

Preschool Hearing Screenings: A Comparison of Distortion Product Otoacoustic Emission and Pure-Tone Protocols

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Distortion product otoacoustic emissions (DPOAE) are sensitive to both sensorineural and conductive hearing losses and have the potential to be used as an effective screening measure across all populations, including children. DPOAE offer a quick and straightforward hearing screening technique for the pediatric population that is not influenced by subjective testing and is highly reproducible. In this study, the mean test times and pass/fail rates from 198 preschool participants were compared between two DPOAE screening protocols (1-5 kHz and 2-5 kHz) and a pure-tone screening protocol (1, 2 and 4 kHz). Significantly less time was needed to conduct the DPOAE screenings compared to the pure-tone screenings. Results suggested similar pass/fail rates for both DPOAE protocols compared to pure-tone screenings. Without diagnostic audiologic test results, the sensitivity and specificity of the screening protocols could not be determined. Until the true sensitivity and specificity of DPOAE and pure-tone screening protocols can be determined, it is recommended that clinicians consider adding DPOAE to their current screening protocol, or at least having DPOAE available to screen children who cannot or will not participate in pure-tone screenings.

Introduction

It is well known that early intervention improves speech and language development as well as cognitive outcomes, diminishing the need for special education services and improving the overall quality of life of children with hearing loss (e.g., Moeller, 2000; Yoshinaga-Itano, Sedey, Coulter, & Mehl, 1998). Therefore, hearing screening programs are utilized across all pediatric age ranges and populations to detect potential hearing loss and to combat delayed language development (Gelfand, 2009). Hearing screenings are designed to provide a quick and cost-effective method of separating individuals into two groups: individuals at risk for hearing loss and individuals not at risk for hearing loss.

Today, hearing screenings begin at birth and continue throughout an individual's school years, when conditions occur that increase risk for hearing loss, or when mandated by state and local laws or practices (Cunningham & Cox, 2003). Professional organizations such as the American Speech-Language-Hearing Association (ASHA) and the American Academy of Audiology

(AAA) have established screening protocols for both hearing sensitivity and middle ear disorders (e.g., otitis media) to separate individuals with and without suspected hearing loss. Both AAA (1997) and ASHA (1997) recommend combining the use of pure-tone and tympanometric screening protocols for the detection of hearing loss and middle ear disorders. However, the use of pure-tone audiometry as part of a screening protocol is often criticized (Lyons, Kei, & Driscoll, 2004).

Pure-tone audiometry requires a higher level of cognitive functioning to produce appropriate responses (Lyons et al., 2004). This requirement becomes especially problematic with the pediatric and developmentally-delayed populations who may be incapable of providing such a response. In recent years, the need for objective, non-invasive tests for monitoring hearing loss in children has become apparent. The use of otoacoustic emissions (OAE) hearing screening protocols for pediatric populations has been suggested because the test is objective (Kei, Brazel, Crebbin, Richards, & Willeston, 2007).

Because OAE are sensitive to both sensorineural and conductive hearing loss, they have the potential to be an effective screening tool across all populations, including children (Kei et al., 2007). However, little research on the use of OAE as a screening method with preschool aged children has been conducted. OAE screening appears to be promising in assessing the integrity of cochlear function and has a major practical advantage over subjective threshold measurements. Offering a quick and straightforward approach to testing pediatric populations, OAE are not influenced by subjective interpretations, making them highly reproducible and more precise than audiometry (Kemp, Ryan, & Bray, 1990). However, in the past, research has indicated that the use of OAE is most effective in ruling out hearing loss when used as part of a multifaceted diagnostic battery. Because limited data have been collected on the use of distortion product otoacoustic emissions (DPOAE) as a first-stage screening protocol in preschool children, further research is needed.

The Effect of Noise on DPOAE

The most common environment to screen for hearing in school-aged children is the educational environment, which is quite different from a clinical setting. Differences between these settings include: the amount of noise in the environment, the amount of time available to conduct the screening, the overall health of the child, the prevalence of hearing loss in the school-aged population, the child's familiarity with the personnel conducting the testing, and the surrounding environment (Sideris & Glatke, 2006). Often, hearing screenings are conducted in non-sound-treated rooms or nurses' offices that were not designed to provide desirable acoustic attenuation (Hallett & Gibbs, 1983).

