Transient effect of Auditory Brainstem Responses on DPOAE in Adults with Normal Hearing Sensitivity

Suchi Soni

Register no. 11AUD027

A Dissertation Submitted as a part fulfilment of the Degree of Masters of Science (Audiology) to the University of Mysore,

Mysore

All India Institute of Speech and Hearing

Manasagangothri

Mysore 570 006

May, 2013

CERTIFICATE

This is to certify that this dissertation entitled **"Transient effect of Auditory Brainstem Responses on DPOAE in Adults with Normal Hearing Sensitivity**" is a bonafide work in part fulfilment of Masters of Science (Audiology) of the student registration no: 11AUD027. This has been carried under the guidance of a faculty of this institute and has not been submitted earlier to any other university for the award of any diploma or degree**.**

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CERTIFICATE

This is to certify that this independent project entitled **"Transient effect of Auditory Brainstem Responses on DPOAE in Adults with Normal Hearing Sensitivity**" has been prepared under my supervision and guidance. It is also certified that this independent project has not been submitted earlier to any other university for the award of any diploma or degree.

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DECLARATION

This dissertation entitled '**Transient effect of Auditory Brainstem Responses on DPOAE in Adults with Normal Hearing Sensitivity**" is the result of my own study and has not been submitted earlier at any university for any other diploma or degree.

Mysore **Register No.**

May, 2013 **11AUD027**

ACKNOWLEDGEMENT

It gives me great pride and pleasure to extend my gratitude to my guide Mrs. Chandni Jain, Lecturer in Audiology, All India Institute of Speech and Hearing, Mysore for her help, guidance, and for being an unending source of inspiration. Thank you ma'am, I certainly consider it an honour that you consented to guide me.

I am grateful to Dr. S. R. Savitri, Director, All India Institute of Speech and Hearing, Mysore for granting me permission to take up this project.

I wish to thank all my teachers and lecturers who have played a major role in moulding my character and helped me in my studies.

"A real friend is one who walks in when the rest of the world walks out". I could appreciate the true sense of this proverb in my life when I met Srishti and Shweta. You both are real true friends in my difficult days. I found treasure of life in you and would always cherish this treasure throughout my life. Thank you "pakodaa" and "shweeeeeta" for your help and

support. Without your help this project would have been a lot more difficult. Thanks a ton.

Thank you Raghu, Hruda, Mamta, Anjana di, Dolly, Neha, Mittali and Shachi for being wonderful friends and for supporting me. This acknowledgement would be incomplete without thanking all the juniors who participated and tolerated the boring and long procedure of the experiment... ☺

Thank u god for giving me such a wonderful siblings.....'love u Bhai and sis'..... The two most wonderful persons on this earth furnished me with all the facilities and' Joys one can dream for. They are my "MOM" and "PAPA". There are no words in this world to describe my gratitude towards you. Love u loads for your support and your confidence in me. I hope I have lived up to the faith they have in me. I love you mom and pa.

'Finally, I want to thank the person who invented "Google". You really come to know- its power when you do something like this'. 

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CHAPTER 1

Introduction

The auditory system is an extremely complicated system, which has high sensitivity, sharp frequency tuning and wide dynamic range. It is sensitive enough to sense acoustic signal. The physical processing of acoustic signal is called as Hearing (Stach, 2008). Hearing sensitivity is defined as the capacity of a sense organ to detect a stimulus and any damage to auditory system will lead to hearing loss, which can be defined as the deviation or change in auditory function (Newby & Popelka, 1992).

Assessment of hearing and auditory system can be done using subjective and objective audiological measures. Subjective measures are based on behavioural responses from the listeners and these measures majorly include pure tone audiometry, which measures thresholds of detection for pure tones and speech audiometry. Objective measures on the other hand, does not rely on behavioural responses but instead use a range of physiological test procedures to measure the integrity of the auditory system. These objective measures include Immittance audiometry, Otoacoustic emission (OAE) and evoked potential audiometry (Water & Staecke, 2005).

