Effects of Noise Attenuation Devices on Screening Distortion Product Otoacoustic Emissions in Different Levels of Background Noise

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The purpose of this study was to compare the effect of active noise cancellation headphones and standard earmuffs on the ability to screen distortion product otoacoustic emissions (DPOAEs) in the presence of background noise. The time required to screen 1000 to 5000 Hz and 2000 to 5000 Hz (including set up time) was analyzed, as well as the pass/refer for each frequency. Four noise conditions were utilized: quiet, 40 dBA, 60 dBA, and 80 dBA of uncorrelated speech babble. Participants had hearing within normal limits as evidenced through behavioral pure-tone testing, tympanometry, and diagnostic DPOAE measurements. The study included screening DPOAEs from 1000 to 5000 Hz using no headphone, the active noise cancellation headphone, and the standard earmuff in all four noise conditions. Results indicated significant differences between the active noise cancellation headphone and the standard earmuff compared to using no headphone in the time required to screen DPOAEs from 1000 to 5000 Hz in the presence of background noise. Significant differences were also noted in the number of refers recorded. Results suggested that using a modified set up with standard earmuffs to screen DPOAEs in background noise may reduce the time to screen DPOAEs, may provide additional audiometric information that may not be otherwise obtained (1000 Hz), and may reduce the number of false refers due to the background noise.

Introduction

Hearing screening programs seek to identify individuals at risk for auditory problems from a group of normal hearing individuals, and those who “refer” on the screening go on for a full diagnostic evaluation. A hearing screening protocol allows for a large number of individuals to undergo an audiometric procedure with accuracy and validity in a short period of time. Otoacoustic emissions (OAEs) have been shown to be a quick, noninvasive, effective screening tool for newborns and adults when evaluating hard-to-test and normal hearing populations (Owens, McCoy, Lonsbury-Martin, & Martin, 1992).

Two main methods of evoking OAEs via a probe in the external ear canal are used clinically today. Transient evoked OAEs (TEOAEs) present a complex stimulus, such as a click or a tone burst, whereas distortion product OAEs (DPOAEs) present a simultaneous pair of pure tones and record the 2f1-f2 distortion product. A healthy middle and inner ear will produce a response recorded by the probe microphone. The presence of middle ear pathology, cochlear pathology, and/or poor fit of the probe will result in lowered or absent OAEs (Kemp, 2007).

Hearing screenings are often performed in acoustically-poor testing environments. Quiet testing rooms may not be available. For example, Greenwood (2010) measured the average background noise in five preschool facilities in the rooms in which screenings were being conducted. The average background noise levels ranged from 52.8 dBA to 66.3 dBA. Peak background noise levels for screenings at Special Olympics games have been measured as high as 85 dBA (Neumann et al., 2006). It is well known that DPOAE testing in areas with high ambient noise levels in the screening environment will interfere with the recording of an accurate response in a timely fashion (Hall, 2000). Attempting to obtain OAEs in a noisy environment can result in increased test time, thus reducing the number of individuals able to be screened.

The Healthy Hearing program, a part of Special Olympics Healthy Athletes, started in 1998 to provide hearing screening for the participating athletes (Herer & Montgomery, 2006). DPOAEs are an integral part of the Healthy Hearing screening protocol. Athletes are screened with DPOAEs after an otoscopic inspection for occluding cerumen. A "pass" completes the screening. Athletes who fail the DPOAE screening would continue on for tympanometry and possibly pure tone testing. To reduce the number of failing athletes, the ambient noise levels have to be controlled, especially if a quiet screening location is not available. The use of active noise cancellation headphones or passive standard ear muffs was examined as a means to control the amount of ambient noise.

