DISTORTION PRODUCT OTO-ACOUSTIC EMISSION SPECTRA AND SPEECH IDENTIFICATION SCORES IN INDIVIDUALS WITH AUDITORY NEUROPATHY SPECTRUM DISORDER

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Abstract

The objective of the study was to compare the specific patterns in distortion product oto-acoustic emissions (DPOAE) spectra and its relationship with speech identification scores in individuals with auditory neuropathy spectrum disorder (ANSD). The DPOAE spectra and speech identification scores of 15 normal hearing and 30 individuals diagnosed as having auditory neuropathy spectrum disorder were studied and compared. DP-gram Spectra was also analyzed in patients with auditory neuropathy spectrum disorder who were further divided into good and poor performers based on their speech identification scores. The results indicated that the mean DPOAE amplitudes across frequencies obtained for good and poor performers of ANSD suggests that the irregularity in DPOAE spectra is more for poor performers than the good performers. The number of notches, depth of notches and the width of the notches are more for poor performers with ANSD. In conclusion, the findings of the present study suggest that individuals with auditory neuropathy spectrum disorder exhibit subtle abnormality in the peripheral auditory system.

Key words: *Auditory Neuropathy Spectrum disorder, DP-gram Spectra, Irregularities, Speech Identification Scores.*

Introduction

Oto-acoustic emissions (OAEs) are usually inaudible sounds measured in the ear canal through a sensitive microphone. Otoacoustic emissions are derived from the active amplification by outer hair cells and linked to outer hair cell electro-motility (Brownell, 1990). These are used extensively in the recent years for different clinical applications. Otoacoustic emissions can be generated spontaneously (SOAEs) and can also be evoked using clicks (transient-evoked otoacoustic emissions, TEOAEs), pure tones (stimulus-frequency otoacoustic emissions, SFOAEs), or two tones presented together (distortion product otoacoustic emissions, DPOAEs). DPOAEs are one type of evoked OAEs that are produced by the ear in response to two primary tones (f1 and f2; f2 > f1) presented simultaneously to the same ear. The most robust DPOAEs are measured at the 2f1-f2 frequency (Lonsbury-Martin & Martin, 2001). DPOAEs reflect the audiometric threshold at the measured frequencies. DPOAEs are absent in cochlear loss of 30-40 dB at a particular frequency. The level of DPOAE responses tends to decrease following exposure to intense sounds or in response to certain drugs that induce OHC damage (Attias & Bresloff, 1996; Bhagat & Davis, 2008; Knight, Kraemer, Winter & Neuwelt, 2007).

One of the explanations for the origin of 2f1-f2 DPOAEs is the two-source interference model involving nonlinear generation near the place of maximum overlap of the primary tones on the basilar membrane, and the liner reflections between the place of distortion product on the basilar membrane and the oval window (Dhar, Talmadge, Long, & Tubis, 2002; Talmadge, long, Tubis, & Dhar, 1999; Talmadge, Tubis, Long, & Piskorski, 1998). DPOAEs are characterized by a rippled pattern of maxima and minima when recorded with high resolution primary-tone frequencies. This results in a fine structure DPOAEs, which is believed to emerge as a result of interference between the generator and reflecting sources. Depth of the notches of DPOAE fine structure varies up to 20 dB regardless of frequency (Gaskill & Brown, 1990; He & Schmiedt, 1993; Heitmann, Waldmann & Plinkert ., 1996) and a periodicity of 3/32 octave (He & Schmiedt, 1993; Mauermann, Uppenkamp, van Hengel & Kollmeier, 1999).

Reuter and Hammershøi (2006) developed an algorithm to measure the occurrence of notch height, and spacing of peaks in the DPOAE fine structure of normal-hearing individuals. They suggested that in addition to DPOAE levels, the DPOAE spectral profile may be useful in distinguishing between individuals with varying degrees of hearing sensitivity within the normal range. This information may be useful in

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identifying subtle impairment in outer hair cells (OHC). Zhao and Stephens (2006) also reported notches in fine structure DPOAE amplitude in individuals with family history of hearing impairment. Mathew (2003) observed abnormal DPOAE fine structure notches in parents of children with hearing impairment between 1-3 KHz regions in a majority of the possible carriers. She concluded that analyzing the fine structure of DPOAEs may be useful in finding sub-clinical and subtle deviations from normal hearing individuals.

