

## Comparison of Pure-Tone and Distortion Product Otoacoustic Emission Screenings in School-Age Children

**Donna Fisher Smiley, Ph.D.**

Arkansas Children's Hospital, Little Rock, AR

**Kathy Shapley, Ph.D.**

University of Arkansas at Little Rock/ University of Arkansas for Medical Sciences

**Darby Eckl, Au.D.**

Arkansas Children's Hospital, Little Rock, AR\*

**Nannette Nicholson, Ph.D.**

University of Arkansas at Little Rock/ University of Arkansas for Medical Sciences

\*This author was an Au.D. student at the University of Arkansas for Medical Sciences, Little Rock, AR when she participated in this project

**The purpose of this study was to compare the outcome of a distortion product otoacoustic emission (DPOAE) screening to the outcome of a pure-tone hearing screening for school-age children. Participants included 565 children in kindergarten through second grade in central Arkansas. Data were analyzed on a total of 547 participants. A McNemar Chi-square test [ $\chi^2(1, N=547) = 2.06; p=.151$ ] revealed there was not a statistically significant difference between the rates of identification for the DPOAE and pure-tone screenings. Four hundred and seven (74%) participants had the same outcome on both screening measures, either pass (N=369) or refer (N=38). However, 140 (26%) of the participants were classified as "pass" or "refer" by one of the screening measures, but not both. Although the majority of these children (74%) obtained the same results on both screening measures, a relatively large percentage (26%) had differing results. Therefore, it was unclear whether those children had hearing sensitivity that was of concern, or whether one or both of those screening measures would have indicated a large over-referral rate. The analyses revealed these screening measures are not interchangeable, and the two may offer unique contributions to the identification of individuals who should be referred for further diagnostic testing. Without a follow-up diagnostic test, the exact relationship between the two screening measures could not be determined. Further testing using a complete diagnostic evaluation (i.e., otoscopy, immittance measures, air- and bone-conduction thresholds, and speech recognition thresholds) should be conducted to identify cases that are false positives and false negatives, something a screening measure cannot do.**

### Introduction

Prelingual and early childhood hearing loss can have an adverse affect on the developing auditory nervous system (Dornan, 2009) and may lead to delays in socio-emotional, cognitive, and academic development (American Speech-Language-Hearing Association [ASHA], 1997; Bess, Dodd-Murphy, & Parker, 1998; Downs, 1994; Gravel, Wallace, & Ruben, 1995; National Institutes of Health, 1993; Roberts, Burchinal, & Zeisel, 2002; Siegel, 2000). According to the National Center for Hearing Assessment and Management (NCHAM), every state and territory in the United States has now established an Early Hearing Detection and Intervention (EHDI) program (White, 2008). The goal of these EHDI programs is to identify every child born with a permanent hearing loss before three months of age. However, there are children who do not receive newborn hearing screenings because of other health issues and home/community birthing options. In addition, an estimated 20% of all cases of childhood hearing loss

are progressive in nature or are acquired after the newborn hearing screening period (Georgalas, Xenellis, Davilis, Tzangaroulakis, & Ferekidis, 2008). Because of these pitfalls in the early screening process, hearing screenings at the pre-school and school-age level are important. These later screenings allow for identification of hearing loss that was not identified by newborn hearing screening programs because it is progressive, late-onset, or acquired by trauma, disease, or other environmental factors (e.g., noise exposure).

### Current Hearing Screening Protocols

The Guidelines for Audiologic Screening published by ASHA (1997) outline the current methods for the screening of outer and middle ear disorders, as well as peripheral hearing loss in the school-age population. Otoscopy and tympanometry are the measures recommended by the ASHA Guidelines to screen for outer and middle ear disorders. According to ASHA, the primary goal of outer and middle ear screening is to identify children with

chronic otitis media with effusion (OME), which has the potential to cause significant medical problems, hearing loss, and long-lasting speech, language, and learning deficits.

