ORIGINAL ARTICLE

Role of Distortion Product Otoacoustic Emissions (DPOAES) In Detecting Early Hearing Impairment in Individuals With Normal Pure Tone Audiometry (PTA)

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Abstract

The objective of this study was to determine whether deterioration in cochlear function, as evaluated by distortion product otoacoustic emissions (DPOAE), exists before the elevation of audiometric threshold. The effect of aging on DPOAE was evaluated in 150 individuals in the age group of 21-65 years with clinically normal hearing. Age dependency of DPOAE level was clearly observed in DP-gram. In elderly persons, DPOAE levels for higher frequency primaries were significantly lower than in younger persons, when no remarkable change of audiometry threshold was noted. These results imply that the DPOAE level can be a sensitive indicator for age-related cochlear dysfunction.

Keywords

Cochlear Function, Distortion Product Otoacoustic Emissions (DPOAE)

Introduction

Hearing is the ability to perceive sounds. Sound occurs over a wide spectrum of frequencies. The human ear is sensitive to a frequency band within that spectrum expressed in decibels (dB). Frequencies capable of being heard by humans are called audio or sonic. Loss of the ability to hear sound frequencies in the normal range of hearing is called hearing impairment (1).

When sound reaches a healthy cochlea within an ear canal, it stimulates the sterocilia of the outer hair cells resulting in amplification and propagation of sounds along the basilar membrane. This is called as an electromotile response, which occurs from the conversion of electrical to acoustical energy.(2) Acoustical energy is represented by otoacoustic emissions (OAEs). Thomas Gold introduced OAEs in the year 1948 and David Kemp practically demonstrated their usefulness in the year 1978. The taxonomy for OAEs is based on the theory that they arise from nonlinear, electromechanical distortion within the human cochlea, which creates a source of energy that is measured in the outer ear as emission.(3) OAEs are classified as either Spontaneous OAEs or Evoked OAEs. SOAEs are recorded without external acoustic stimulation and are present in only 50% of normal hearing ears, thus having little clinical value; EOAEs are obtained by presenting external stimulus to the ear and are present in nearly all normal hearing ears. Transient evoked OAEs, stimulus frequency OAEs and distortion product OAEs are three subclasses of EOAEs. TEOAEs require click stimulus, SFOAEs require continuous pure-tone stimulus, and DPOAEs require two pure tones as stimulus to evoke emission that differ slightly in frequency (4).

Pure tone audiometry (PTA), the key hearing test used to identify hearing threshold levels of an individual, enables determination of the degree, type and configuration of a hearing loss and thus provides the basis for diagnosis and management. But since, it relies on patient response to pure tone stimuli for the behavioural measurement of hearing threshold, it is a subjective test and is used in adults and children old enough to cooperate with the test procedure. A pure-tone audiogram only measures thresholds, rather than other aspects of hearing such as sound localization. Also, it can detect the hearing loss only once, it is already established. The bottom line is, audiogram is a diagnostic tool and it is relatively insensitive to multiple important aspects of hearing and listening. Of importance, a normal audiogram (or a normal pure-tone screening result) does not and cannot indicate normal "hearing" or "normal listening" ability (5).

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Distortion product otoacoustic emissions(DPOAE)

When two tones are presented simultaneously to a healthy cochlea, the response measured in the ear canal will contain several tones that are not present in the eliciting stimuli. These additional tones are called distortion products (DPs) which are attributed to the nonlinear processes of the normally functioning cochlea. DPOAEs are effective in identifying subjects with known sensorineural hearing loss. But an important requirement to ensure their clinical usefulness is that the DPOAEs must be measured using the appropriate recordings and parameters that produce the most robust response, reflecting the cochlear status and integrity.6 The most robust of these DPs occurs at the frequency equal to 2f1-f2, where f1 indicates the lower frequency tone and f2 indicates the higher frequency tone of the pair. An f2/f1 ratio of 1.22 produces the largest 2f1-f2 DPs, on the average, in adults. Optimal stimulus intensities range from 50 to 70 dB SPL, with the higher frequency tone (L2) presented 10 to 15 dB less intense than the lower frequency tone (L1). Under these stimulus conditions, the interaction of primary tones on the basilar membrane occurs near the region of f2. It is the cochlear integrity being assessed using these stimulus parameters.7

This study, unique of its kind in this part of the region, was conducted to detect early hearing impairment and deterioration in cochlear function by DPOAE in individuals with normal pure tone audiometry.

