuating hearing loss. It is important to identify children with AOM or OME at an early age so that appropriate referrals and intervention plans can be made. TEOAEs have been found to be sensitive to middle ear disorders and negative middle ear pressure while screening for hearing loss. These complications can have an effect on the emission and prevent a reproducible response from being obtained. Since TEOAEs can show the presence or absence of a hearing loss and are affected by middle ear disorders, TEOAEs could be an ideal screening tool for preschool and school-aged children (Taylor & Brooks, 2000).

Sensitivity and Specificity of OAEs

The purpose of a hearing screening is to determine which children are most likely to have hearing loss and require further evaluation, and which children do not have the disorder. The validity of the screening protocol refers to the degree to which the results of the screening are consistent with the actual presence or absence of the disorder. Sensitivity and specificity are two ways that identify the validity of the screening. The sensitivity of the screening tool refers to the accuracy in correctly identifying children who have hearing loss, while the specificity refers to the accuracy in correctly identifying children who do not have hearing loss. An effective screening protocol should correctly identify 90-95% of children who have existing hearing loss, and should fail no more than 5-10% of children who have normal hearing (AAA, 2011), meaning that false negatives and false positives are minimal.

Although pure tone hearing screenings have been deemed the “gold standard”, several studies have found poor sensitivity and specificity rates while screening school-aged children. One study investigated the use of pure tone hearing screenings for identifying children with minimal hearing loss. They found that when screening children at 20 dB HL the sensitivity was only 61.5%, and 35.4% while screening at 25 dB HL (Dodd-Murphy, Murphy & Bess, 2003). A similar study found poor specificity (50%) while screening at 20 dB HL, and 78% specificity while screening at 25 dB HL (Dodd-Murphy & Murphy, 2006). This raised concern for missing children with mild hearing loss, and the authors concluded that pure tone hearing screenings have unacceptable sensitivity while screening for this population. Roeser & Northern (1981) believed that by decreasing the intensity level of the screening, the sensitivity of the test could be increased. However, many screening programs are using a higher screening intensity of 25 dB HL due to the noisy environments that screenings often take place in. A study completed by

FitzZaland & Zink (1984) found that out of the 115 students that initially failed the hearing screening, 70% of those children actually had clinically established thresholds better than the screening levels when screened in a sound-treated room. Screening protocols require a specific pass/fail criterion that is applied to the results. Changing the criteria can have an effect on the number of children who pass the screening or require a rescreen. With pure tone screenings, some professionals believe it is preferable to have a single failure at any one frequency in either ear result in a failure of the screening. This strict criterion could maximize the number of children with previously existing or newly identified hearing loss. If the criterion requires failure at more than one frequency in either or both ears, the number of children who require a rescreen will decrease. This may increase the number of false negatives, meaning more children who have hearing loss may be missed while increasing the number of children who pass the screening. The number of presentations at each frequency can also have an effect on the validity of the screening. It can be common that children fail to respond to one pure tone presentation while conducting the screening. This can be due to the levels of ambient noise, limited attention spans, or if the intensity of the pure tone is close to their threshold (AAA, 2011). However, presenting a pure tone several times can lead to false positive responses that will result in the child passing the screening. Screening professionals must be cautious of the number of presentations to reduce the number of false positives

TEOAEs can be recorded in some ears with hearing sensitivity in the mild range (20-30 dB), and DPOAEs can be recorded in some ears with hearing sensitivity in the mild to moderate range (20-50 dB HL) (AAA, 2011). The pass/fail criteria for OAEs must be chosen carefully to maximize the sensitivity and specificity. In a study of children ranging 6 months to 15 years, OAE screenings were found to be highly sensitive (100%) and reasonably specific (91%) (Richardson et al., 1998). In a similar large-scale OAE screening study, results yielded 100% sensitivity and 95% specificity (White et al., 1994). Vohr et al. (1998) found that TEOAE screenings yielded 95% sensitivity and 90% specificity during an initial screening. A second screening was completed for children with confirmed SNHL after a diagnostic evaluation, and the screening yielded 95% sensitivity and 87% specificity. In a study by Yin et al. (2009), 91% of preschool children screened with TEOAEs received a passing score. The TEOAE screening was then followed by a pure tone screening. It was found that not one child who initially passed the OAE screening went on to fail the pure tone screening, meaning there were zero false-negatives. Only eight preschool children failed the OAE screening then passed the pure tone screening. The study yielded 94% specificity and a 100% negative predictive value, indicating that any child who passed the TEOAE screening had a very low likelihood of a having hearing loss. Given that TEOAEs are affected by both hearing loss and middle-ear disorders, school screening programs could benefit from using TEOAEs as a screening tool (Taylor & Brooks, 2000).