In addition to these two measures of screening for outer and middle ear pathologies, pure-tone hearing screenings are recommended for identifying peripheral hearing impairment (ASHA, 1997). The goal of screening pre-school and school-age populations for hearing loss is the identification of peripheral hearing impairments that may interfere with communication, development, health, or future academic performance (ASHA, 1997). In order to screen for middle ear disorders and hearing impairment, both tympanometry and pure-tone screenings must be used (Nozza, Sabo, & Mandel, 1997).

The goal of a good screening tool is to maximize the identification of individuals who need a referral for further diagnostic testing and to correctly identify individuals who do not need further testing. Sensitivity is defined as the likelihood that a test is able to detect the presence of a specific characteristic in someone who has that characteristic, and specificity is defined as the likelihood that a test is able to detect the absence of a specific characteristic in someone without that characteristic. Comparing one screening test to another screening test only examines the relationship between the two measures.

#### **Otoacoustic Emissions as a Screening Tool**

An alternative measure that has been used to screen for peripheral hearing loss, as well as outer and middle ear disorders, is otoacoustic emissions (OAEs; Driscoll, Kei, & McPherson, 2000, 2003; Eiserman, Shisler et al., 2008; Lyons, Kei, & Driscoll, 2004; Nozza et al., 1997; Sabo, Winston, & Macias, 2000; Yin, Bottrell, Clarke, Shacks, & Poulsen, 2009). OAEs are a physiological measure, highly reproducible, non-invasive, and well suited for use with infants, children, and other difficult-to-test populations. The presence of an OAE measured in an ear canal is considered evidence of the functional integrity of the entire middle ear and cochlear systems, including the basilar membrane, organ of Corti, stria vascularis, and outer hair cell system (Allen, 2001). OAEs are present in ears of children with normal peripheral auditory function and absent in children with middle ear pathology and/or hearing thresholds greater than 25 dB HL (Eiserman, Shisler et al., 2008; Georgalas et al., 2008; Nozza et al., 1997; Nozza, 2001).

OAE technology offers many benefits that make it ideal for conducting school-based hearing screenings (Driscoll et al., 2000; Eiserman, Shisler et al., 2008; Nozza, 2001; Yin et al., 2009). As a quick, objective, simple, and inexpensive tool, OAEs may be a good alternative to current screening tools. It takes approximately 2 minutes to complete an OAE screening, compared to 7 minutes (on average) for pure-tone screening (Foust, Eiserman & Shisler, 2011). OAEs do not require active participation, cooperation, or

conditioning to the task, which are needed for pure-tone screenings. Personnel other than audiologists can be successfully trained to administer OAE screenings (Eiserman, Shisler et al., 2008; Nozza, 2001). Because OAEs can detect the presence of both middle ear disorders and peripheral hearing loss, the need for the school district to purchase and maintain multiple pieces of equipment (i.e., pure-tone audiometer and tympanometer) is potentially eliminated (Nozza et al., 1997). All of these characteristics of OAE screenings make them an attractive alternative to the current school-based hearing screening protocol. In fact, some authors have suggested that OAEs, coupled with otoscopy, could fulfill the current ASHA guidelines (1997) while possibly being more time efficient (Driscoll et al., 2000; Nozza et al., 1997; Nozza, 2001).

Transient evoked otoacoustic emissions (TEOAEs) and distortion product otoacoustic emissions (DPOAEs) are the two most commonly used evoked otoacoustic emissions in the clinical setting (Probst & Harris, 1993; Sabo et al., 2000). TEOAEs and DPOAEs differ mainly in the stimulus type used to evoke the emission. TEOAEs are elicited by a brief stimulus, such as a click or tone-burst, while DPOAEs are elicited by the simultaneous presentation of two pure tones. It has been suggested that DPOAEs offer more frequency-specific information than do TEOAEs, due to the nature of the stimuli (Gorga et al., 1993). Reportedly, DPOAEs are more sensitive to the higher-frequency region (i.e., 4000-6000 Hz) of the cochlea (Gorga, et al., 1993; Prieve, Gorga, Schmidt, Neely, Peters, Schultes, & Jesteadt, 1993).