OAE is one of the objective measures of the ear's ability to process acoustic stimuli and can be defined as "sound generated within the cochlea, by the outer hair cells. OAEs can be detected at tympanic membrane by a miniaturized sensitive microphone" (Norton & Stover, 1994). The otoacoustic emission phenomenon is based on an active mechanism in the cochlea and was first described by Kemp (1978). They are low-level sounds reflecting the non-linear active processes of the cochlea.

These processes are responsible for the high sensitivity, sharp frequency selectivity and wide dynamic range of the human auditory system (Norton, 1992).

The OAEs as a clinical tool, provides several advantages. OAEs are non-invasive and objective in nature so they are widely used in clinical settings and in hearing screening programs for newborns and infants (Prieve, 2002). It is also used for the objective assessment of hearing status in difficult-to-test population, objective estimation of the degree of hearing loss, and as a valuable tool in the audiological diagnostic test battery to determine the site of lesion (Lonsbury-Martin & Martin, 2003). Further OAE is used in monitoring the cochlear hearing status during or after therapeutic intervention (Lonsbury-Martin & Martin, 2001).

OAEs are broadly classified as spontaneous OAEs (SOAE) and evoked OAE (EOAE). SOAEs can occur without any external stimulation and EOAE require an evoking stimulus to occur. EOAEs are classified as transient evoked OAE (TEOAE), distortion product OAE (DPOAE) and stimulus frequency OAE (SFOAE).

DPOAE is a type of EOAE which is the result of an inter modulation distortion produced by the nonlinear aspects of cochlear processing in response to two simultaneous, primary tones that are nearby in frequency. It is recorded in the ear canal, and effective reverse transmission is needed to transmit the OAEs from the inner ear to the ear canal (Robinette & Glattke, 2007).

It is known that DPOAEs are emitted at a known frequency related to the stimuli; it helps in determining the exact place on the basilar membrane, which responds to two known stimuli, but there are various factors which influence DPOAEs. These factors include; stimulus parameters, patient variables and environmental factors (Hall, 2000). Among environmental variables exposure to noise

is most important. DPOAE analysis is important in studies related to acquired hearing losses as most often hair cells are primarily affected such as during the initial stages of noise exposure (Clark & Bohne, 1978; Davis, Ahroon, & Hamernik, 1989). Hearing assessment in noise-exposed groups such as chinchillas has shown a decrease in DPOAE amplitude but ABR thresholds didn't differ much (Bohne, Harding & Ahmad, 2002). Similar results have been reported in army recruits (Desai, Reed, Cheyne, Richards, & Prasher, 1999; Lapsley-Miller, Marshall, & Heller, 2004; and Lapsley-Miller, Marshall, & Heller, & Hughes, 2006). Thus, reduced OAEs are considered as a risk factor which can indicate future hearing loss in people exposed to continuous and impact noise (Lapsley-Miller , et al, 2006).

In a similar study ABR evoked temporary threshold shift was assessed by Mhatre, et al (2010) in multiple mouse strain. DPOAE was performed before and just after ABR measurement and they found reduced DPOAE response, when the DPOAEs were performed post ABR testing. However the reduction in DPOAE was temporary and when retested after one hour, DPOAE amplitude was same as that to pre ABR level. Thus above studies support the view that DPOAE is a very useful clinical tool in early detection of threshold shift due to noise exposure.

Need for the study

The hearing assessment of clinical population and infant screening is usually assessed by the combined use of auditory brainstem response (ABR) and DPOAEs carried out in sequence, with normally the ABR recording preceding the DPOAE testing. The use of this regimen can yield lower DPOAE response, when the DPOAEs are performed after ABR testing, thus might lead to mis diagnosis. In a study by Mhatre, et al (2010), DPOAEs amplitude were temporarily reduced in all frequencies

post-ABR in multiple mouse strains suggesting that ABR can induce temporary threshold shift (TTS) and DPOAEs can provide a sensitive measure of the functional integrity of the outer hair cell.

Thus, present study would help in deciding the protocol whether there ought to be reversal of the conventional order for carrying out audiological tests with the OAE measurements preceding the ABR assessment, thus ensuring that the DPOAE response is unaffected, leading to proper diagnosis of hearing sensitivity.