Conducting OAE testing in settings with high environmental noise levels may affect the detectability of the emission given from the ear. As a result, ambient noise will always be a contributing factor to hearing screening results (Nozza et al., 1997). It should be noted that DPOAE at or below 1000 Hz are difficult to obtain even in a sound-treated booth with adults due to physiological noise (Gorga, Neely, Johnson, Dierking, & Garner, 2007). Obtaining DPOAE in high background noise levels becomes even more difficult. Typically, noise has adverse effects on the measurement of otoacoustic emissions at low frequency levels (at and below 1000 Hz), but minimal effects on the high frequencies (Kei et al., 2007; Torre, Cruickshanks, Nondahl, & Wiley, 2003). For these reasons, most screening protocols recommend not testing DPOAE at 250 and 500 Hz, even though valuable information regarding the status of the inner ear can be obtained at these frequencies (Kei et al., 2007). Screening DPOAE at and below 1000 Hz in high noise level environments should be conducted with caution due to potentially low hit and high false alarm rates due to both physiological and background noise (Gorga et al., 2007; Torre et

al., 2003). An optimal solution to the noise problem in educational settings is the use of sound treated rooms or portable tests booths; however, this solution is often unattainable due to cost, availability, and space issues.

Hearing Screening Protocols

In previous years, there has been some debate over the goal of school-age hearing screening programs and whether to screen for hearing loss alone or hearing loss and middle ear disorders (otitis media) (Gelfand, 2009; Nozza, Sabo, & Mandel, 1997). The recommended screening procedure for infants and young children varies slightly among professional organizations and across age category. Typically, the screening protocols in existence today utilize pure-tone and tympanometric screening in the protocol (AAA, 1997; ASHA, 1997; Lyons et al., 2004). The use of both of these techniques allows for the detection of sensorineural hearing loss, as well as conductive hearing loss caused by pathologies such as otitis media with effusion or impacted cerumen (Lyons et al., 2004). Separate follow-up screening protocols have been established as well to identify sensorineural hearing loss or middle ear disorders independently.

Pure-tone Screening Protocol

The American Academy of Audiology Position Statement (1997) and Clinical Practice Guidelines (2011) also recommend pure-tone screening at 1000, 2000, and 4000 Hz at 20 dB HL. The goal of screening for hearing loss in preschoolers (ages 3-5 years) is to identify children most likely to have hearing loss that may interfere with communication, development, health, or future school performance. In addition, because hearing loss in this age range is so often associated with middle ear disease, it is also recommended that children in this age group be screened for outer and middle ear disorders. The screening protocol for children aged three to five years old typically involves pure-tone testing under earphones at 1000, 2000, and 4000 Hz at 20 dB HL using conditioned play audiometry. If a child cannot attend to the testing or does not have the cognitive ability to participate in conditioned play audiometry then visual reinforcement audiometry may also be used.

In order for a child to pass the hearing screening, he or she must respond to at least two out of three pure-tone presentations at all frequencies in both ears (ASHA, 1997). If a child fails the screening, they must then be referred for a full audiological evaluation. Children who are thought to have failed the screening due to their inability to be properly conditioned may be screened using screening procedures designed for younger children.

The AAA (1997) guidelines also recommend air conducted pure-tone screening at 1000, 2000, and 4000 Hz at 20 dB HL. However, AAA does not specify which type of audiometry (visual reinforcement or conditioned play) should be utilized, only that

a type of manual method is conducted. Failure to respond at any one frequency in either ear constitutes failing the screening, and the child should then be referred for a full audiological evaluation. AAA (1997) recommends that all children should be screened for hearing loss: (a) at least once during the preschool years, (b) if a parent expresses concerns about a child's hearing ability, and (c) if a child is being considered for entrance into a special education.

Pure-tone screening closely follows typical diagnostic techniques used in an audiology practice; however, certain limitations exist when utilizing this type of screening procedure for children (Sideris & Glatke, 2006). Pure-tone audiometric testing requires a conditioned response that some children may not be capable of giving. A study conducted by Decreton, Hanssens, and De Sloovere (1991) suggested that as many as one in every ten children could not be assessed using an overt response to pure tones and that these children may be overlooked until a reliable response to the recommended pure-tone screening protocol is given.

Screening for Middle Ear Disorders

To screen for outer and middle ear pathologies in children, ASHA (1997) established a second screening protocol that includes the use of tympanometric measures. Children whose test results include a flat tympanogram should be referred for medical evaluation. Other abnormalities such as drainage from the ear, ear pain, perforations, impacted cerumen, foreign bodies, and the presence of blood during the otoscopic evaluation should also be medically evaluated.