Following the successful implementation of OAEs in newborn hearing screening, researchers began to examine the application for early childhood screenings. The Early Childhood Hearing Outcomes (ECHO) program has been successful in implementing such a protocol in Head Start and Early Head Start Centers (Eiserman, Behl, & Shisler, 2009; Eiserman, Hartel et al., 2008; Munoz, 2003). A child who fails (i.e., does not pass) the initial OAE screening is rescreened in two weeks. If a child fails the second screening, he is referred for medical clearance of middle ear problems and then sent to a pediatric audiologist for audiometric testing (Eiserman & Shisler, 2011). The ECHO program authors cite one of the main advantages of this model is the cost-efficiency and timeliness of follow-up. The ECHO model includes training Head Start staff to conduct screenings, which contributes to the cost efficiency of the protocol.

#### **Rationale**

Many studies have evaluated transient evoked otoacoustic emissions (TEOAEs) as a potential screening tool in pre-school and school-age populations (Driscoll et al., 2000, 2003; Georgalas et al., 2008; Nozza et al., 1997; Sabo et al., 2000; Taylor & Brooks, 2000; Yin et al., 2009). Fewer studies have evaluated the use of distortion product otoacoustic emissions (DPOAEs) for hearing

screenings in the school-age population (Lyons et al., 2004). Taylor and Brooks (2000) compared TEOAE screenings to pure-tone screenings for 297 ears of 152 children, aged 3 to 8 years. They calculated sensitivity as 81% and specificity as 95% when compared to pure-tone screenings and suggested that screening outcomes were comparable enough to consider substituting TEOAEs for traditional pure-tone screenings.

Lyons et al. (2004) examined DPOAE responses to determine optimal referral criteria compared to pure-tone screenings, tympanometric screenings, and a combined approach of pure-tone and tympanometric screenings. The authors reported that the use of DPOAE testing alone would have missed about 32 to 38% of children who failed a combined screening program of pure-tone screening plus tympanometry.

While pure-tone screenings remain the accepted procedure and best practice for school-based hearing screenings, further evaluation of DPOAE measurements for use as a screening tool is warranted. DPOAE measures are quick, inexpensive, and easy for screening personnel to learn and administer. In addition, DPOAEs are a noninvasive measure of the function of the ear from the ear canal to the outer hair cells of the cochlea. DPOAEs are well suited as a public health screening tool (Wilson & Junger, 1968). Therefore, the purpose of the current study was to compare the outcome of a DPOAE screening to the outcome of a pure-tone hearing screening for school-age children in kindergarten through second grade.

## Methods

### Participants

The sample consisted of 565 children (280 females, 285 males) who were enrolled in three different elementary schools in a suburban area in central Arkansas. There were 194 children in kindergarten, 181 in first grade, and 190 in second grade. These three grades are included in the routine hearing and vision screening program in the state of Arkansas. Children with known hearing loss do not participate in this hearing screening program; therefore, children with known hearing loss were not included in the sample.

### Equipment

A DSP Pure-Tone Audiometer® and TDH-39 headphones (Micro Audiometrics Corporation) were used for the pure-tone screenings and were calibrated to the American National Standards Institute (ANSI) S3.6-1989 standards (1989). An AuDX OAE testing device manufactured by Bio-logic was used for the DPOAE screenings (Bio-logic Systems Corporation). Probe tips supplied by the manufacturer were used with this equipment.

### Procedures

All participants underwent a pure-tone screening and a DPOAE screening. The order of the two screening measures was counterbalanced. In accordance with ASHA guidelines, the pure-tone screenings were conducted at 1000, 2000, and 4000 Hz with a passing criterion of 20 dB HL in both ears (ASHA, 1997). Participants were instructed to raise a hand to indicate when the tone was heard. Failure to respond to one or more frequencies in either ear resulted in a “refer” on the pure-tone screening.