Objectives of the study

- To assess the immediate effect of ABR on DPOAE amplitude and signal to noise ratio (SNR) across frequencies.
- To assess DPOAE amplitude and SNR across frequencies after one hour of ABR recording.

CHAPTER 2

Review of Literature

The association between noise exposure and its affect on hearing acuity has been broadly researched over the years. Exposure to noise can lead to hearing loss; however the effect of noise exposure depends on various factors like duration of exposure, frequency of exposure, type of noise and intensity of exposure. For example, the frequency of the sound exposure determines the location of damage in the cochlea. The intensity of the noise in decibels determines the extent of the initial anatomical alteration. The duration of the exposure has an effect correlated with intensity i.e. higher the intensity of noise exposure, shorter exposure can also cause permanent damage. On the other hand, lower-intensity noise may be safe, even when the ear is exposed for long durations.

Fraenkel, Freeman and Sohmer, (2001) found out the effect of duration of noise on susceptibility of rats. Noise was presented for duration of 1 hours and 3 days. Results showed longer duration of noise exposure lead to greater reduction in DPOAE responses and permanent threshold shift (PTS). The scheduling of the exposure (i.e., continuous vs. intermittent) also affects the magnitude of damage. Rest or quiet periods between following exposures provide some recovery from the alterations (Bohne & Clark, 1990; Bredberg, 1968).

Frequency of the noise exposure determines the apex-to-base location of damage in the organ of corti (Willot, 2001). Lee, Bohne & Harding (2008) found scattered loss of OHCs in apical portion of organ of corti following 0.5 kHz noise exposure. Similarly intensity of the noise also affect the speediness with which the ear

is damaged and the level of the initial anatomical lesion. It also determines whether the associated hearing loss will be temporary or permanent (Willott, 2001).

There are some hypotheses which explains pathogenesis of noise induced threshold shift which include: 1) Reduced blood flow for the period of the exposure (Hawkins, 1971) causing hypoxia (i.e., reduced oxygen) and the release of reactive oxygen species in the cochlea (Quirk et al., 1992); 2) Metabolic exhaustion of the stimulated sensory cells (Gelfand, 1997); 3) Excessive release of neurotransmitter during the exposure leading to excite toxic damage of afferent nerve fibres and terminals (Pujol, 1992); 4) Intermixing of cochlear fluids through the damaged reticular lamina (Bohne and Rabbitt, 1983).

Exposure to moderate-intensity noise for several minutes or hours initially results in temporary threshold shift (TTS) only. If thresholds are measured after the individual has been away from the noise for some time, thresholds will return to pre-exposure levels (Taylor et al., 1965). The occurrence of improvement of thresholds during an intermittent exposure may indicate that the cells of the ear have become more resistant to the effects of noise. This has been termed the "toughening" phenomenon (Canlon, Borg, & Flock, 1988).

Threshold shift due to noise exposure has been studied using various audiological tests such as high frequency audiometry and OAEs. OAE is a suitable tool for investigating the effect of noise exposure on the auditory system of humans and it has been shown to be physiologically vulnerable and to reflect the mechanical nonlinearity of the cochlea (Anderson & Kemp, 1979). It has also been shown to distinguish reliably between normal and abnormal ears and they are regarded as a valid measure of cochlear function (Gorga, Neely, & Dorn, 1999; Shera & Guinan,

1999). Both TEAOE and DPOAE have been used to study the effect of noise exposure.

Changes that are introduced by moderate noise exposure, give rise to temporary threshold shift (TTS) which alters the amplitude or frequency composition of DPOAEs (Martin et al., 1987; Schmiedt, 1986; Sutton, Martin, Martin & Whitehead, 1994). These changes are nothing but the preclinical frequency-specific hearing loss i.e. damage that has not yet resulted in hearing loss. This damage is measured by calculating difference between the DPOAE measure before and after noise exposure (Marshell, Miller & Heller, 2001).

Abnormal DP amplitude is recorded in patients with hearing sensitivity within normal limits (< 25 dB HL) because of high sensitivity to OHC dysfunction. The high sensitivity of OAEs to outer hair cell dysfunction is a huge advantage for early citations of auditory abnormalities. Patients with completely normal OAE findings usually have normal hearing sensitivity.