DPOAE fine structure can provide additional information on cochlear status, but the measurement of fine structure DPOAEs are time consuming for many commercially available instruments and uses low primary-tone resolution of around 1/8 octaves. He and Schmiedt (1993) reported DPOAE spectra shows more peaks with 1/64 octave resolution than compared with 1/16 and 1/32 octave band steps. However, the DPOAEs spectral peaks obtained using 1/16 octave frequencies were similar to those obtained at 1/32, and 1/64 octave steps. For these reasons, DPOAE fine structure measurements have not been used in general clinical practice because of excessive time consumption for recording. However, spectral features remain similar in low and high freq resolution DPOAE (He & Schmiedt, 1993) and thus DPOAE spectra can measurements with lower resolution of the primary tones also.

OAE measure has been an integral part of audiological test battery to identify Auditory Neuropathy Spectrum disorder. ANSD is described as a hearing disorder characterized by abnormal auditory nerve functioning in presence of normal cochlear receptor hair cell activity (Starr, Picton, Sininger, Hood & Berlin, 1996). Cochlear responses like otoacoustic emissions and /or cochlear microphonics are present indicating normal functioning of outer hair cells (Berlin, 1999; Santarelli & Arslan, 2002; Starr et al., 1996). However, most of the studies have used the conventional DP gram to measure DPOAE amplitude in individuals with ANSD. There is dearth of information regarding the fine structure DPOAE amplitude in individuals with ANSD. Thus, in the present study DPOAE spectral characteristics were considered, to determine whether individuals with ANSD would exhibit any specific pattern in DPOAE spectra.

Speech identification ability varies considerably among individuals with Auditory Neuropathy Spectrum disorder. However, approximately 60 to 70% of individuals exhibit poor correlation between their speech identification scores and the pure-tone thresholds (Sininger & Oba, 2001, Zeng, Oba, Garde, Sininger, & Starr, 1999). In the present study, an attempt was also made to determine the relationship between the DPOAE spectra and varying speech identification scores in individuals with ANSD.

Objectives of the study: The primary objective of this study was to determine whether DPOAE spectral peaks in distortion product grams (DP-grams) obtained with 1/8 octave primary-tone steps significantly differed between individuals with normal hearing and Auditory Neuropathy Spectrum disorder and also to observe whether there is any specific DPOAE spectra patterns in relation to speech identification scores that is obtained in individuals with Auditory Neuropathy Spectrum disorder.

Ethical Considerations: In the present study, all the testing procedures done were using non-invasive technique and all the procedures were explained to the patients and their family members before testing and informed consent has been taken from all the patients and their family members for participating in the study.

Method

Participants: The participants were categorized into two groups with control group consisting of 15 (7 males and 8 females) with normal hearing and a mean age of 23.5 years. Participants in the control group had pure tone thresholds within 15 dB HL and speech identification scores of 100 % in quiet at 40 dB SL on routine speech audiometry. They also had normal tympanometric results with both ipsilateral and contralateral reflexes present. The experimental group consisted of 30 individuals (15 males and 15 females) with acquired Auditory Neuropathy Spectrum disorder with a mean age of 30.2 years. The participants in the clinical group had pure tone thresholds less than 60 dB HL and had symmetrical sensorineural hearing loss in both ears. These participants had normal tympanometric findings with absent ipsilateral and contralateral acoustic reflexes and auditory brainstem responses. An otological evaluation was also performed to rule out any middle ear disorders. All the participants in the experimental group had TEOAEs suggestive of normal hair cell functioning and absent abnormal auditory brainstem responses was the basis to diagnose them as having Auditory Neuropathy Spectrum disorder. A neurologist confirmed the diagnosis with a detailed clinical neurological examination.