Set-Up for Screening Programs

Discrepancies between screening programs, such as the instruments used during testing, the amount of training the testers have received, the amount of ambient noise present during the hearing screening, and the pass/fail criteria used, will affect the overall effectiveness of the program (Nozza, 2001). Generally, a screening test should adhere to certain criteria. Tests should be simple, easy to administer, comfortable to the client, inexpensive, and short in duration (Nozza, Sabo, & Mandel, 1997). The costs of personnel, instrumentation, testing space, and other miscellaneous expenses should not be overlooked and often play a crucial role in the decisions made about screening programs. The level of expertise and education of the screening personnel may be considered important at one location and irrelevant at another.

Use of OAE in a Screening Protocol

More recent ASHA guidelines for audiologic screening of children ages birth to 5 include consideration of the use of otoacoustic emissions among other procedures and protocols in the detection of hearing loss and middle ear disorders (ASHA 2004). Evoked OAE have been used in newborn hearing screenings since it was determined that OAE technology could be applied to the

screening of hearing in infants. One study evaluated the use of a TEOAE and DPOAE screening protocol as part of a newborn hearing screening program (Hatzopoulos, et al., 2001). In terms of screening performance, both OAE screening protocols performed well, with equally high sensitivity and specificity rates when later compared to ABR test results. Also, the amount of time needed to complete each screening was evaluated. Timing results indicated that the DPOAE protocol was 50% shorter than the TEOAE protocol. The results suggested that DPOAE and TEOAE were useful in newborn screening. However, further research needs to be conducted on the use of DPOAE in other populations.

To date there has been little research on the use of DPOAE in the preschool population. Dille et al. (2007) compared referral rates between DPOAE and TEOAE protocols and found no statistically-significant difference in the referral rate at any of the frequencies compared. They concluded that both TEOAEs and DPOAEs were equally suitable for screening the hearing of preschool-aged children. It has been suggested that DPOAE may serve as a non-invasive, objective clinical tool for use in the assessment of the cochlea, across all age ranges (Norton & Widen, 1990). However, it is necessary to compare the effectiveness of the use of diagnostic OAE versus the effectiveness of screening OAE used in a screening protocol. Several automated OAE screening devices are being used clinically; however, limited data exist on the accuracy of these devices in hearing screening protocols in school children.

The amount of time necessary to conduct OAE screenings on adults has been evaluated. A study conducted by Parthasarathy and Klostermann (2001) evaluated the use of the three hand held screeners (Audioscreener, EroScan, and AuDX). Each piece of equipment was set to the default criteria and run on a total of 42 adult subjects. The results of the study indicated that the use of the screening devices took an average of 17 seconds per ear. These machines were preset to utilize statistical criterion to determine if the emission was present or not, leading to a pass versus fail criterion that does not have to be interpreted by a licensed audiologist. This may also diminish the cost needed to utilize effective hearing screenings across populations.

The amount of time necessary to complete pure-tone screening in comparison to DPOAE has yet to be evaluated. However, Sideris and Glatke (2006) compared the use of conventional pure-tone behavioral screening to the use of TEOAE screening in the preschool population under the conditions common to educational settings. Participants included 200 children ranging in age from 2 years 1 month to 5 years 10 months. Pure-tone screening was conducted under earphones using conditioned play audiometry. The screening level was 20 dB HL for the frequencies 1000, 2000, and 4000 Hz. A child passed the screening if he or she responded to

the 20 dB HL tone at all frequencies in both ears. A lack of response to the 20 dB HL test tone at any frequency in either ear, or the inability of a child to condition to the task, constituted a screening failure. The audiologist used a stopwatch to note the time required to condition and test each child. Mean testing time for pure-tone screening was 137.6 seconds. In contrast, the mean testing time for TEOAE screening was 113.4 seconds. A matched *t*-test was conducted and revealed that pure-tone screening took significantly longer to complete than TEOAE screening emphasizing the time effectiveness of TEOAE.

Several studies evaluating the use of TEOAE as part of a hearing screening protocol have been conducted (e.g., Nozza et al., 1997; Sideris & Glatke, 2006; Yin, Bottrell, Clarke, Shacks & Poulsen, 2009). However, limited research on the performance level of DPOAE in preschool or school-aged children exists. In one study, 1003 elementary school children were tested using pure-tone screening, tympanometry, and DPOAE (Lyons et al., 2004). Testing the performance of DPOAE in this population was concluded to be more accurate at high frequencies compared to low frequencies. When DPOAE screening was evaluated against pure-tone testing, a hit rate of .62-.68 was determined; meaning the use of DPOAE alone would have missed approximately 32-38% of the children failing the pure-tone screening. In addition, this study determined that the use of DPOAE and tympanometry screening in identifying school aged children with auditory dysfunction is superior to using DPOAE screening alone.