DPAOE and Noise exposure

DPOAE are generated in the nonlinear aspect of OHC transduction process at the level of basilar membrane. With noise exposure, these properties of OHC are altered and the ear's sensitivity level decreases as a measure of protection. This process is called as a shift in the “threshold of hearing”, which means that only sounds louder than a certain level will be heard. This shift can be temporary, chronic or permanent. Susceptibility to temporary threshold shift varies greatly from person to person (Hall, 2000). DPOAE measurement is highly sensitive to identify early

evidence of damage to the outer hair cells from noise (Hall, 2000), and which cannot be detected by the analysis of sound-evoked potentials.

To measure the changes in cochlear function via OAE there are three general steps. The first step is to verify satisfactory measurement conditions. Specifically, noise levels must be sufficiently low (usually less than – 10 dB SPL) to allow precise detection of OAE activity and the stimulus intensity levels in the ear canal should be close to the required levels. Subsequently to look for repeatable OAEs and whether OAE amplitude exceeds the noise level by 6 dB or more at the test frequency. Finally, to say as OAE present difference between OAE amplitude and noise floor (NF) should be more than 6 dB SPL. However, it has been shown that a DP-NF of 6 dB SPL, and even as low as 3 dB SPL, can be used as acceptable DP-NF differences (Cilento, Norton, & Gates, 2003)

Kemp (1995) evaluated DPOAE amplitude and phase difference in nine individuals with normal hearing before and after the exposure to moderate level of noise. The results showed that DPOAE amplitude was reduced in that frequency specifically with the supreme reduction approximately half an octave above the frequency of the noise.

In another study DPOAE fine structure was measured following exposure to a narrowband noise centred at 2000 Hz. Results revealed that there was a significant decrease in the maximum to minimum ratio of the fine structure starting at 2-min post exposure that tended to recover over the 32-min post exposure (Engdahl & Kemp, 1996). Similarly Emmerich, Richter, Reinhold and Linss (2000) found stable DPOAE levels in 12 awake guinea pigs before industrial noise exposure, which were significantly reduced after one hour noise exposure. However after 4 months post exposure there was 70 % recovery of DPOAE.

Hotz, Probst, Harris, and Hauser, (1993) measured DPOAE before and at the end of a 17-week training period that included exposure to noise from firearms. Results revealed significant changes in response amplitudes in the frequency range from 2 to 4 kHz, whereas changes in the frequency range from 0.5 to 2 kHz were not significant for either group. This change can be attributed to the frequency spectrum of the noise which caused reduction in DPOAE amplitude in a particular frequency range.

Fraenkel, et al (2001) investigated the effect of various durations of noise exposure in animals on physiological responses from the cochlea. Rats were exposed to 113 dB SPL broad-band noise (12 h on/12 h off) for durations of 3, 6, 9, 12, 15 and 21 days. Animals were tested 24 hours after cessation of the noise and again after a period of 6 weeks using ABR for click stimuli and a 2-kHz tone burst (TB), TEOAE energy content and DPOAE amplitude. ABR thresholds (click and TB) were significantly elevated and DPOAE amplitudes and TEOAE energy content were significantly reduced in all exposure duration groups compared to control rats. This could be explained by the possibility that short noise exposures may cause damage to the early, more active stages of cochlear transduction.

Savitha, (2002) studied the efficacy of DPOAE as early identifier of noise induced hearing loss in 40 noise exposed ears with hearing sensitivity within normal limits. Results showed that DPOAE was an early indicator of noise induced hearing loss though it was not shown in the pure tone and the frequency of 4.053 kHz was most sensitive for noise damage

Reuter, Ordonez & Hammershoi (2007), studied the effects of over exposure of 1-kHz tone lasting for 3 min at an equivalent threshold sound-pressure level of 105.5 dB monaurally on 39 individuals with normal hearing sensitivity. The effects of

overexposure were studied on the broadband DPOAE and on the DPOAE fine structure. The obtained DPOAE shifts were compared to TTS obtained after a similar exposure. Similarities between DPOAE shifts and TTS were found in the affected frequency range and the time course of recovery.