For the DPOAE screenings, an appropriately-sized probe tip was selected and placed in the ear canal of each ear. The manufacturer’s default protocol was utilized for the screenings. The 2f1-f2 distortion product was evaluated at stimulus intensities of 65 (f1) and 55 (f2) dB SPL for the following f2 frequencies: 2000, 3000, 4000, and 5000 Hz. The f2/f1 ratio was set at 1.22. The time window was set at a maximum of 10 seconds per test frequency. At each frequency, the DP response amplitude had to meet a minimum level of at least 6 dB SPL above the noise floor for inclusion in the average. If three of the four test frequencies met the manufacturer’s criterion, a “pass” result was obtained for that ear (Bio-logic Systems Corporation, 2002).

## Results

A total of 565 participants were tested; however, 18 individuals had to be excluded because data on one or both ears could not be obtained (e.g., a child refused the second screening measure, a child exhibited drainage in an ear, or a child refused screening in the second ear). Therefore, data were analyzed on a total of 547 participants. Because an individual is referred for a full diagnostic evaluation upon failing just one frequency in either ear, results were reported for each individual participant, not each ear.

There were 369 (67%) individuals who passed both the pure-tone and DPOAE screenings, while 38 (7%) individuals failed (“referred on”) both screenings. Additionally, there were 61 (11%) individuals who passed the pure-tone screening but failed the DPOAE screening, and 79 (14%) individuals who passed the DPOAE screening but failed the pure-tone screening. A McNemar test was used to analyze the proportion of individuals who had different results on each screening measure (e.g. the 61 and 79 participants). The McNemar Chi-square test indicated there was not a statistically significant difference in the proportion of individuals who passed the pure-tone screening but failed the DPOAE screening and those who passed DPOAE screening but failed the pure-tone screening [ $\chi^2(1, N=547) = 2.06, p = .151$ ]. The crosstabulation results are presented in Figure 1.

		Pure-Tone		
		Pass	Refer	Total
DPOAE	Pass	369 (67%)	79 (14%)	448 (82%)
	Refer	61 (11%)	38 (7%)	99 (18%)
	Total	430 (79%)	117 (21%)	547 (100%)

**Figure 1.** Two by two (2x2) contingency table depicts pass/refer results for pure-tone and distortion product otoacoustic emission screening.

Four hundred and seven (74%) participants had the same outcome on both screening measures, either pass ( $n=369$ ) or fail/refer ( $n=38$ ). However, 140 (26%) of the participants were classified as “pass” or “refer” by one of the screening measures, but not both. Of the 79 participants (14%) classified as “pass” by OAEs but “refer” by pure tones, 14 were referred due to the right ear, 26 were referred due to the left ear, and 39 were referred for both ears. Of the 61 participants (11%) classified as “pass” by pure tones but “refer” by OAEs, 16 were referred due to the right ear, 17 were referred due to the left ear, and 28 were referred for both ears.

### Discussion

The purpose of the current study was to compare the outcome of a DPOAE screening to the outcome of a pure-tone screening for school-age children in kindergarten through second grade. Seventy-four percent of these children obtained the same results on both screening measures; however, 26% had differing results. Therefore, it was unclear whether the children with differing results had hearing sensitivity that was of concern, or whether one or both of the results of the screening measures resulted in over or under identification. Without a follow-up diagnostic test, in a clinical rather than educational setting, the exact relationship between the two screening tests cannot be determined. Likewise, sensitivity and specificity for screening methods used in this study could not be calculated for this data due to the lack of diagnostic data. A diagnostic evaluation would identify the cases that were false positives and false negatives, something a screening test cannot do. Furthermore, because there were no known clinical cases included in this study, positive predictive power and negative predictive power could not be calculated.