Materials and Methods

This prospective observational study was conducted in the Department of Otorhinolaryngology and Head and Neck Surgery, SMGS Hospital, Government Medical College, Jammu for a period of one year, w.e.f. November 2014 to October 2015. One hundred and fifty adults attending outpatient department with non-otological pathology in the age group of 21 to 65 years of either sex, with normal pure tone audiometry were included in the study. Patients with pure tone threshold > 20 dB across the test frequencies 250 to 8000 Hz were excluded from the study.

Fifty subjects each in the age groups of 21-35 years, 36-50 years and 51-65 years fulfilling the inclusion criteria were enrolled for the study. All enrolled participants had normal appearing outer ears as determined by visual inspection, normal otoscopic examination and normal auditory threshold as determined by Pure Tone Audiometry. Also, all participants had a negative history of extensive noise exposure, intake of ototoxic drugs, and familial hearing loss.

Prior to any testing, the purpose and procedures of the experiment were explained to the patient and consent was taken. Detailed history of any systemic disease, its duration and treatment for the same (if any) was taken. The patient was asked for any history of head trauma, ear surgery, noise exposure, or history of familial hearing loss. The subjects were asked to answer a questionnaire about occupation, ototoxic drug intake, personal habits (alcohol intake, smoking, tobacco chewing). General physical examination followed by full ear, nose and throat examination of every patient was done. An otoscopic examination was performed to confirm that each participant had normal outer ear function. Air conduction thresholds at 250, 500, 1000, 2000, 3000, 4000, and 6000 Hz, and bone conduction thresholds at octave intervals from 500 to 4000 Hz were obtained by pure-tone audiometry. Hearing thresholds were measured on a Elkon 3N3 Multi-Diagnostic audiometer calibrated in accordance with the International Standards. These measurements were obtained in a sound-treated booth. The patients who had normal outer and middle ear function as well as normal hearing sensitivity were asked to stay for DPOAE measurements. Normal hearing sensitivity was defined as pure tone thresholds <20dB HL. The participants were instructed to relax and remain quiet for the duration of the test.

A Neurosoft Neuro-audio device 2010 (OAE System Otodynamics) connected to a desktop computer with DP gram software was the principle equipment. For DPOAE acquisition a special OAE probe was used. This probe has built-in miniature speakers and a microphone, which was inserted into the external auditory canal of the patient and sealed with a flexible rubber mold. DP gram was obtained using the Neurosoft Neuro-Audio 2010 software package (Version 1.0.36). This package consists of several programs, and the P 300 software module was used to obtain DPOAEs as a function of f2/f1 ratio. The hardware included an Intel Core Duo compatible desktop, an IEC 601-1-88 PC power unit, and an ER1000-RPT DPOAE probe system. The test was performed in an acoustic chamber with background noise less than 30 dB.

Distortion product otoacoustic emission (DPOAE) is an acoustic response generated by patient's cochlea when provided with two-tone stimulation. DPOAE represents extremely weak acoustic vibrations which can be recorded in external auditory canal by very sensitive low-noise microphone. The technique is rooted in spectrum analysis of activity recorded in response to simultaneous stimulation by two tones - f1 and f2. At the beginning of DPOAE measurements, the transducers were calibrated for each ear. The microphone measured the sensitivity of two transducers while a "chirp" was present in the ear. The current study used the manufacturer default settings with stimulus frequency ratio f2/f1 as 1.22. The intensity of L1 and L2 primaries was fixed at 65dB SPL and 55dB SPL respectively. The f2 frequency was swept from low to high for each measurement condition. The frequency of maximum response intensity distortion product (DP) was calculated by following formula: DP= 2f1-f2. Because of the manner in which the system defaults, the specific f2 frequencies that were examined included: 981, 1481, 2222, 2963, 4444, 5714, and 8000 Hz. During the acquisition at one frequency the responses were averaged and the signal noise values in decibels were calculated by response spectrum. During DPOAE acquisition the dependence of OAE intensity on stimulation frequency (f2) was plotted on DP-gram. Noise level on each frequency was plotted on the graph as well.