Thus studies support that early changes in the micromechanical function of the cochlea can be monitored by OAEs. In humans, TTS following loud tone exposures are usually associated with a temporary reduction in DPOAE levels, with similarities exhibited in the time course of TTS and DPOAE recovery functions (Reuter et al., 2007; Sutton et al., 1994).

Regarding the high, selective sensitivity of OAEs in relation to damage of outer hair cells, this test is valuable, and is a diagnostic tool for monitoring the early, noise induced changes in the inner ear. Above mentioned studies clearly reveal that TTS which is caused by exposure to moderate-to-high levels of sound, is associated with changes in DPOAEs amplitude (Hall, 2000). But some researches propose the use of DPOAEs and TEOAEs measure to get better prediction of the auditory status (Vinck, Cauwenberge, Leroy, & Corthals, 1999).

Studies have been done to compare noise exposure differences in TEOAE and DPOAEs. Souza, (2009) did a study on 60 individuals exposed to industrial noise and 60 non-exposed control subjects to measure the difference between DPOAE and TEOAE. The result showed that military personnel who were not exposed to noise had higher TEOAE recordings and DPOAE amplitudes compared to the noise-exposed group; however DPOAE had been more sensitive in detecting the earlier effects of noise exposure. DPOAEs have been found to be more effective than TEOAEs due to the wider frequency range (between 1000 – 8000 Hz) available for

assessment (Avan, Bonfils & Loth, 1996). TEOAEs are limited to a frequency range of 500 - 6000 Hz (Avan et al, 1996).

However Libbin (2008), found post noise exposure reduction in both DPOAE and TEOAE amplitude at higher frequencies when compared to unchanged pure tone thresholds, in marching band members thus, combination of both DPOAE and TEOAE measure would increase the sensitivity to identify small amount of OHC damage which is not shown in pure tone thresholds.

Thus OAEs reflects the outer hair cell activity in the cochlea required for normal hearing and reduced outer hair cell activity usually will lead reduction in OAEs. OAE assessment may be an appropriate screening tool for hearing sensitivity, as the test–retest reliability of DPOAE is also highly acceptable (Franklin et al, 1992) and DPOAEs detects alterations in the cochlea‘s susceptibility to brief tonal over-stimulations. As a whole, the over-exposure results of animal studies indicate that DPOAEs may provide a promising approach to assess the cochlea’s sensitivity and susceptibility to acoustic overstimulation (Mensh et al., 1993).

Thus it is evident from above studies that OAE is a very helpful clinical tool in noise exposed ears and the effect of noise could be visible in OAEs even if it is unidentified in pure tone audiometry. OAE is also a very important clinical tool in infant hearing screening along with ABR. However if OAEs are performed after ABR testing, it can cause TTS leading to reduced or absent OAEs. In one animal study when ABR was done prior to OAE assessment it lead to reduced OAE amplitude. This could be because ABR assessment involved continues presentation of clicks and tone bursts which itself can induce TTS (Mhatre et.al, 2010). However present study is the first attempt to study the transient effect of ABR on DPOAE amplitude in humans.

CHAPTER 3

Method

The present study aimed to study the transient effect of auditory brainstem response on distortion product otoacoustic emissions. To investigate the same, following method was used.

Participants

To fulfil the aim of the present study, data was collected on 50 participants. All the participants were in the age range of 18 to 29 years (mean age = 22.5 years) and had hearing thresholds within normal limits in both the ears. DPOAEs were recorded from any one randomly chosen ear of each subject.