To date, there are few studies which have assessed specific methods for attenuating background noise with DPOAE screenings. In the 2004 German Summer Special Olympics games, attempts at creating a quiet environment for DPOAE screening were made using sound-attenuating ear muffs placed over the DPOAE probes on 184 of the 755 athletes tested, in an outdoor tent area (Neumann et al., 2006). DPOAEs were also recorded without any noise-reducing method (463 athletes), in a sound attenuating van (64 athletes), and in a sound attenuating booth (44 athletes). Peak noise levels recorded for the screening areas were between 75 and 85 dBA. No specific data were recorded regarding the effect of the specially constructed sound-attenuating muffs on the pass/refer rate for the DPOAE station. The authors noted, however, that approximately one-third of the athletes screened did not pass the healthy hearing screening, with 56.1% of those athletes failing the DPOAE and pure tone stations. It was acknowledged that the level of ambient noise, among other reasons, could account for the high refer rate for the summer 2004 German games; however, the authors did not provide information regarding how the earmuffs were adapted for the DPOAE probe or effect of noise reduction techniques on overall pass/refer rates.

Purpose

In order for OAEs to be accurately measured, the response level of the emission needs to be larger than the level of the noise floor. The main problem with using OAEs in a screening setting is the level of ambient noise. Often screenings are held in less than ideal acoustic environments (i.e., cafeterias, rooms with high ceilings, crowded auditoriums), which can create a problem when trying to obtain accurate OAE measurements, especially at frequencies below 2000 Hz (Neumann et al., 2006). Excessive noise can lead to the over-estimation of DPOAE amplitude (especially with already low signal-to-noise ratios), thus reducing the specificity of DPOAE results (Whitehead, Lonsbury-Martin, & Martin, 1993).

The effect of noise on the accuracy and length of DPOAE screening time has been documented; however, to date, there remains a paucity of data regarding the use of sound-attenuating earmuffs to reduce background noise during OAE screenings. Data regarding the effect of sound-attenuating ear muffs on the ability to accurately record DPOAEs can positively affect the screenings in environments with loud background noise, including preschool screenings and the Healthy Hearing Program.

The purpose of this study was to determine the effect of passive noise-attenuating earmuffs and active noise cancellation headphones on the ability to obtain DPOAEs in background noise, as well as the length of time needed to screen DPOAEs in each condition. This study aimed to determine the effect of each type of headphone on the time it takes to screen DPOAEs under noisy conditions, as well as the specificity of pass/refer rates under each condition when compared to not using the headphones or earmuffs. It was hypothesized that the use of either headphone type would result in more accurate pass/refer rates and would reduce the time needed to screen DPOAEs in background noise.

Method

Participants

Thirty adult volunteers participated in this study; however, data from only 29 were included in the analyses. One participant was not included in the statistical analysis because diagnostic DPOAE measurements for one frequency did not meet inclusion criterion. Participants had to sign an informed consent form approved by the Towson University Institutional Review Board. An *a priori* power analysis was conducted to determine the number of participants needed for this study based on Lenth (2009). With $\beta = 0.8$, a sample size of 26 was required. The participants ranged in age from 19 to 34 years, with a mean age of 23 years. In order to be included in the study, each subject needed to have normal hearing (thresholds of 15 dB HL or better, no air-bone gaps for 250 to 8000 Hz including interoctaves), normal diagnostic DPOAEs, normal tympanometric results, and no known cochlear or middle ear pathologies.

Background Noise

Uncorrelated speech babble from the second track of the commercially available Modified Rhyme Test (MRT) compact disc (Cosmos Distributing, Inc.) served as the background noise.

Earmuffs and Headphones

Two types of noise cancellation headphones were used. The active noise cancellation headphone used was the Bose® Quiet Comfort 2 Acoustic Noise Cancelling, around-the-ear headphone (AH), and the standard noise attenuation headphone used was the Bilsom® Leightning L3 noise blocking earmuff (SE). The following adaptations were made to both the SE and AH headphones in order to accommodate the DPOAE probe. Masking tape was fashioned into a loop with the sticky surface facing outward and applied to the sides and top of an extra Bilsom® Leightning earmuff cushion. This cushion was then pressed against the existing cushion of the earmuff (SE) or headphone (AH). The DPOAE probe was threaded through the bottom, between the two cushions, leaving several inches of cord hanging and then placed into the ear canal. The cord was gently pulled to reduce the length of DPOAE cord between the ear and cushion, allowing the probe to fit inside the earmuff/headphone cushion with the cushion snug against the head. The earmuff/headphone was then applied over the opposite ear. Figures 1 through 3 display photos of the headphone modifications.