Dille, Glatke, and Earl (2007) compared referral rates between DPOAE and TEOAE protocols for 33 children in preschool settings. They found no statistically-significant difference in the referral rate at any of the frequencies compared. They concluded that both TEOAE and DPOAE were equally suitable for screening the hearing of preschool aged children.

More recently, Smiley, Shapley, Eckl, and Nicholson (2012) compared pure-tone and DPOAE screenings in 565 school-age children. They reported that 67% of the children passed both screenings and 7% failed both screenings. The remainder of the children either passed the pure-tone screening and failed the DPOAE screening (11%) or passed the DPAOE screening and failed the pure-tone screening (14%). The authors recommended that a full diagnostic evaluation would be needed to determine true sensitivity and specificity of DPOAE and pure-tone screenings. In addition, they concluded that use of DPOAE in screening protocols should continue to be evaluated and that “more research is needed to evaluate the cost- and time-effectiveness of DPOAE screening protocols for the school-age population” (Smiley et al., 2012, p. 36).

Purpose of Study

The use of DPOAE as part of a screening protocol appears to be feasible because they are easy to administer, quick, objective, and present in virtually all individuals with normal peripheral auditory function. Several studies have reported anecdotally that screening with otoacoustic emissions is faster than screening with pure tones in the pediatric population. However, there remains limited data comparing time to complete DPOAE screening and pure-tone screening and the pass/fail rates of these protocols in the preschool population. The aim of this study was to compare the time needed to complete, and the pass/fail rates of, DPOAE screening from 2-5 kHz, DPOAE screening from 1-5 kHz, and pure-tone screening within the preschool population.

Methods

Participants

Participants were 198 volunteers (101 male, 97 female; mean age 4.5 years, range: 3.0 to 6.5 years) in various preschools that take part in Towson University’s speech and hearing screening program. Specifically, children in the following preschools participated in the study: Timonium United Methodist Nursery School, Dulaney Day School, Holy Spirit Early Childhood Learning Center, Mayfield Christian Preschool, Yeshivat Rambam School, Bais Yaakov School for Girls, Beth Tfiloh Preschool, and Ward’s Chapel Preschool. No pre-selection criteria were used to determine study participants. To be included in the screenings, each participant had to be cooperative throughout testing. A child was considered uncooperative if the child did not allow the examiner to complete screening in an efficient manner. Of the 198 children, two females (ages 3 years 10 months and 4 years 2 months) could not complete the pure-tone screenings either due to the child’s lack of cooperation or their inability to condition to the task. Conditioned play audiometry has previously been shown to be difficult for some preschoolers (Northern & Downs, 2002), as it requires a level of cognitive functioning that children may not yet possess; whereas, DPOAE do not. All 198 children were able to complete the DPOAE screenings in this study, suggesting that pure-tone screenings were a slightly more difficult task for some participants to complete. Descriptive statistics of participant gender and ages by schools are presented in Table 1.

Table 1. Descriptive Statistics of Participants across Preschool Sites

	SITE								
	TUM	DDS	HSP	MCP	YRS	BYS	BTP	WCP	TOTAL
Mean Age (years)	4.4	4.6	4.5	4.7	4.5	4.2	4.4	4.5	4.5
Gender Male	19	4	8	8	20	0	7	35	101
Female	13	6	12	8	18	8	11	20	97
Total Participants	32	10	20	17	38	8	18	55	198

Note. TUM=Timonium United Methodist Nursery School, DDS= Dulaney Day School, HSP= Holy Spirit Early Childhood Learning Center, MCP= Mayfield Christian Preschool, YRS= Yeshivat Rambam School, BYS= Bais Yaakov School for Girls, BTP= Beth Tfiloh Preschool, WCP= Ward’s Chapel Preschool

Procedures

Three Grason-Stadler Incorporated (GSI) model 17 portable audiometers with TDH 39 headphones were used for all pure-tone hearing screenings. Although the use of insert earphones decreases the amount of ambient noise allowed into the ear canal, they could not be used for financial reasons. The AuDX II Pro, manufactured by Bio-logic Systems Cooperation, was used to obtain all DPOAE measurements.