The criterion for "acceptance" of a signal as an emission is arbitrary.7 "Pass/Refer criteria" for the particular software worked in the following way: if OAE is detected at specified Frequencies count as minimum (percentage of total count), with present Signal noise ratio, and the OAE level equals to the present value in decibels (if the check box is checked), then the test result is "Pass". Otherwise, the test result is "Refer". We used a signal 6 dB above the noise floor as a conservative estimate of the presence of an emission i.e. SNR>6 dB and when 70% frequencies had SNR>6 dB the result was considered "Pass" for that ear.

Data was compiled using computer software MS Excel for Windows. Descriptive statistics for three experimental groups and seven test frequencies were reported. The data was analyzed with the help of SPSS version 17.0 for Windows. Data reported as mean ± standard deviation and proportions as deemed appropriate for quantitative and qualitative variables respectively. Statistical significance assessed by paired and unpaired Student 't'-test. A 'p'-value of <0.05 was considered as statistically significant. All p-values reported were two-tailed.

Results

There were 79 (57.67%) females and 71 (47.33%) males in the study with a ratio of 1.11:1 (*Table 1*).

When mean distortion product otoacoustic levels were compared in right ears between three age groups for all f2 frequencies, statistically significant difference was observed in low and high frequencies in 21-35 versus 51-65 years age group comparison (*Table 2*).

When mean distortion product otoacoustic levels were compared in left ears between three age groups for all f2 frequencies, no statistically significant difference was observed between any age groups (*Table 3*).

In the age group of 21-35 years, a total of 14 ears were refer, which included 5 right and 9 left ears. In the age group of 36-50 years, 15 (10 right and 5 left) ears failed the test. In the age group of 51-65 years, a total of 46, out of which 21 right and 25 left ears. Statistically, there was no significant difference in refer cases between right and left ears (p>0.05) (*Table 4*).

In the age group of 21-35 years, 28% were refer ears and all of them were unilateral. In the age group of 36-50 years, 14% unilateral and 8% bilateral refer ears were found. In the older age group of 51-65 years, out of 66% refer result, 40% were unilateral and 26% were bilateral (*Table 5*).

Table 1. Agewise Percentage of OAEs Absent in Right and Left Ears

Amplitudes f2 (Hz)	OAEs absent					
	21 – 35 years (n=50)		36 – 50 years (n=50)		51 – 65 years (n=50)	
	Right ear %	Left ear %	Right ear %	Left ear %	Right ear %	Left ear %
988	30.00	30.00	44.00	34.00	54.00	34.00
1481	10.00	18.00	18.00	24.00	28.00	26.00
2222	10.00	16.00	22.00	26.00	54.00	72.00
2963	4.00	12.00	16.00	14.00	40.00	74.00
4444	0	14.00	6.00	14.00	26.00	32.00
5714	4.00	6.00	12.00	12.00	14.00	22.00
8000	18.00	18.00	22.00	20.00	40.00	28.00

Table 2. Comparison of Distortion Product Otoacoustic Emission Levels (Mean) for F2 Frequencies in all Three Age Groups for Right Ears