Figure 1. Masking tape was applied to the top and two sides of a second cushion from a Bilsom Leightning Earmuff. The second cushion was then placed on the existing standard earmuff (SE) or active noise-cancellation headphone cushion (SE shown).

Procedures

Hearing thresholds were determined using the Grason-Stadler Instruments (GSI) 61 audiometer with EAR 3A insert earphones and the Radioear B-71 bone oscillator. Thresholds were determined following the American Speech-Language-Hearing Association (ASHA) guidelines for manual pure-tone audiometry (2005). Middle ear status was determined using the GSI Tympstar. Diagnostic DPOAEs were elicited using the ILO-V.6 OAE software in the Speech, Language & Hearing Center at Towson University.

Figure 2. The probe cord was threaded through the cushions.

Figure 3. The DPOAE probe was inserted into the ear canal and the cord gently pulled to reduce slack and allow the probe to fit securely and comfortably in the ear canal.

The DPOAEs were measured using eight points per octave with L1=65 dB, L2= 55 dB, and an f2/f1 ratio of 1.22. An analysis of each participant's DPOAEs was made using the DP gram as described by Gorga (1993). Screening DPOAE measurements were taken using the AuDX Pro II hand-held OAE screener using a stop criterion of 260 sweeps, f2/f1 ratio of 1.22, and L1= 65 dB, L2= 55 dB. Information regarding the screened measurements was stored in a Dell computer using Microsoft Excel. Results were also recorded on paper, indicating DPOAE results for each condition, as well as timing information. .

The uncorrelated speech babble was presented using the ProTools 7.3 software on an iMac laptop computer. The signal was transmitted from the ProTools 7.3 software by the DigiDesign 002, through balanced line cables which were connected to an 8-speaker KRK System's Rokit5 powered arrangement. The speakers were set at a height of 3.5 feet and were located at 0-, 45-, 90-, 135-, 225-, 270-, 315-, 335-degrees azimuths, 0.75 meters from the participant. The participant was seated in the center of the speaker array. Measurements using the AuDX Pro II took place in the Center for Amplification, Rehabilitation, & Listening (CARL) at Towson University in a 7.5' X 7.0' IAC double-walled booth.

Once all inclusion criteria were met, DPOAE screening measurements were taken in the following conditions for both ears:

1. Without headphones in:
    a. ambient background noise
    b. 40 dBA background noise
    c. 60 dBA background noise
    d. 80 dBA background noise
2. With Bose® Quiet Comfort 2 headphones (AH) in:
    a. ambient background noise
    b. 40 dBA background noise
    c. 60 dBA background noise
    d. 80 dBA background noise e
3. With Bilsom® Leightning earmuffs (SE) in:
    a. ambient background noise
    b. 40 dBA background noise
    c. 60 dBA background noise
    d. 80 dBA background noise

The frequencies that were used for screening DPOAEs included 1000, 2000, 3000, 4000 and 5000 Hz in descending order. These test frequencies follow the protocol of the Healthy Hearing Screening program of the Special Olympics, with the exception of 1000 Hz. Screening included 1000 Hz to determine if lower-frequency DPOAEs, which are most affected by background noise, could be recorded in a noisy environment with the use of noise-attenuating headphones. Being able to screen DPOAEs at 1000 Hz could provide additional audiometric information that otherwise could not be obtained.

Background noise levels were determined based upon measurements taken during the 2008 Maryland Summer Special Olympic games at Towson University. Noise levels were monitored throughout the day of screening and ranged from 41 to 80 dBA. The three noise levels used were as follows: Soft: 40 dBA, Medium: 60 dBA, and Loud: 80 dBA. Noise levels were calibrated at the center of the speaker array via the Ivie IE-35 Audio Analysis System, functioning as a Type I sound level meter.