When compared to pure tone hearing screenings, sensitivity and specificity of TEOAE screenings were found to be 81% and 95%. Out of 152 children ages 3 to 8 years, 81.3% of the ears that failed the pure tone hearing screening also failed the TEOAE screening. The results obtained from this study showed a statistically significant relationship between traditional pure tone hearing screening and TEOAE screening. Authors Taylor & Brooks (2000) concluded that the sensitivity and specificity were acceptable enough to consider substituting TEOAEs for traditional pure tone hearing screenings. In a similar study by Yin et al. (2009), a large group of preschool children were screened with both TEOAEs and a pure tone hearing screening. Results revealed that 93.3% of the children passed both screenings and demonstrated the feasibility and ease of using TEOAEs in substitution of pure tone screenings. The TEOAE screening demonstrated a clinically applicable specificity and negative predictive value, and was also found to be a more cost-effective option. It was concluded that a TEOAE screening may be more appropriate given the developmental stage of young preschool children.

Research has indicated that DPOAEs would be a sufficient screening technique for preschool and school-aged children due to their objectivity, non-invasive procedure, and short screening time. Additionally, it has been found that DPOAEs have improved high-frequency sensitivity and frequency specificity when compared to TEOAEs. However, the need for highly descriptive normative data for school-aged children has not been thoroughly examined. The creation of normative data may lead to the development of appropriate pass/fail criteria for this age group. A study completed by O'Rourke et a. (2002) investigated the implications of using DPOAEs as a screening for 788 school aged-children with a mean age of 6.0 years. Two pure-tones of frequencies f1 and f2 with intensities of 65 dB SPL (L1) and 55 dB SPL (L2) were delivered to each ear to produce a DP-gram. The study revealed that DPOAE results for 6-year-old children in school settings were influenced by ear asymmetry, gender, and history effects. Specifically, right ears typically showed greater signal-to-noise ratios and DP amplitude values than left ears, especially at higher frequencies. It was also found that female school-aged children had higher signal-to-noise ratios and DP amplitudes than males. One theory as to why there is a gender effect is due to differences in the anatomy of the cochlea. School-aged children with a positive history of ear infections demonstrated lower signal-to-noise ratios and

DP amplitude values when compared to children with a negative history. These findings are consistent with research stating that DPOAEs are substantially reduced in the presence of abnormal middle ear status. The use of descriptive normative data could lead to future improvements and the successful use of DPOAE screenings for school-aged children.

Limitations of OAEs

There are some limitations to using OAEs in preschool and early childhood hearing screenings. Richardson et al. (1995) reported two major difficulties while recording OAEs in children. The first is that some older children will not sit and tolerate the test procedure due to the probe being inserted into their ear. The proper selection and placement of the probe tip can reduce the effects of background noise significantly if there is a good acoustic seal. An improper seal can result in portions of the OAE signal to escape the ear canal, which can affect the acceptable noise floor and signal to noise ratio (SNR). The second limitation is there is an unacceptably high number of false positive results, despite the good sensitivity of the test. This low specificity is due to the signal of the OAE being obscured by other noises, such as internal or external noises. This contamination from physiological and ambient noises also leads to the difficulty in recording OAEs at lower test frequencies, often including 1000 Hz and lower. The screening environment should be free from excessive noise and vibration. Conducting OAE screenings in settings with excessive environmental noise levels can have an effect on the detectability of the emission being received from the ear. Excessive ambient noise and background noise levels could prevent screening children at frequencies below 2000 Hz. Physiological sources of noise can also play a role in recording OAEs, such as noises from the patient moving and breathing. Physiological noise can contaminate screening results in the low frequencies, typically 1000 Hz and lower. For these reasons, most screening protocols suggest not testing at 250 and 500 Hz. The results obtained from screenings that were conducted in noisy environments should be interpreted with caution due to the potential for low hit and high false alarm rates (Kreisman et al., 2013). The solution would be to conduct screenings in sound treated rooms or portable test booths. Due to cost, availability and space issues, these solutions are often not implemented.