All children were screened individually, in a seated position, in a quiet room provided within each school. Although ambient noise levels were not measured using a sound level meter, each room was subjectively evaluated and set up so that maximum responses could be obtained during testing. Test rooms were examined for ambient noise sources that may interfere with obtaining OAE responses. OAE equipment was then set-up as far away from these sources as possible. Children were brought to the screening room individually or in groups of no more than four or five. Each OAE tester attempted to put the child at ease and explained the screening by stating, "Today you are going to sit in the chair and listen to some beeps. I just need you to sit still and be as quiet as a statue." Each person screening via pure tones explained testing by stating, "We are going to play a listening game today. I want you to put a block in the bucket/basket when you hear the tiny beep." The screener then conditioned the child to the task. Any additional explanation was provided as needed. Children began the screening process at either pure-tone or DPOAE screening. For both screening procedures, the right ear was always screened first. Children also received a tympanometry screening. The order of screening for these tests was determined by the availability of instruments and the flow of students through the screening protocol. In order to minimize the potential confounding effects of changes in the child's health or cooperation, all three procedures were completed on the same day.

Bilateral pure-tone screening using conditioned play audiometry was conducted on all cooperative participants. Based on ASHA (1997) recommendations, pure-tone screening was conducted at 1 kHz, 2 kHz, and 4 kHz at 20 dB HL. If the child responded to the tone as presented at 20 dB for all of the frequencies, then that ear was categorized as a pass. If the child failed to respond to 20 dB HL in one or more test frequencies, that ear was categorized as a "refer". Children failing in one or both ears were referred for further diagnostic testing.

In order to limit tester error, audiology doctoral students who had courses and clinical work on the use of DPOAE screening conducted all DPOAE screenings. Speech-language pathology and audiology graduate students, who also had undergone training, conducted all tympanometry and pure-tone screenings. All students were supervised by a licensed and certified speech-language

pathologist. Prior to DPOAE screening, otoscopy was performed using a Welsh-Allyn otoscope. A series of simultaneous pure-tone pairs, frequencies f_1 and f_2 , at intensities of 65 and 55 dB SPL respectively, were delivered to the test ear. These simultaneous intensity levels were chosen based on the recommendations concerning optimal results in humans (Kimberley, Hernadi, Lee, & Brown, 1994; Stover et al., 1996). The test frequency ratio ($2f_2/f_1$) was set at 1.2 to optimize DPOAE results (Abdala, 1996; Gaskill & Brown, 1990; Harris et al., 1989). The frequency protocol was: 1, 2, 3, 4, and 5 kHz, in reverse order. This protocol was used to obtain the most amount of information about the integrity of the outer hair cells. In order to pass the screening, the child had to pass all five frequencies in each ear. A series of stop criteria were also included to maximize screening time within the schools. Pass/refer criteria included: DP-NF 8 dB, DP amplitude minimum -5 dB, NF amplitude minimum -17 dB, time out 14 seconds. These criteria are utilized by the Special Olympics Healthy Hearing screening program (Herer & Montgomery, 2006), where screenings are often performed in sub-optimal noise levels. In a pilot study, these criteria provided equal sensitivity outside of and inside of a sound-treated booth (G. Herer, personal communication, October 18, 2013).

Each screening protocol was timed in order to evaluate any possible differences between the three protocols. For the pure-tone screening, the time began as soon as the child was seated and quiet. The tester gave instructions, conditioned the child to the task, and then tested the child's right ear. Once the child's right ear was complete, the time was stopped and noted. Then, the time was started again and the tester continued testing the child's left ear. Once this was complete, the time was stopped again and noted. When testing the DPAOE screenings, timing did not begin until after otoscopy was complete. Otoscopy was not needed for the pure-tone screening due to the use of supra aural headphones. However, it was necessary for DPOAE because insert ear probe tips were used. Following otoscopy the time was started and the child was instructed. Again, the tester began with the right ear to limit variability. Following instructions, the tester reviewed the screening results for each frequency as they were obtained on the AuDX II Pro screen. Split test times were acquired between 2-5 kHz and 1 kHz. Following the completion of 1 kHz the overall time was stopped and noted. This process was then repeated for the left ear. Because instructions were already given in the beginning, the child was not reinstructed between ears for either screening. A child received a pass if both ears passed the screening. The child was referred for further testing if one or both ears were referred from the screening.

Parents were provided with a report of the screening results. Any child who received a refer outcome for DPOAE, pure-tone,

and/or tympanometric screening was referred for further diagnostic testing.