Participant selection criteria

The participants who met the following criteria were selected for the study:

- No history of middle ear infection, tympanic membrane perforation, head trauma, noise exposure and ear discharge.
- Subjects with pure-tone thresholds less than 15 dB HL for octave frequencies between 250 Hz to 8000 Hz for air conduction and 250 Hz to 4000 Hz for bone conduction. Pure tone threshold were obtained by using modified version of Hughson and Westlake procedure (Carhart & Jerger, 1959).
- Speech recognition scores within ± 12 dB with reference to pure tone average (PTA).
- Speech identification scores greater than 90% in both the ears.
- Bilateral 'A' type tympanogram with ipsilateral and contralateral reflexes present in both the ears. During this testing subjects were made to sit comfortably and asked not

to swallow. Tympanometry was carried out with 226 Hz probe tone and ipsilateral and contralateral acoustic reflex were obtained at 500, 1000, 2000 and 4000 Hz.

- No current illness at the time of testing.

Research design

The current study followed a specific research design. The research design used in this study was one group pre test post test design (Schiavetti & Metz, 2006)).

Instrumentation

- Otoscope was used to inspect the ear canal and to rule out any contra indication of audiological evaluation
- A calibrated two channel diagnostic audiometer (Madsen OB922) with acoustically matched headphones (TDH 39) and bone vibrator (radio ear B71) was used to estimate pure tone thresholds, speech recognition threshold and speech identification scores.
- Calibrated GSI-TympStar (Version-2) middle ear analyzer was used for estimating tympanogram and acoustic reflex threshold.
- A calibrated ILOV6 OAE analyzer (Otodynamics Ltd) was used for recording DPOAE.
- A calibrated Biologic Navigation Pro system (version 7.0.0) fitted with an ER-3A insert receiver was used for ABR recording.

Test environment

All the experiments were conducted in acoustically treated room where the noise levels were within permissible limits as per ANSI S3.1; (1991).

Procedure

The testing was done in following steps:

Case history. A detailed case history was taken to ensure that the participants do not have any history of middle ear infection, noise trauma and other otological diseases.

Otoscopic examination. Otoscopic examination was done to examine the external ear and tympanic membrane. Only those participants who had normal otoscopic findings were considered for the experiment.

Pure tone testing. To ensure normal hearing, pure tone testing was carried out for all the participants. Pure tone thresholds for air conduction and bone conduction were obtained for the frequencies from 250 Hz to 8 kHz and 250 Hz to 4 kHz respectively.

Immittance testing. To rule out middle ear pathology Immittance assessment was carried out. Subjects who had 'A' type tympanogram with acoustic reflexes present were considered for the study. Static compliance and middle ear pressure was noted for each subject.

DPOAE Measurement. DPOAE was recorded using the ILOV6 OAE analyzer (Otodynamics Ltd). Two primary signals were used to record distortion products. Prerecording preparation include unobstructed outer ear canal, optimal positioning of the probe, relatively quiet recording environment.

Stimulus parameters of DPOAE. Primary signals *f1* and f_2, with f2/f1 = 1.3, generated with test frequencies ranging from 1001 Hz to 6006 Hz with a frequency resolution of one DPOAEs per octave was used. Two level chosen were L_1 = 65 dB SPL, L_2 = 55 dB SPL. L2 was lower than L1 to equate the amplitudes of the vibration of the travelling waves representing the two primaries, where they interact on the BM

(Robinette & Glattke, 2007). The response parameters to consider DPOAE as present included DP amplitude and SNR. A peak at $2f_1 - f_2$ in the spectrum was accepted as a DPOAE if it is 3 dB above the noise floor. The protocol of DPOAE is summarized in Table 1.

Table 1

Test protocol for DPOAE measurement.

Primary signals	f1 and f2
f2/f1	1.3
Test frequencies	1001 to 6006
Frequency resolution	1 point/octave
Levels of primaries	L_1 = 65 dB SPL, L_2 = 55 dB SPL

ABR measurement. While recording ABR, the participants were made to sit on a reclining chair, instructed to relax, close the eyes and sleep if possible. The sites of electrode placement were prepared with skin preparing gel. Disc type silver coated electrodes were placed with conduction gel. The protocol used for the measurement of ABR is mentioned in Table 2.

Table 2

Test protocol for ABR measurements.

Transducer type	ER-3A Insert earphones
Type of stimulus	Clicks
Intensity	The intensity of the input stimulus was initially set at 90 dB nHL and sequentially attenuated in 20 dB steps until a threshold level was reached.