The participants in the clinical group were further categorized into two sub groups' namely good performers (15 individuals with ANSD) and poor

performers (15 individuals with ANSD) based on their speech identification scores in quiet for phonemically balanced words developed by Yathiraj and Vijayalakshmi, (2005). The individuals with speech identification scores of more than 50% were considered as good performers and the individuals with speech identification scores of less than or equal to 50% were considered as poor performers (Narne & Vanaja, 2008). However, all the participants in the clinical group exhibited very poor speech identification scores at 0 dB Signal-to-Noise ratio (SNR).

Procedure: To estimate the pure-tone air conduction thresholds and speech identification scores, a calibrated dual channel Grason Stadler (GSI-61) diagnostic audiometer with TDH-39 headphones housed in MX-41/AR ear cushions was used. The bone conduction thresholds were estimated with a Radio Ear B-71 bone vibrator. Pure tone testing was done with a Modified Hughson and Westlake procedure (Carhart & Jerger, 1959). Speech identification testing was done with monitored live voice presentation of phonemically balanced words in Kannada (Yathiraj & Vijayalakshmi, 2005) at 40 dB SL (*re:* SRT). Speech Perception in Noise test was also administered at 0 dB SNR using the word list developed by Yathiraj and Vijayalakshmi (2005). Immitance evaluation (tympanometry and acoustic reflex testing at 500, 1000, 2000 and 4000 Hz) was carried out with a calibrated middle ear analyzer (GSI-Tympstar V 2.0) and a 226 Hz probe tone.

TEOAEs were measured with a calibrated OAE analyzer ILO (V6) for non-linear click trains presented at 80 dB peak equivalent SPL. An emission was considered to be present if the waveform reproducibility was more than 50%, and the overall signal to noise ratio was more than 3 dB at least at two frequency bands. Auditory Brainstem Responses (ABR) were recorded using Intelligent Hearing Systems (IHS) instrument with ER-3A insert earphones, and 100 µsec click stimuli at a level of 90 dB nHL, at 11.1 Hz presentation rate with a filter setting of 100 Hz to 3000Hz. An identical protocol was incorporated to test all subjects. ABR testing was performed twice to ensure reproducibility of waveforms. All testing was completed in a sound treated room.

DPOAE measurement was done using the same ILO V6-USB system (Otodynamics Ltd.) along with a periodically calibrated probe. The primary frequency tones were generated through the ILO V6 software and the F2 frequency varied from 842 – 7996 Hz. The data was collected for 8 points per octave for two sweeps across the frequencies tested. To determine the optimal DPOAE responses, a constant F2 and F1 frequency ratio of 1.22 was used as recommended by Harris, Lonsbury-Martin, Stagner, Coats, and Martin (1989). The levels of the primary tones were 65 dB SPL for L1 and 55 dB SPL for L2. DPOAE measurement was done for each ear separately. DP-grams were obtained by plotting the amplitude of the DPOAE as a function of f2 frequency. Each f2 frequency was presented a minimum of two times, and when the DPOAE levels had stabilized, the testing was terminated.

The parameters that were considered from each DP-Gram acquired are:

1. Grand mean average: The average of DPOAE absolute levels for all the 25 frequencies for each ear.
2. Number of notches: A notch was defined when the difference in amplitude of peak and trough of the notch was at least 6 dB.
3. Depth of the largest notch: A notch was decided as the largest if it had maximum amplitude among the notches in the DP-gram and its amplitude was considered.
4. Width of the notch: the difference in frequency (Hz) between the two extreme edges of the notch.

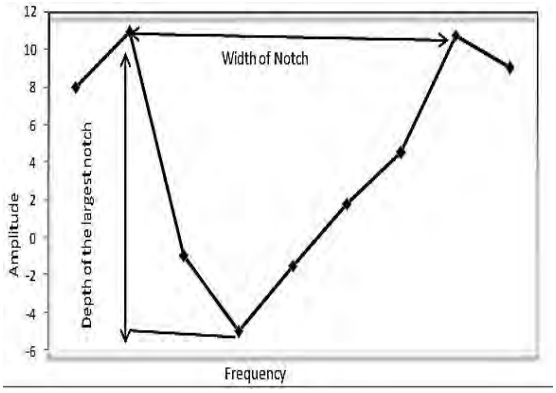

Figure 1: The figure depicts the method used in measurement of width of the notch and depth of the largest notch.