Statistical Analyses

Statistical analysis was completed using SPSS version 15.0 for Windows. SPSS was used to calculate descriptive statistics for age, gender, pass/fail rates and the amount of time necessary to conduct each of the three screening protocols. Paired-sample *t*-tests, with a Bonferroni family-wise correction ($\alpha = .05/3 = .017$) applied to guard against the possibility of a Type I error, were used to compare the mean amount of time needed to complete each of the three screening protocols. Two-by-two contingency tables were used to compare pass/fail rates for the pure-tone screening protocol (1, 2, 4 kHz) with the five frequency DPOAE screening (1-5 kHz) and the four frequency DPOAE screening protocol (2-5 kHz). Pearson chi-square analysis for independence (χ^2) tests were then completed in order to determine possible relationships of the pass/fail rates of each of the DPOAE protocols to those of the pure-tone screening protocol.

Post-hoc analyses were also conducted to examine any possible differences between gender and age of the pediatric participants. Pearson product-moment correlation coefficients (*r*) for continuous variables were used to analyze relationships between the ages of participants to the amount of time necessary to complete each protocol. Finally, chi-square analysis for independence (χ^2) tests was used to compare participant genders to the pass/fail rates of

each of the three screening protocols.

Results

Time to Complete Screening Protocols

Figure 1 displays the mean time to complete each of the screening protocols. Paired-samples *t*-tests, using a Bonferroni family-wise correction was made ($\alpha = .05/3 = .017$) to guard against the possibility of a Type I error, were conducted to compare the mean time to complete the DPOAE 1-5 kHz ($M=94.52, SD=60.12$), DPOAE 2-5 kHz ($M=55.19, SD=40.19$), and pure-tone ($M=213.14, SD=168.09$) screening protocols. Results suggested statistically-significant differences between the mean times to complete all three protocols. Specifically, the DPOAE 2-5 kHz was significantly faster than both the DPOAE 1-5 kHz ($t[197]=19.13, p<.001$) and pure-tone ($t[195]=13.57, p<.001$) screenings. Additionally, the DPOAE 1-5 kHz was significantly faster than the pure-tone ($t[195]=10.14, p<.001$) screening.

Screening Pass/Fail Rates

Pass/fail rates were examined for each of the three screening protocols. The descriptive statistics for the pass/fail rates of five-frequency DPOAE screening protocol, the four-frequency DPOAE screening protocol, and the pure-tone screening protocol are displayed in Table 2. Data were analyzed via chi-squared (χ^2) tests for independence to determine if the pass/fail rates were significantly related between each of the DPOAE screening protocols and pure-tone screening. Both analyses showed a

statistically-significant relationship (DPOAE 1-5 kHz to pure-tone [$df=1; 6.61; p<.05$]; DPOAE 2-5 kHz to pure-tone [$df=1; 9.61; p<.05$]). These results suggested there is a relationship between the pass/fail rates of both DPOAE screening protocols and the pure-tone screening protocol.

Post-Hoc Statistics

Pass/fail rates of males versus females were examined for each of the three screening protocols. A Chi-Squared (χ^2) calculation (2-tailed) was completed to determine if a relationship existed between gender and the pass/fail rates in the five frequency DPOAE screening, the four frequency DPOAE screening, or the pure-tone screening. Findings were not statistically significant ($p=.075, p=.165, \text{ and } p=.934, \text{ respectively}$). These results suggest that the genders of the participants were not related to the pass/fail rate for any of the three screening protocols.

Pearson product-moment correlation (*r*) was used to evaluate the relationship between age and the amount of time it took each participant to complete each of the screening protocols. Preliminary analyses

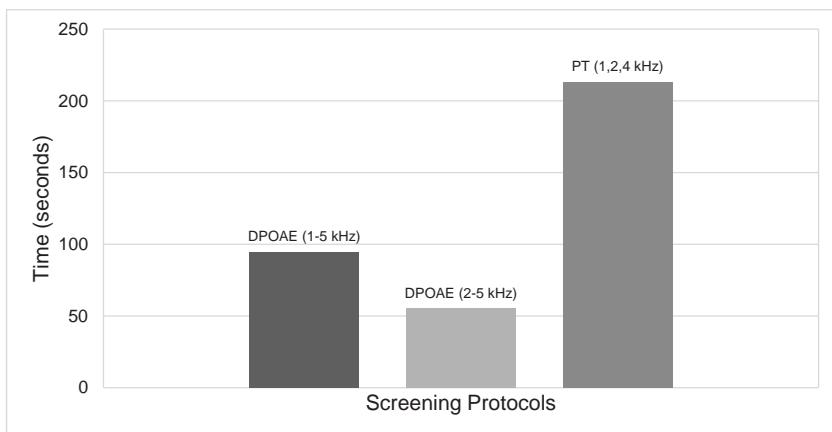


Figure 1. Mean time to complete each screening protocol.