Three measurements of time were recorded during testing: the length of time for the headphone/probe to be placed on the ear, the length of time needed to record DPOAEs from 2000 to 5000 Hz, as well as the length of time for all five frequencies to be screened (1000 to5000 Hz) under the above background noise conditions. Two time measurements were made to follow the Healthy Hearing Program protocol, as well as to measure the amount of time needed to add 1000 Hz to the screening. Pass/refer rates were also recorded for each frequency under each condition. A refer was recorded if the AuDX Pro II specifically stated "refer" for a specific frequency or if noise was recorded for a specific frequency. If the AuDX Pro II presented with the message of "could not calibrate" or excessive noise levels ("noisy"), the exact answer was recorded and still classified as a refer. The message of excessive noise levels was only recorded if the message continued to appear after selecting "continue" on the testing screen three times in a row.

Measurements using the Knowles Electronic Manikin for Acoustic Research (KEMAR)

Measurements of the background noise on KEMAR were made using the Bruel & Kjaer Digital Frequency Analyzer Type 2131 sound level meter. Noise levels per frequency band from 125 to 8000 Hz for each background noise level were measured using KEMAR without headphones. The same measures were then made with the modified earmuffs and headphones, with the probe cord inserted between the regular padding and the taped-on pad (but without the probe in KEMAR's ear) in order to determine the attenuation of the SE and AH.

Statistical Analyses

Statistical analysis included a 3x4 analysis of variance (ANOVA) for time to determine if there was a significant difference in length of screening time with and without the headphones/earmuffs in noise, with post-hoc testing completed via paired-samples *t*-tests. Independent variables were headphone condition (NH, AH, SE) and background noise condition (quiet, 40, 60, 80 dBA). The dependent variable was the time (in seconds), beginning with setting up the DPOAE (and AH or SE, when appropriate) and ending when the screening results displayed on the AuDX II Pro. Friedman's Tests for repeated measures nonparametric data were completed to determine the significance of pass and refer rates for screening DPOAEs using the headphones/earmuffs in background noise, with post-hoc analysis completed via Wilcoxon signed rank tests. For these analyses, the dependent variable was the number of passes and refers, while the independent variables remained the headphone condition and background noise condition.

Results

Noise Measurements

In order to determine the amount of attenuation of the modified SE and AH, measurements were made on KEMAR for frequency bands from 125 to 8000 Hz. Table 1 displays the noise measures per frequency band in the IAC booth, as measured on KEMAR without the addition of headphones. Tables 2 and 3 display the attenuation for the modified headphones with the probe cord inserted through the headphones, but without the probe in KEMAR's ear, for the SE and AH respectively.

Preliminary Analysis

The length of time it took to set up and screen 2000 to 5000 Hz and 1000 to 5000 Hz in each background noise condition for the right and left ears were compared via paired-sample *t*-tests. Results suggested no significant ear effects; therefore, the data for both ears were combined for all further statistical analyses (N = 58).

Effect of Headphone/Earmuff on Time

For each headphone condition, the following times were recorded: the time to set up before testing, the time to record DPOAEs from 2000 to 5000 Hz for each background noise condition, and the time to obtain DPOAE results for 1000 Hz for each background noise condition. The set up time for each headphone was added to the DPOAE recording times, as significant differences were noted in the set up time between no-headphone (NH), active headphone (AH), and standard earmuff (SE). Data were analyzed via 3x4 repeated-measures ANOVAs. These analyses compared whether there was a statistically significant difference in the timing between any background noise conditions or headphone conditions. Separate ANOVAs were completed for the time to set up and obtain DPOAE results for 2000 to 5000 Hz and for the time to set up and obtain DPOAE results for 1000 to 5000 Hz, with post-hoc analyses via paired-samples *t*-tests using a Bonferroni family-wise correction for each background noise condition ($\alpha = .05/3 = .017$) to guard against the possibility of a Type I error. Descriptive statistics (mean and standard deviation) for all noise and earphone conditions are shown in Table 4.