The data points at the low- and high-frequency endpoints 842 Hz and 7996 Hz respectively of the DP-Grams were excluded for further analysis. The low frequency end point was contaminated by noise and high frequency end point had very less amplitude in majority of the subjects. The values of the above mentioned parameters were noted and used for comparison across the group and also with the speech identification scores obtained in the clinical group.

Results and Discussion

The grand mean average of DPOAE amplitude, number of notches in each DP-gram, depth and average width of notches was calculated for each group (control group and two clinical groups). The grand mean average of DPOAE amplitude was calculated at all 25 frequencies for the three groups. The mean, standard deviation and range of DPOAE amplitude obtained from the both subgroups of ANSD are depicted in Table 1.

Table 1: The mean, standard deviation (SD) and range of the DPOAE amplitude in dB SPL of individuals with Auditory Neuropathy Spectrum disorder of both the groups

Frequency (Hz)	Poor Performers of ANSD			Good Performers of ANSD		
	Mean	SD	Range	Mean	SD	Range
916	7.75	8.73	-6.6 -19.5	7.78	8.37	-10 -19.6
1001	10.11	7.54	-0.2 – 22.3	9.35	8.75	-6.1 – 21.4
1086	11.09	9.28	-7.1 – 24.5	9.04	9.14	-10 – 21.6
1184	14.23	8.83	-4.3 – 23.4	10.84	7.97	-4.2 – 23.9
1294	15.95	6.84	4 – 24.9	11.48	9.15	-8 – 24
1416	14.85	6.49	1.6 – 23.2	9.06	10.17	-6 -24.1
1538	14.28	8.02	-1 – 23.8	10.81	7.84	-0.5 – 27.1
1685	11.45	9.17	-11.1 – 21.7	10.64	6.21	1.8 – 19.8
1837	12.21	6.83	-1.5 – 19.8	9.38	7.91	-6.7 – 19.6
2002	9.94	4.57	1.8 – 15.7	7.38	10.06	-11.4 – 23.7
2185	10.42	7.55	-1.8 – 19	8.26	7.99	-3.1 – 20.3
2380	7.96	6.72	-6.8 – 20.7	6.1	9.81	-13 – 23.2
2600	4.60	5.42	-5.5 – 12.1	7.71	8.09	-10 – 17.7
2832	9.19	6.96	-3.3 – 19.2	20.48	5.72	-16.4 – 21.7
3088	8.1	8.05	-9.3 – 16.6	6.21	11.38	-12.8 – 22.3
3369	5.94	7.03	-9.6 – 15.9	8.91	7.31	-0.9 – 20.4
3662	7.29	6.59	-3.8 – 15.7	8.55	7.65	-0.8 – 21
4004	8.79	7.18	-4.1 – 20.7	9.01	8.24	-6.7 – 20.8
4358	5.84	6.35	-2.9 – 14.1	10.56	5.16	2.7 – 20.9
4761	7.1	5.48	-5.9 – 14.4	7.26	9.24	-11 – 18
5188	5.57	8.51	-10.4 – 17.3	17.03	37.41	-9.9 – 14.3
5652	6.81	9.59	-13.7 – 15.8	5.57	10.11	-11.4 – 17.7
6165	5.83	9.97	-16 – 17.8	7.86	9.65	-17.4 – 11.5
6726	1.67	9.72	-13.4 – 15.2	-4.93	10.77	-21.4 – 12.9
7336	-1.92	9.73	-18.1 – 8.8	-8.45	9.44	-22.5 – 14.8

The mean DPOAE amplitude obtained for normal hearing, good performers of ANSD and poor performers of ANSD were plotted across all the 25 frequencies and shown in figure 2. The figure shows that the mean DPOAE spectrum curves obtained were smooth for normal hearing individuals. However, mean DPOAE spectrum amplitude curves were more irregular for individuals with ANSD. The irregularities are more for poor performers than the good performers. It can be observed that, at mid-frequencies both ANSD and normal hearing group showed similar OAE amplitude. However, at high frequencies, normal hearing individuals had higher OAE amplitude and individuals with Auditory Neuropathy Spectrum disorder had relatively lesser amplitude.