A number of factors may have contributed to the referral of children who passed the pure-tone screening but referred on the DPOAE screening ( $N=61$ ). Although ambient noise levels may have been acceptable for the pure-tone screenings, those same noise levels could have been loud enough to interfere with the measurement of the OAE (Frank, 2000). Cerumen in the ear canal

may have blocked or entered the probe tip, causing increased referrals. Middle ear disease (e.g., fluid in the middle ear) may have affected the outcome of the DPOAE screening, but not the pure-tone screening if the middle ear disorder was not significant enough to impact hearing thresholds.

Pure-tone screening is a behavioral test and subject to human test error. For example, a potential error that may occur includes inadvertently giving the child visual cues. Children who passed the DPOAE screenings but were referred on the pure-tone screenings ( $N=79$ ) may not have been able to perform the pure-tone screening task. Children considered difficult-to-test or children who did not understand the directions for the pure-tone screenings would have been unable to perform the task required of them for the pure-tone screening. In addition, children with auditory neuropathy may have failed the pure-tone screenings but passed the OAE screenings.

DPOAEs are not considered to be a test of hearing sensitivity, but an assessment of cochlear outer hair cell function. When conducting a DPOAE screening, the function of the cochlear inner hair cells and auditory nerve is unknown. If an OAE screening were the only assessment tool implemented, a child having normal outer hair cell function and abnormal function further up the auditory pathway, as seen in cases of auditory neuropathy, may be missed or incorrectly identified as not having a hearing loss (Rapin & Gravel, 2003; Starr, Picton, Sininger, Hood, & Berlin, 1996).

The purpose of a screening test is to quickly and accurately separate individuals who may have a hearing loss from those who do not. Researchers have shown DPOAE stimulus levels of 65/55 dB SPL to be the most accurate intensity levels for use in categorizing individuals into one of two categories with 20 dB HL used as the criterion (Stover, Gorga, Neely & Montoya, 1996). Depending upon the stimulus level, DPOAEs may be elicited in individuals with mild hearing loss (Gorga et al., 1993; Harrison & Norton, 1999; Probst & Harris, 1993). The use of DPOAE screening equipment with preset parameters helps reduce human test error.

Automated technology is expanding at a rapid rate and researchers continue to seek information that will contribute to better DPOAE test performance. Improved algorithms for DPOAE screening may lead to improved screening outcomes. Algorithms for DPOAE screening equipment are proprietary; therefore, care must be taken when selecting screening equipment. Equipment purchased from manufacturers who provide disclosure of screening stimuli parameters is desirable.

A screening test with 100% accuracy does not exist. However, by continuing to compare screening tools and by reporting sensitivity and specificity without follow up diagnostic testing, the possibility of over-referrals (or worse, under-referrals) remains, and the knowledge base of the profession of audiology will not improve.

## Conclusion

A well-defined and universally accepted pass/refer DPOAE criteria for the school-age population has yet to be established. In future studies, comparing pure-tone and DPOAE screening results with a full diagnostic evaluation, including otoscopy and tympanometry, should be performed. The feasibility of a screening protocol is dependent upon it meeting the requirements of public health screening criteria (Wilson & Junger, 1968), as defined by the World Health Organization (WHO). The data in the present study adds to the body of literature indicating that OAEs may not be a direct substitute for pure-tone screenings. In light of the limitations to using a DPOAE screening for identifying hearing impairment, additional research is needed. Advances in digital signal processing algorithms may contribute to improved DPOAE test performance. Therefore, more research is needed to evaluate the cost- and time-effectiveness of DPOAE screening protocols for the school-age population and the continued evaluation of a school hearing screening protocol utilizing DPOAEs is warranted.

## Acknowledgements

This data was collected while the first author (Donna Fisher Smiley) was an instructor/assistant professor at the University of Central Arkansas. Thanks to those faculty and students who participated in the data collection for this project: Natalie Benafield (audiology faculty), Laura Bull, Carie Elliott, Mark Fortenberry, Audrey Mayfield, Amy Roller, Allison Thornton, and Brandy York. This project was funded by a University Research Grant from the University of Central Arkansas. In addition, the first author would like to thank the school nurses who helped to make this data collection possible.

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