Time to Set Up and Obtain DPOAEs from 2000 to 5000 Hz

Results for the ANOVA comparing the time it took to set up and obtain DPOAEs from 2000 to 5000 Hz suggested a significant interaction effect between headphone conditions and noise conditions (F (6,342) = 18.69, $p < .001$), as well as significant main effects for headphone condition (F(2,114) = 23.80, $p < .001$) and noise condition (F(3,171) = 114.88, $p < .001$). Post-hoc analyses for the quiet and 40 dBA background noise conditions indicated that recording the DPOAEs from 2000 to 5000 Hz with NH was significantly faster than either AH or SE ($p < .001$ for all paired comparisons). For the 60 dBA background noise condition, both the SE and AH took significantly less time to record the DPOAEs than the NH ($p < .001$ for both paired comparisons), with no significant differences between the SE or AH. For the 80 dBA background noise, the SE took significantly less time to record DPOAEs than the NH (p = .007) as well as the AH ($p < .001$).

Time to Set Up and Obtain DPOAEs from 1000 to 5000 Hz

Results for the ANOVA

Table 1. Noise levels (in dBA) on KEMAR for the background noise conditions.

	Frequency (Hz)									
Noise Condition	125	250	500	1000	1600	2000	3000	4000	6000	8000
Quiet	11.2	5.4	3.0	3.0	6.0	10.2	11.6	8.7	10.2	10.9
40 dBA	26.7	24.1	23.6	22.1	22.6	22.9	19.4	14.9	10.4	10.3
60 dBA	46.0	45.3	45.1	43.1	44.7	41.6	41.1	37.1	27.1	23.4
80 dBA	64.4	66.5	64.8	62.3	61.6	63.2	60.9	56.1	44.0	40.4

Table 2. Noise reduction (attenuation in dBA) on KEMAR for modified standard earmuffs with the probe cord inserted through the headphones.

	Frequency (Hz)									
Noise Condition	125	250	500	1000	1600	2000	3000	4000	6000	8000
Quiet	-2.8	0.0	1.2	2.0	3.6	8.4	7.6	5.7	5.8	5.8
40 dBA	-3.0	1.3	16.0	20.3	20.2	21.1	12.4	9.5	6.0	5.2
60 dBA	-6.5	0.9	16.2	26.9	30.3	24.2	13.6	18.5	16.9	16.9
80 dBA	-4.7	2.8	19.5	25.3	26.5	26.6	16.6	17	18.9	20.3

Table 3. Noise reduction (attenuation in dBA) on KEMAR for modified active noise cancellation headphones with the probe cord inserted through the headphones.

	Frequency (Hz)									
Noise Condition	125	250	500	1000	1600	2000	3000	4000	6000	8000
Quiet	0.0	0.3	-1.0	-2.7	3.5	5.8	2.9	5.2	1.8	5.2
40 dBA	10.0	8.7	9.7	8.4	16.3	18.5	11.1	10.5	2.0	4.6
60 dBA	7.6	9.7	9.7	8.9	20.2	21.9	21.6	22.4	17.4	17.7
80 dBA	8.1	10.8	10.0	9.0	17.5	25.1	23.3	22.0	20.6	21.7

comparing the time it took to set up and obtain DPOAEs from 1000 to 5000 Hz suggested a significant interaction effect between headphone conditions and noise conditions (F (6,342) = 73.44, $p < .001$), as well as significant main effects for headphone condition (F(2,114) = 27.87, $p < .001$) and noise condition (F(3,171) = 306.07, $p < .001$). Post-hoc analyses for the quiet and 40 dBA background noise conditions suggested that the screening of DPOAEs from 1000 to 5000 Hz with NH was significantly faster than either AH or SE ($p < .001$ for all paired comparisons). For the 60 dBA background noise condition, the SE was significantly faster than the AH ($p = .001$), while there were no significant differences between NH and either AH or SE. For the 80 dBA background noise condition, the SE was significantly faster than the AH or the NH ($p < .001$ for both comparisons), with no significant differences between NH and AH.

Table 4. Mean time (standard deviation) in seconds to screen DPOAEs from 1000 to 5000 Hz and 2000 to 5000 Hz.