There are two significant populations that could be missed due to the use of OAE screenings alone. The first population includes children with auditory neuropathy spectrum disorder (ANSD). ANSD is known as an auditory neural hearing loss that occurs when outer hair cell function is normal but neural transmission in the auditory pathway is impaired (Rance, 2005). When tested, children with ANSD will most likely have normal OAEs with variable pure tone audiometric results and significantly poorer speech recognition abilities than expected. It has been found that as many as 10% of children with normal OAEs may have ANSD (Berlin et al., 2003). The use of OAEs alone may not identify this small population of children. The second population is children with slight or mild hearing loss. There is contradicting research regarding whether OAE screenings will detect a mild hearing loss. Gorga et al. (1997) reported that TEOAEs and DPOAEs are measurable in ears with abnormal hearing sensitivity of up to 30-40 dB HL. Since OAEs can be present in ears with mild hearing sensitivity, OAE screenings alone will likely miss cases of educationally significant mild and moderate hearing loss. Therefore, multiple studies have recommended the use of a multistep screening program which includes a two-pronged approach including OAEs and a pure tone screening (AAA, 2011).

A third limitation to implementing OAEs in a school screening program is the lack of a standard pass/fail criteria. There is a need for the establishment of developmental norms and appropriate pass/fail criteria for preschool and school-aged children for both TEOAEs and DPOAEs. Most studies have been found to use a pass criterion of an OAE to noise floor difference of >3 or > 6 dB SPL. The issue found is that there is a reliance of a pass/fail criterion that is based only on the OAE amplitude vs. noise floor levels, without considering the absolute OAE amplitude value. Hall (2016) suggested a simple strategy for increasing sensitivity to differing degrees of hearing loss is to add a second pass/fail criterion involving the absolute amplitude of OAEs. With two pass/fail requirements, a pass outcome would be achieved when the OAE amplitude minus noise floor difference of 6 dB SPL plus the requirement of an absolute OAE amplitude of $\geq$ 0 dB SPL are achieved. It has been found that many children with hearing thresholds of 20 dB HL or less have OAE amplitudes of $\geq$ 0 dB SPL. However, there is always the possibility that a child with normal hearing sensitivity may not meet this criterion. By including a rigorous criterion of $\geq$ 0 dB SPL for OAE amplitude, the sensitivity of OAE screenings may exceed the sensitivity of pure tone screenings in the future. A study completed by Lyons (2004) reported a mean DP-amp range of 6.2 to 8.3 dB SPL with a higher mean for the noise floor than previous studies. Many studies have attempted to establish a fixed SNR criterion for all test frequencies for DPOAEs. This study showed this is not realistic because the optimal criterion for SNR varied across the frequencies. When DPOAEs were compared to pure tone screenings, results indicated low hit rates. This revealed that the use of DPOAEs alone would have missed 32-38% of the children who failed pure tone screenings. This study recommended use of a combined two-pronged protocol instead of DPOAEs alone. Additional research must be completed to develop more efficient hearing screening protocols for preschool and school-aged children.