DPOAE at f2 (Hz)	Age groups (in years)			Statistical interpretation (Student's t-test)		
	21 – 35 Mean (dB)	36 – 50 Mean (dB)	51 – 65 Mean (dB)	21-35 vs 36-50 years	21-35 vs 51-65 years	36-50 vs 51-65 years
988	20.04	12.33	3.24	t=1.39; p=0.16*	t=3.19; **p=0.001****	t=1.81; p=0.07*
1481	9.70	5.89	2.45	t=0.88; p=0.37*	t = 1.74; p=0.08*	t=0.76; p=0.44*
2222	2.31	1.68	1.12	t=0.15; p=0.88*	t=0.26; p=0.79*	t = 0.16; p=0.87*
2963	7.89	6.05	5.17	t=0.45; p=0.65*	t=0.62; p=0.53*	t=0.25; p=0.79*
4444	11.70	10.61	5.98	t=0.22; p=0.82*	t=1.05; p=0.29*	t=0.09; p=0.27*
5714	13.49	9.10	9.09	t=1.13; p=0.25*	t=1.25; p=0.21*	t=0.02; p=0.99*
8000	0.53	-2.68	-9.02	t=0.87; p=0.38*	t=2.50; **p=0.01****	t=1.66; p=0.09*

**Not significant; **Highly significant*

Table 3. Comparison of Distortion Product Otoacoustic Emission Levels (Mean) for f2 Frequencies in all Three Age Groups for Left Ears

DPOAE at f2 (Hz)	Age groups (in years)			Statistical interpretation (Student's t-test)		
	21 – 35 Mean (dB)	36 – 50 Mean (dB)	51 – 65 Mean (dB)	21-35 vs 36-50 years	21-35 vs 51-65 years	36-50 vs 51-65 years
988	15.76	13.40	10.08	t=0.66; p=0.50*	t=1.56; p=0.12*	t=0.93; p=0.35*
1481	13.35	10.43	6.88	t=0.86; p=0.38*	t=1.60; p=0.11*	t=0.84; p=0.40*
2222	8.03	6.75	6.32	t=0.32; p=0.74*	t=0.38; p=0.70*	t=0.09; p=0.92*
2963	2.97	1.93	1.19	t=0.27; p=0.78*	t=0.35; p=0.72*	t=0.13; p=0.88*
4444	7.53	5.67	5.50	t=0.41; p=0.68*	t=0.44; p=0.65*	t=0.03; p=0.96*
5714	8.78	8.32	3.38	t=0.10; p=0.91*	t=0.13; p=0.18*	t=1.38; p=0.17*
8000	-0.55	-2.67	-3.85	t=0.31; p=0.75*	t=0.47; p=0.63*	t=0.23; p=0.81*

**Not significant*

Table 4. Test Result of DPOAE Analysis of Right, Left and Both Ears in Three Age Groups

Age group (in years)	Right ears (n=50)		Left ears (n=50)		Both ears (n=100)	
	Pass No. (%)	Refer No. (%)	Pass No. (%)	Refer No. (%)	Pass No. (%)	Refer No. (%)
21 – 35	45 (98.00)	5 (10.00)	41 (82.00)	9 (18.00)	86 (86.00)	14 (14.00)
36 – 50	40 (80.00)	10 (20.00)	45 (90.00)	5 (10.00)	85 (85.00)	15 (15.00)
51 – 65	29 (58.00)	21 (42.00)	25 (50.00)	25 (50.00)	54 (54.00)	46 (46.00)

Statistical interpretation (Fischer's exact test):
For age group 21 – 35 years right, refer vs left refer = 5 vs 9 = p=0.38; NS
For age group 36 – 50 years, right refer vs left refer = 10 vs 5 = p=0.26; NS
For age group 51 – 65 years, right refer vs left refer = 21 vs 25 = p=0.54; NS

Table 5. Test result of DPOAE Analysis for Unilateral and Bilateral Ears in Three Age Groups

Refer ears		Age group (in years)		
		21 – 35 (n=14) No. (%)	36 – 50 (n=15) No. (%)	51 – 65 (n=46) No. (%)
Unilateral	Right	5 (35.71)	6 (40.00)	8 (17.39)
	Left	9 (64.29)	1 (6.67)	12 (26.09)
Bilateral		0	4 (26.67)	13 (28.26)

Discussion

DPOAE is most diagnostically effective i.e., has the greatest "hit" rate for detection of hearing loss when recorded in the range of f2 frequencies between 2000Hz and 8000Hz. At an f2 frequency of 500 Hz, the ability to separate individuals with normal hearing from those with hearing loss is limited because of the elevated noise floor. At 1000 Hz, it is only slightly better. Accuracy in the detection of hearing loss using DPOAEs is optimal when using primary tones in the mid-to-high frequency range.(6, 7) Thus clinical DP-gram will typically include f2 frequencies ranging from approximately 800 Hz through 6000 Hz or 8000 Hz. Likewise, in adults with normal hearing, absent DPOAEs are common at the highest frequencies tested, probably reflecting age-related OHC loss in this frequency range.