Noise level	Headphone	1000-5000 Hz	2000-5000 Hz
Quiet	NH	24.5 (6.5)	22.9 (6.4)
	AH	35.4 (4.5)	33.6 (4.4)
	SE	35.4 (5.7)	33.6 (5.5)
40 dBA	NH	25.5 (9.6)	22.9 (6.2)
	AH	35.7 (4.8)	33.3 (4.4)
	SE	35.3 (5.8)	33.5 (5.4)
60 dBA	NH	38.6 (23.9)	24.7 (7.7)
	AH	42.5 (10.8)	34.4 (4.8)
	SE	37.0 (7.4)	33.4 (5.4)
80 dBA	NH	88.3 (33.7)	51.8 (27.2)
	AH	85.0 (27.4)	54.4 (18.6)
	SE	63.3 (20.8)	41.5 (10.9)

Note. NH = no headphone; AH = active noise-cancellation headphone; SE = standard earmuff

Effect of Headphone on Pass or Refer Result

Table 5 provides the detailed pass/refer results for each headphone condition and background noise condition. In quiet and 40 dBA background noise, no significant differences were found between the pass/refer results for headphone conditions at any of the frequencies screened. With 60 dBA of background noise, the number of refers recorded with NH at 1000 Hz increased to six, compared to one refer with AH, and no refers with SE. In 80 dBA background noise, the number of refers for 2000 Hz were 13, five, and two for NH, AH, and SE, respectively. A similar decrease in the number of refers for 1000 Hz were 32, 24, and 10 for NH, AH, and SE, respectively.

Results of the Friedman's test for non-parametric data suggested significant overall results for pass/refer rates between headphones in 80 dBA background noise ($x^2(14) = 241.68$, $p < .001$). Further analysis using the Freidman's tests also suggested significant differences between headphone and background noise conditions for 1000 Hz in 60 dBA ($x^2(2) = 8.86$, $p = .012$) and 80 dBA ($x^2(2) = 24.80$, $p < .001$), as well as for 2000 Hz in 80 dBA ($x^2(2) = 14.92$, $p = .001$). Post hoc analysis found significant differences between the number of refers for headphones/NHs for the following conditions: 1000 Hz at 60 and 80 dBA, as well as 2000 Hz at 80 dBA (see Table 6).

Specific reasons for refers recorded at 1000 Hz in the 60 and 80 dBA background noise conditions, as well as the 2000 Hz in 80 dBA background noise condition, are displayed in Table 7. These conditions were noted as having significant differences between headphone, frequency, and noise conditions using the Wilcoxon Signed Rank test. A majority of refers for 1000 Hz in the 80 dBA background noise (with no-headphone) were the result of a reading of "noisy," or the AuDX Pro II could not complete testing. Although the participant had normal DPOAEs (as evidenced by the diagnostic OAEs), the AuDX Pro II was unable to record a DPOAE in the presence of 80 dBA of noise.

Table 5. DPOAE pass/refer results for each background noise condition.

Headphone Condition	Noise	1kHz	2kHz	3kHz	4kHz	5kHz
No Headphone	Quiet	58/0	58/0	58/0	58/0	58/0
	40 dBA	58/0	58/0	57/1	58/0	58/0
	60 dBA	52/6	57/1	57/1	58/0	58/0
	80 dBA	26/32	45/13	55/3	56/2	56/2
Active Headphone	Quiet	58/0	57/1	58/0	58/0	57/1
	40 dBA	58/0	58/0	58/0	58/0	57/1
	60 dBA	57/1	57/1	58/0	58/0	57/1
	80 dBA	34/24	53/5	57/1	58/0	54/4
Standard Earmuff	Quiet	58/0	58/0	58/0	58/0	57/1
	40 dBA	58/0	58/0	58/0	58/0	57/1
	60 dBA	58/0	58/0	58/0	58/0	57/1
	80 dBA	48/10	56/2	56/2	57/1	56/2

Note. Number of passes/number of refers.

Table 6. Significant differences in DPOAE "refers" for the Wilcoxon Signed Rank Test.

Frequency	Noise level	Comparison	Z Value	p-value
1000 Hz	60 dBA	SE - NH	-2.449	0.014
	80 dBA	SE - NH	-4.69	< 0.001
		SE - AH	-3.3	0.001
2000 Hz	80 dBA	AH - NH	-2.309	0.021
		SE - NH	-3.317	0.001

Note. NH = no headphone; AH = active noise-cancellation headphone; SE = standard earmuff

Table 7. Specific "refer" reasons pertaining to conditions found to have significant differences via the Wilcoxon Signed Rank Test.