The results suggest that there was a significant difference in DPOAE amplitude [F (3, 100) = 122.9, $p < 0.01$)] across the three groups. Duncan's Post hoc test was carried out to determine which of the groups were significantly different from each other. The results are depicted in Table 2. It shows that there was a significant difference between normal and both the clinical groups. There was no significant difference between good and poor performers with ANSD.

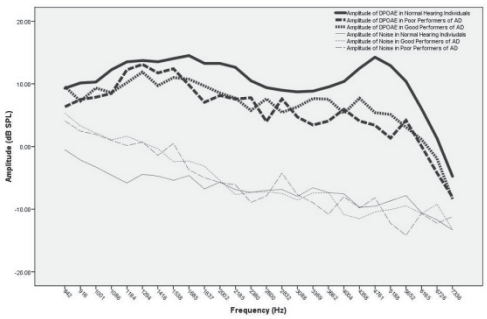

Figure 2: The darker bands represent the mean DPOAE amplitude in all the three groups and the lighter bands represent the noise floor in the respective groups.

Table 2: Duncan's post hoc table to determine significant difference across the three groups

	Good performers ANSD	Poor performers ANSD
Normal hearing	Significant difference ($p < 0.05$)	
Good performers ANSD	No significant difference	

The notches found in DPOAE spectrum in individuals with Auditory Neuropathy Spectrum disorder were more at high frequencies. The number of notches and larger depth of these notches might have reduced the amplitude of DPOAE, at high frequencies in individuals with ANSD. The higher amplitude of evoked otoacoustic emission in patients with Auditory Neuropathy Spectrum disorder can be attributed to lack of efferent suppression of otoacoustic emissions. Thus, the larger amplitude at low frequencies compared to high frequencies might suggest that there could be lack of efferent inhibition which is prominent at low- and mid-frequency region of the cochlea in individuals with ANSD resulted in greater amplitude at those frequencies compared to high frequencies.

The studies reported in literature have used either 1/32 (Mathew, 2003) or 3/32 (He & Schmiedt, 1993; Mauermann *et al.*, 1999) per octave DPOAE fine structure measures and reported the presence of notches in normal hearing individuals. In the present study, 8 points per octave was considered for measuring DPOAE amplitude. The wider range used to record DPOAE amplitude might have resulted in smoothening of curves in individuals with normal hearing.

The irregularities in peaks and notches in DPOAE were observed in both the sub groups of ANSD. DP-gram obtained for a participant with normal hearing, a patient with ANSD who had good speech identification scores and another patient with ANSD with poor speech identification scores are shown in figure 3. The number of notches, depth of notches and the width of the notches are more for the participant who is a poor performer. It can also be observed that the notches are confined more at the high frequencies in the poor performer compared to the good performer.

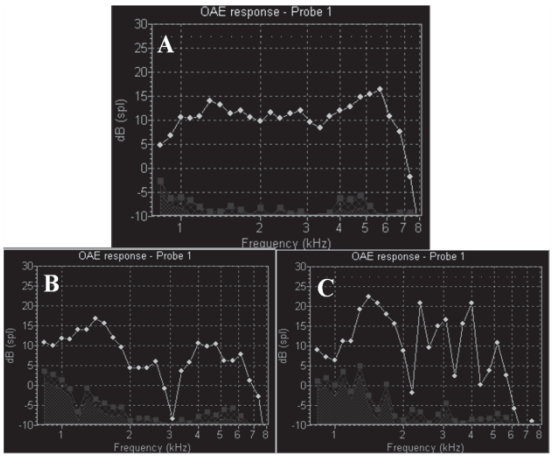

Figure 3: DP-gram of a randomly selected individual from each group of participants. A) Normal Hearing individual, B) Individual with Auditory Neuropathy Spectrum disorder whose speech identification score was better, and C) Individual with Auditory Neuropathy Spectrum disorder who had poor speech identification scores.