Table 2. Pass/Fail Rates for DPOAE (1-5 kHz), DPOAE (2-5 kHz) and Pure-Tone (1,2,4 kHz) Protocols

Protocol	Pass	Fail	Total
DPOAE (1-5 kHz)	134	64	198
DPOAE (2-5 kHz)	141	57	198
Pure-Tone (1,2,4 kHz)	175	21	196

Note. DPOAE=Distortion Product Otoacoustic Emissions. Two children would not cooperate to be screened using pure tones.

were performed to ensure no violation of the assumptions of normality, linearity, and homoscedasticity. A small negative correlation was found between the participant's age and the pure-tone screening ($r = -.15, p = .035$). In other words, as the age of a participant increased, there was a slight decrease in the amount of time it took them to complete the pure-tone screening. No significant correlations were found between the participants' ages and the five-frequency DPOAE screening ($r = -.06, p = .369$) or the participants' ages and the four-frequency DPOAE screening ($r = -.06, p = .369$).

Discussion

The aim of this study was to evaluate the use of DPOAE as a first line screening tool in a pediatric population and to compare their referral rate against a traditional pure-tone screening battery. The results of this study indicated that significant time differences between the mean time to complete the screening protocols, with the DPOAE 2-5 kHz screening taking the least time and the pure-tone screening taking the most time. Extended testing times were expected for the five frequency protocol due to the incidence of higher levels of ambient noise present in lower frequencies. In addition, it was anticipated that the pure-tone screening would take longer to complete due to the increased amount of time needed for instruction and conditioning versus the DPOAE screenings. These timing results are significant for preschool screening programs. With either DPOAE protocol taking significantly less time to complete than pure-tone screenings, personnel would be able to screen more children on a day to day basis. In addition, the screener may have the opportunity to rescreen children who may not have passed the screening the first time.

No previous studies have compared the amount of time necessary to complete a five frequency DPOAE screening and a pure-tone screening; however, a study by Sideris & Glatke (2006) evaluated the amount of time needed to complete a TEOAE screening (1-4 kHz) and traditional school based hearing screenings. They found significant differences, with mean screening times of 137.6 and 113.4 seconds for the pure-tone and TEOAE screenings, respectively. Comparing the results of Sideris & Glatke (2006) with the current study, it appears that DPOAE screening may take less time on average than TEOAE screening; however, this conclusion should be interpreted with caution as the background noise levels were not recorded for either study.

In the present study, a statistically-significant relationship was noted between the pass/fail rates of both the four and five frequency DPOAE screening protocols and the pure-tone screening protocol. In similar studies by Taylor and Brooks (2000) and Sideris and Glatke (2006), significant relationships were found between the pass/fail rates of a TEOAE screening protocol and pure-tone screening protocol in the pediatric population. The results of

this study suggested the comparable use of DPOAE to pure-tone screenings in the detection of hearing loss.

The pass/fail rates for the present study were relatively similar to Sideris and Glatke (2006), who also conducted their screenings in preschools. Pure-tone screening pass rates for this study were 88.4% and were 78.5% as reported by Sideris and Glatke (2006). They obtained a pass rate for TEOAE screenings of 79% while we obtained pass rates for DPOAE of 71.2% (for 2-5 kHz) and 67.7% (for 1-5 kHz). In contrast, the pass rates were higher for TEOAE screening in the Taylor and Brooks (2000) study than in the present study. The main reason for this difference is likely due to the effect of noise within the screening environments. Taylor and Brooks (2000) conducted all testing within a sound-treated room, whereas we conducted the screenings in regular rooms within each preschool. Taylor and Brooks (2000) reported sensitivity and specificity by comparing the TEOAE screening results with pure-tone screening results. On the other hand, we do not report sensitivity and specificity of the DPOAE protocols.

Our reasoning for not reporting sensitivity is as follows. First, true sensitivity or specificity of the screening protocols cannot be determined unless a diagnostic evaluation of each preschooler would have been completed in a sound-treated booth. Similar to other studies that conducted screenings at the school sites (Sideris & Glatke, 2006; Smiley et al., 2012); we were unable to obtain diagnostic test results. Second, without the true gold standard of a diagnostic evaluation, we are left with less-than-ideal choices for reporting sensitivity and specificity. These choices include 1) making the assumption that every child tested was indeed normal and therefore calculating sensitivity and specificity based on this assumption; or, 2) making the assumption that pure-tone screening results can serve as the gold standard; thus, comparing DPOAE screening protocols to the pure-tone screening protocol results to calculate sensitivity and specificity of the DPAOE protocols. No screening test is completely accurate; however, we concur with the principle that "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 will do nothing to improve our knowledge base (Smiley et al., 2012, p. 35).