Frequency	Noise level	Result	NH	AH	SE
1000 Hz	60 dBA	Could not calibrate	0	0	0
		Could not Test	1	0	0
		Noisy	5	1	0
		Refer	0	0	0
		Total	6	1	0
	80 dBA	Could not calibrate	1	0	0
		Could not Test	19	13	4
		Noisy	12	11	6
		Refer	0	0	0
		Total	32	24	10
2000 Hz	80 dBA	Could not calibrate	1	0	0
		Could not Test	4	0	1
		Noisy	8	5	1
		Refer	0	0	0
		Total	13	5	2

Note. NH = no headphone; AH = active noise-cancellation headphone; SE = standard earmuff

Discussion

The purpose of this study was to examine the effect of active noise-cancelling headphones (AH) and standard hearing protection earmuffs (SE) on the ability to screen DPOAEs in background noise in a timely and accurate manner.

Effects of Headphone/Earmuffs on Time to Set Up and Obtain DPOAEs from 2000 to 5000 Hz

Results indicated that the time needed to screen 2000 to 5000 Hz (including set up time) was significantly reduced with the use of a SE or AH in high noise levels (i.e. 60 dBA or higher) when compared to NH. Specifically, in 60 dBA background noise, both SE and AH were equally effective in decreasing the time needed to set up and screen DPOAEs from 2000 to 5000 Hz. In 80 dBA background noise, the SE was more effective than NH or the use of the AH in reducing time to screen 2000 to 5000Hz. For those screening programs whose protocol includes screening from 2000 to 5000 Hz (such as the Special Olympics Healthy Hearing program), this finding is especially noteworthy. The use of a standard hearing protection earmuff in their screening protocol may increase the number of people who are able to be screened, regardless of the noise environment. These findings are consistent with Hall (2000), who suggests limiting noise levels when obtaining DPOAEs.

Effects of Headphone/Earmuffs on Time to Set Up and Obtain DPOAEs from 1000 to 5000 Hz

Similar results were recorded for the time needed to screen 1000 to 5000 Hz. In 60 and 80 dBA background noise, the SE was more effective in reducing the time needed to set up and screen all five frequencies. For those who are hesitant to include 1000 Hz in DPOAE screening because of the negative effect of background noise (Zhao & Stephens, 1999), these results suggest that it may be possible to add this frequency without significantly increasing the time needed to screen DPOAEs in noise.

In contrast, in lower noise levels (less than or equal to 40 dBA) the SE and AH required significantly more time than the NH condition. When testing in a relatively quiet setting, the use of AH or SE devices may not be warranted. However, in noisy conditions, such as those found at the 2008 Special Olympics held at Towson University, it may take several minutes to obtain DPOAE results. Using the SE to help attenuate the background noise may decrease the time needed to screen, thus reducing the amount of time needed to screen each individual and increasing the number of individuals who can be screened each day.

Effects of Headphones/Earmuffs on Pass/Refer Results

The difference in the number of refers between NH and the use of a headphone/earmuff was significant, especially when screening 1000 Hz. This finding supports the hypothesis that the use of either type of headphone would result in more accurate pass/refer results than no-headphone. No significant differences in pass/refers were noted for 5000, 4000, or 3000 Hz, which is in agreement with the idea that DPOAEs are more easily recorded for mid and high frequencies than for low frequencies (below 1500 Hz) even with background noise (Gorga et al., 1993). Improving the signal-to-noise ratio (SNR) will increase the likelihood that a true DPOAE has been recorded at 1000 Hz, as poor SNRs are one of the main reasons for a refer to be noted at 1000 Hz even in normal ears (Gorga et al., 1993).