Stimulus Polarity	Rarefaction
Stimulus Rate	30.1/sec
Filter setting	100 Hz to 3000 Hz
No of Sweeps	1500
No. of recording	2
Electrode montage	Inverting (-) – test ear mastoid
	Non inverting (+) - forehead (Cz)
	Ground – non test ear mastoid
Inter-electrode Impedance	Less than 5 k Ω.
Gain	10,000 µv

The whole experiment was conducted in two steps including pre exposure measurement and post exposure measurement.

Pre exposure measurements

Three repeated DPOAE recordings were taken before the ABR test. For three DPOAEs recordings the probe was removed and replaced before each measurement. This was done to reduce the variability seen in DPOAE due to probe insertion and the average of three recordings was considered for final analysis.

Post exposure measurements

Post-exposure DPOAE measurement was done twice; one immediately after ABR recording and another one hour after ABR recording. Thus the DPOAE recording for each subject included the three measurements which were taken just after ABR recording and three measurements taken one hour after ABR recording,

reason for 3 measurements being the same as mentioned in pre exposure test. DPOAE recording 1 hour post ABR was done to look for TTS recovery.

Calculation of DPOAE shift

It was likely that DPOAE levels would lower after ABR testing; thus, the magnitude of the DPOAE shift was taken as the difference between the pre and the post ABR level. All pre exposure DPOAE levels are calculated as the average of repeated measurements.

Statistical analysis

The data was subjected to statistical analysis using SPSS software (version 17). Descriptive statistics was used to estimate mean and standard deviation. To analyse the data across three evaluations, repeated measure ANOVA and Friedman test was done.

CHAPTER 4

Results and Discussion

The present study was aimed to evaluate the transient effect of ABR on DPOAE amplitude and SNR across frequencies and DPOAE amplitude and SNR across frequencies after one hour of ABR recording. To reach the aim, a series of DPOAE test was performed before, after and one hour after ABR testing at different frequencies. Data obtained from the subjects after three measurements was averaged and tabulated and analysis was done for each condition using statistical package for social sciences (SPSS) software version 17.

To fulfil the aim of the present study 50 participants with normal hearing sensitivity in both the ears which was confirmed by routine behavioural audiometric testing and immittance evaluation were selected. Data was analysed using repeated measure ANOVA and Friedman test and results show that there was change in DPOAE amplitude and SNR response before and after ABR testing. The results of the present study will be discussed under three headings.

a. Effect of ABR on SNR
b. Effect of ABR on DP amplitude
c. Recovery Pattern of DPOAE

Effect of ABR on SNR

DPOAE SNR for all the 50 subjects was measured in all the three conditions. A significant inter subject variation was seen in SNR. Table 3 shows the mean and standard deviation (SD) for SNR values of DPOAE across each frequency. From the

table it can be noted that the mean absolute DPOAE SNR value obtained for lower frequencies after ABR exposure is lower than at higher frequencies.

Table 3

Mean and SD for absolute SNR of DPOAE at different frequencies obtained for three different conditions (PE-pre exposure, PO-post exposure, HR-one hour after exposure).

Frequency (Hz)	**Conditions**	**Mean**	**SD**
1001	PE	12.0947	5.91437
	PO	7.6273	5.89953
	HR	10.2893	5.48798
1501	PE	18.3187	5.10447
	PO	14.1823	5.00135
	HR	15.7807	4.70513
2002	PE	18.4003	5.26785
	PO	15.7513	6.02093
	HR	16.8953	5.84086
3003	PE	15.8487	4.45638
	PO	13.9100	5.16674
	HR	15.2181	4.70289
4004	PE	17.7393	4.95996
	PO	16.2487	5.26640
	HR	16.4520	5.49940
6006	PE	13.9440	6.14045
	PO	12.2440	6.91402
	HR	13.4340	6.54336

Figure 1 represents the magnitude of difference between three conditions for individual frequencies presented in the form of bar graph. Figure 2, 3 and 4 shows an example of DP gram from one participant for all the 3 conditions.