Discussion

There is the need for a standardized protocol for screening preschool and school-aged children with specific and standardized pass/fail criteria. The current gold standard set by AAA and ASHA is to perform a conditioned play pure tone screening on every child ages 3 and up. Some arguments have been made regarding the practicality of performing a pure tone hearing screening on every child during school screenings. The use of OAEs in hearing screenings has been suggested in place of pure tone hearing screenings due to the quick and objective screening process. OAE screening results are easily recorded and interpreted, and do not require the children to provide an appropriate behavioral response. Although research has shown that DPOAEs and TEOAEs may be effective tools in identifying children with hearing loss, there is no standard pass/fail criteria. This makes it difficult to determine the sensitivity and specificity of OAE screenings since there is no set criteria to use. Until more research is conducted and developmental norms are established, school screening programs may choose to continue using the gold standard and conduct pure tone hearing screenings. However, there may be some cases where it is appropriate to conduct OAE screenings instead of pure tone screenings. For some younger children, a pure tone screening may not be developmentally appropriate given their cognitive skills, age, or language skills. In cases where the child is too young and is not able to provide an accurate and reliable behavioral response, OAEs may be performed. School screenings are typically conducted for multiple grade levels over a day or two, with screening time for each child only being around 4 to 5 minutes. There may be some days where there is a large group of children that needs to be screened quickly, and conducting a pure tone hearing screening may not be practical. When there are too many children that need to be screened, personnel may choose to perform OAE screenings because they are quick and efficient and could allow more children to be screened per day. Typically, an audiologist is not available to conduct hearing screenings. Instead, trained personnel and staff members may be conducting the screenings. Pure tone hearing screenings require that the staff member conditions the child to the task, and results must be interpreted with caution. The staff member must be confident that the child is giving a true behavioral response to the tones being presented, and that they are not responding to visual cues. OAE screeners provide immediate pass/fail results that do not require interpretation from the staff member. OAE screeners may be easier and more efficient to use in cases where an audiologist is not available to interpret pure tone behavioral responses.

A two-step screening approach has been recommended by some authors. ASHA has a recommended two-step protocol using OAEs and tympanometry. The screening will begin with OAEs, and the child will receive a pass or fail result. If the child passes the initial OAE screening, they will receive a passing result and the screening will be complete. If the child does not pass the initial OAE screening, they will be immediately screened with tympanometry. If the child passes the tympanometry screening, they should be screened once more with OAEs. If the child fails the tympanometry screening, they should be rescreened in four weeks with both OAEs and tympanometry. During the rescreen, if the child fails either of the screening tests they should be referred to an audiologist for a full diagnostic evaluation. A study completed by Lyons (2004) found the most effective screening protocol may involve both OAEs and tympanometry. It was recommended that due to a high prevalence of middle ear dysfunction in school aged children, a complete test protocol of both OAEs and tympanometry is essential for identifying children with hearing loss. This protocol may be effective in testing children who are too young and unable to follow directions. Future development of hearing screening protocols may investigate the use of a two-step approach using both OAEs and pure tones. If the child fails the initial OAE screening, they could be screened with pure tones as a follow up. If the child fails the second step of pure tones, they should be referred for an audiologic evaluation.

Conclusion

Newborn hearing screenings are the first step to detecting a hearing loss in infants. However, some hearing losses are not detected whether due to loss to follow-up or a late-onset hearing loss. Performing preschool and school-aged hearing screenings are important for identifying children who may have developed hearing loss from birth or during childhood. The current hearing screening protocol follows the gold standard set by ASHA and AAA. It is important to establish strict pass/fail criteria for OAE screenings to maximize sensitivity and specificity of the test. It has been concluded that OAEs may be an appropriate screening tool in some cases because they provide a quick and objective way to test a child's hearing. DPOAEs and TEOAEs have been shown to be sensitive to middle ear dysfunction and cochlear hearing loss across a range of frequencies. However, it has also been suggested to use a two-step approach involving OAEs with tympanometry or pure tones to further increase the sensitivity. Future research should focus on establishing a set of developmental norms for preschool and school-aged children for conducting DPOAE or TEOAE hearing screenings. Until this further research is completed and norms are established, professionals may still choose to follow the current gold standard to complete preschool and school-aged hearing screenings.

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