Refers recorded for 1000 Hz at 80 dBA with NH were the result of either "could not test" or "noisy." With AH, the number of refers reduced from 34 to 24 when compared to the NH. The number of refers was reduced even more with the use of the SE (34 refers reduced to 10 refers). Screening 1000 Hz in 60 dBA of noise using the AH reduced the number of refers from six to one and from six to none when using the SE. The number of refers recorded when screening 2000 Hz in 80 dBA of noise was also remarkable, with refers reducing from 13 to five with the AH and 13 to two with the SE.

Overall, the number of refers were reduced the most when using the SE. When combined with the significant reduction in time found when screening 1000 Hz, the SE was better at improving the ability to screen DPOAEs in noise than the AH. This finding is important because the SE is less expensive than the AN and would, therefore, be more affordable for screening programs. These results may be due to the actual noise attenuation of the SE for the frequencies tested (with or without the addition of the second cushion) when compared to the AH.

The findings also lead to the possibility of adding 1000 Hz to the Healthy Hearing screening protocol and other DPOAE screening protocols that normally screen 2000 to 5000 Hz. If it is possible to include more frequencies in hearing screening (without significantly increasing the time needed to screen each athlete), the use of the SE would be justified, especially in poor screening environments.

Limitations of the Study

Although current results suggest that the use of a SE for screening DPOAEs in high levels of background noise may reduce the number of refers due to noise, testing was performed on adults with normal hearing. Applications of this study to other populations, such as pre-school and school-age children, would be necessary to generalize findings to those who participate in hearing screenings. The method in which each headphone/earmuff was manipulated to accommodate the DPOAE probe is also a limitation of this study. A cushion made specifically for accommodating the DPOAE probe would likely eliminate the possibility of changing the acoustics of the existing ear cushions. The accommodations required for the DPOAE probe also may affect the fit of the probe itself. Proper fit of the DPOAE probe is essential for reducing the effect of noise on the recording of the DPOAE and must be taken into consideration when altering the way it is inserted into the ear canal (Hall, 2000). It should be noted that, depending on the size and configuration of the probe and cord, different OAE screening devices may or may not be able to accommodate the probe under the earmuffs.

Using only the AuDX Pro II OAE hand-held screener limits the ability to generalize the findings of this study to all screening environments and protocols. Although the AuDX Pro II is used by the Special Olympics Healthy Hearing Screening, it may not be the equipment of choice for other screening programs. Also, as only one type of AH and one type of SE were used, other headphones/earmuffs should be evaluated for their efficiency. Evaluating specific costs against actual benefit in noise of reduced screening times and more accurate screenings will provide more information to organizations that may benefit from the use of a headphone or earmuff in their screening protocols.

Future Research

More research is necessary to apply the findings of this study to the general population. The use of the AuDX Pro II in screening environments may be more effective if a cushion is made specifically to accommodate the DPOAE probe. It would also be beneficial to study the impact of headphones/earmuffs on the ability to screen DPOAEs to other populations, including individuals with hearing loss. Although the effect of the SE on refer rates may not be applicable to those with hearing loss, reducing the time spent screening DPOAEs will reduce the amount of time those with true hearing loss spend as they continue through the hearing screening stations. Finally, evaluation of the AuDX Pro II in comparison with other OAE screening devices should be considered.

Conclusion

For individuals with normal hearing, the use of a standard hearing protection earmuff (SE) significantly reduced the amount of time needed to screen DPOAEs from 2000 to 5000 Hz, as well as from 1000 to 5000 Hz, in background noise at or above 60 dBA. Although the active noise-cancellation headphone (AH) also reduced the time needed to screen DPOAEs in these noise levels, the SE was more efficient. The effect of the SE and AH on reducing the number of referrals recorded due to noise was also significant for 1000 and 2000 Hz for background noise levels at or above 60 dBA. It is noteworthy that the SE was more effective than no headphone (NH) and the AH in reducing the number of refers recorded. In summary, results suggested that using a modified set up with standard earmuffs to screen DPOAEs in moderate to high levels of background noise may reduce the time needed to screen DPOAEs, may provide additional audiometric information (1000 Hz) that may not be otherwise obtained, and may reduce the number of false referrals due to the background noise. This information is potentially noteworthy for preschool screening programs that include DPOAEs in their protocol, as well as other organizations (such as the Special Olympics Healthy Hearing program).

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