Nevertheless, the results of the present study suggested that DPOAE screenings could be used in a preschool population. Clinicians should be aware that each screening measure has its merits. A "pass" for a child using a DPOAE screening does not necessarily mean that the child will "pass" a pure-tone screening, and vice versa (Smiley et al., 2012). Again, there is no way to know which screening measure is more accurate without the diagnostic evaluation results. More generally, DPOAE could be used as part of a screening protocol to aid in the detection of hearing loss in the

pediatric population (Dhar & Hall, 2012). We suggest that using DPOAE screening may allow intervention services to begin sooner for children whose screenings may have otherwise been delayed until the child's cognitive level matured. As previous research has reported, the provision of early intervention services improves a child's speech and language development as well as cognitive outcomes and overall quality of life (Moeller, 2000; Yoshinaga-Itano et al., 1998).

A small negative correlation was found between the participant's age and the amount of time necessary to complete the pure-tone screening protocol. A minimal correlation is understandable because of the participant's need for higher cognitive functioning to condition to the task. However, no significant correlations were found between the participants' age and either DPOAE screening. No correlation was expected because no conditioning was needed and instructions for the DPOAE were minimal. In addition, no significant relationship was expected or found when gender and pass/fail rates of the three screening protocols were compared. This again emphasizes the practicality of using DPOAE across the young pediatric population in detecting hearing loss.

Limitations

All of the participants were recruited from various schools within a limited geographical area (Baltimore County, Baltimore City, and Carroll County). It is important to note that the participants may not be a full representation of the prevalence of middle ear disorders within various socioeconomic statuses or ethnicities. A more heterogeneous participant group would be desirable. Another limitation to note is that a certain amount of error in timing may have occurred when the examiners finished testing and when they stopped timing the procedure. Although all examiners were instructed on the timing protocol in the same manner, it is possible that there was some variation between examiners. Another limitation of the study was the variability of the testing environments. In every school, the quietest possible testing environment was chosen to conduct DPOAE screenings. In some instances the DPOAE screening was conducted in a room unto itself, and in other sites, pure-tone screenings were being conducted in the same room as the DPOAE screenings.

Future Research

While we are cautiously optimistic regarding the applications of these findings to preschool hearing screening protocols, further research is needed to test the true sensitivity and specificity of using DPOAE screenings in comparison to pure-tone hearing screenings in this population as well as others. In future studies, we suggest that a full diagnostic hearing test battery should be completed to determine the efficacy of these screening procedures. Obtaining diagnostic results (perhaps with the use of a portable sound-treated booth) on the same day the screenings take place would

finally answer the questions regarding sensitivity and specificity of these various screening methods within the natural screening environment of a preschool. In addition, future research should evaluate whether conducting screenings on different populations, including cognitive ability, age, socioeconomic status, and ethnicity, would produce similar pass/fail rates. For instance, DPOAE screening protocols may be more useful than pure-tone screening protocols for other populations, such as individuals with intellectual disabilities. Lastly, a more heterogeneous participant group should be used, if possible.

Conclusion

This study investigated pass/fail rates and the time to complete protocols using DPOAE in comparison to pure-tone hearing screening in a preschool population. The data adds to the body of literature concerning the time-effectiveness of DPOAE screening compared to pure-tone screenings, including the feasibility of including 1 kHz in the DPOAE screening protocol in a preschool population, and provides further data regarding pass/fail rates of those protocols. Results suggested that the use of DPOAE is faster than pure-tone screening with relatively similar pass/fail rates. We recommend that clinicians consider adding DPOAE to their current screening protocol (not substituting DPOAE for pure-tone screening), or at least having DPOAE available to screen children who cannot or will not participate in pure-tone screenings. The ease of administration and lack of behavioral response needed from the child make the use of DPOAE screening desirable for the preschool population. The results of this study demonstrated that DPOAE can potentially aid in identifying hearing loss that can interrupt normal language development, impede cognitive growth, and delay the development of a child's socialization skills. Despite the findings of this study, we suggest that further research is needed to compare these various screening methods with the gold standard of diagnostic audiologic test results in the pediatric population and other populations.

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