DPOAE spectral characteristics were calculated and its relationship with speech identification scores was determined. The normal hearing group had smooth curve with slight irregularities but the amplitude of these dips was less than 6 dB. Hence, the number of notches, depth of the largest notch and the average notch width (in Hz) was calculated for both good and poor performers having ANSD. The mean and SD were calculated for all the parameters and the results are depicted in Table 3.

Table 3: The mean and standard deviation for the number of notches, depth of largest notch and average width of notch for good and poor performers of ANSD.

Groups	*N*	*Number of Notches*			*Depth of largest notch (dB)*			*Average width of notch (Hz)*	
		Mean	*SD*	*Range*	*Mean*	*SD*	*Range*	*Mean*	*SD*
ANSD good performer	15	2	0.65	1-3	11.23	3.2	7.4 –17.3	499.75	151
ANSD poor performer	15	3.42	1.01	2-5	13.3	4.2	8.3 – 22.5	1071	257

The statistical analysis of the DPOAE spectral parameters suggests that the number of notches which had amplitude of greater than 6 dB was more in poor performers of ANSD. The depth of the largest notch and the average width of the notch was also more in individuals with ANSD who had poor speech identification scores. Independent sample t-test was carried out to determine whether the parameters were significantly different across the two sub groups

of ANSD (good and poor performers). The results of independent t-test showed that there was a significant difference in the number of notches [t (27) = 4.53, p < 0.001)] and average width of the notch [t (27) = 8.33, p < 0.001)] between good and poor performers with ANSD. However, there was no significant difference [t (27) = 1.49, p > 0.05)] between the two groups when the depth of largest notch was compared across the groups.

The increased number of notches and larger average width of notch in the DPOAE spectra are seen in individuals with poor speech identification scores with ANSD. This could possibly indicate abnormal frequency resolution in individuals with ANSD. Thus, the impaired frequency resolution at the level of cochlea would lead to poor speech perception. Dhar et al. (2009) also reported correlation between brainstem evoked responses for speech and DPOAE responses. They suggest that poor coding at the level of brainstem can be correlated with abnormal DPOAE measures and there can be a correlation in clinical population. Thus, the abnormal brainstem responses seen in patients with ANSD could also be related to abnormal DPOAE spectra. Zhao and Stephens (2006) also reported dips and notches in individuals with obscure auditory dysfunction whose pure-tone thresholds are normal but have difficulty listening in presence of noise. Mathew (2003) reported abnormal notches in fine structure DPOAE even when the overall DPOAE amplitude was normal in individuals in possible carriers. This suggests that the abnormal DPOAE spectral pattern observed in individuals with ANSD in the present study is associated with subtle abnormality in auditory system and might be resulting in poor understanding of speech in individuals with ANSD.

Conclusions

The results of the current study show that normal hearing individuals had smooth DP-gram, whereas, individuals with Auditory Neuropathy Spectrum disorder showed notches in DP-gram. This study also reveals that with the increase in the number of notches and/or increased depth of notch, there is a significant reduction in the speech identification scores. The average peak width is also more in individuals with ANSD with poor speech identification scores. The findings of the present study suggest that individuals with Auditory Neuropathy Spectrum disorder are likely to have more problems in understanding speech as the number of notches increases. The multiple notches and the increased width of notches could indicate a subtle abnormality in the auditory system which needs to be delineated. Thus, analyzing the DPOAE spectra of individuals with ANSD is useful in understanding sub-clinical and subtle deviations from normal.

Implications of the study: The study provides an insight into the subtle abnormalities in finer aspects of DPOAE in individuals with Auditory Neuropathy Spectrum disorder. DPOAE spectra could be used as a tool to identify severity of difficulty in speech perception. It also suggests that DPOAE spectra curve can be used to predict perceptual consequences of Auditory Neuropathy Spectrum disorder in pediatric population in whom speech identification scores cannot be obtained. It also highlights the need for further studies to identify whether any specific gene is related to this type of pattern which leads to Auditory Neuropathy Spectrum disorder.

Declaration of Interest: The authors report no conflicts of interest. The authors alone are responsible for the content and writing of the paper.

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