The present study demonstrates the fact that DPOAE testing has great potential as a diagnostic tool in the evaluation of patients with normal hearing. In the assessment of patients with suspected cochlear dysfunction, the DP gram provides an accurate assessment of outer hair cell damage with great frequency specificity. DPOAE can assess individual frequencies over a broad range and detect early cochlear damage at a particular frequency with a great deal of specificity.

Our study showed the decrease activity in outer hair cells in aged people with normal hearing thresholds. It was found that in comparison with other age groups, the DPOAE amplitude was significantly reduced in the older age group 51-65 years versus 21-35 years for DPOAEs at low and high frequencies (988 Hz; p=0.001 and 8000 Hz; p=0.01) in right ear. In addition, a mid frequency "dip" or low amplitude was seen in both right and left ears at f2 2222 Hz and 2963 Hz respectively. The decreased amplitude level of otoacoustic emissions with age, indicates the onset of degenerative changes in OHC that occur, especially in the base turn of the cochlea, as has been confirmed by numerous studies.(8,9)

The findings in this study are in agreement with the study conducted by Uchida10 where 331 subjects (136 men and 195 women) aged 40 to 82 years were evaluated. The study observed a statistically significant difference in DPOAE amplitudes among age groups at four test frequencies, ranging from 4761 to 6165 Hz. Older ears had reduced DPOAE amplitude compared with young-adult ears. The OAE compression threshold was elevated at test frequencies above 2?kHz in the middle-aged subjects by 19 dB (35 versus 54 dB SPL), thereby reducing the compression range.(10, 11) It substantiated the hypothesis that DPOAEs deteriorate with age independently of hearing sensitivity. Lisowska (12) showed a significant differences when comparing the subgroups, between 10-25 years and 41-60 years at 4,639 Hz (p=0.03) and between 26-40 years and 41-60 years at 977 Hz (p=0.004), 4639 Hz (p=0.002) and 5,164 Hz (p=0.04). A significant difference was also found between the 10-25 year and 26-40 year subgroups at 977 Hz (p=0.004).

The two ears are linked with a neural pathway such that stimulation of one ear has a modulating effect on the contralateral cochlea.(13) Most studies report better responses for otoacoustic emissions in right ear. Some explanations to these findings are related to differences in ears associated with the slight advantage of right aural awareness and the dominance of the left hemisphere in the perception of speech and language function, besides the effect of higher suppression of otoacoustic emissions in the right ear, which proves that there is an asymmetric activity between ears and favors the acoustic signal detection and morphological asymmetry between the right and left craniofacial regions.(14) However, some studies have not shown significant differences in responses to otoacoustic emissions as to ear side.(15) The results of initial studies on OAE were aimed at recording responses in otologically normal individuals and establishing test-retest validity. The clinical utility of DPOAE testing is an area of study which is continuing to evolve. The results of studies demonstrating ideal recording parameters and findings in normal as well as in various clinical disorders will further assist in optimizing this test for routine application.

Conclusion

DPOAE may not be a direct measure of hearing sensitivity and not follow the audiogram perfectly however, it does demonstrate impressively significant deterioration in amplitudes across the age groups. DPOAE is found to be highly frequency specific and is recordable over a broad frequency range. Thus, DPOAE might be the revolutionary new objective, non-invasive, rapid and accurate test of hearing with its application as screening test for not only infants but also as an early indicator of hearing impairment in healthy adults before the elevation of audiometric threshold.

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