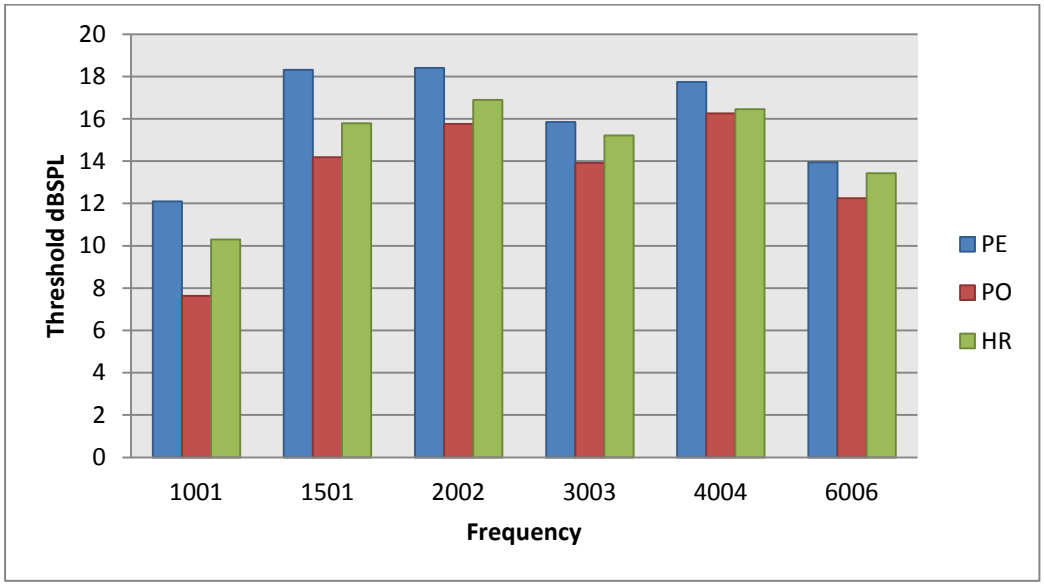

Figure 1. Mean value of DPOAE SNR before, after and one hour after ABR testing in individuals with normal hearing sensitivity.

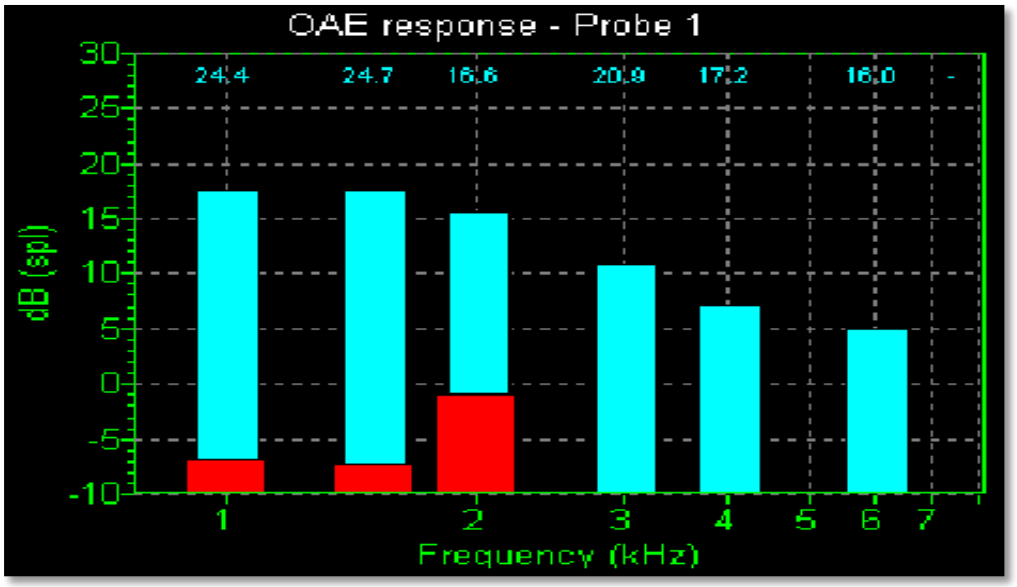

Figure 2. Representative example of DP gram of one of the participant in pre (ABR) exposure condition.

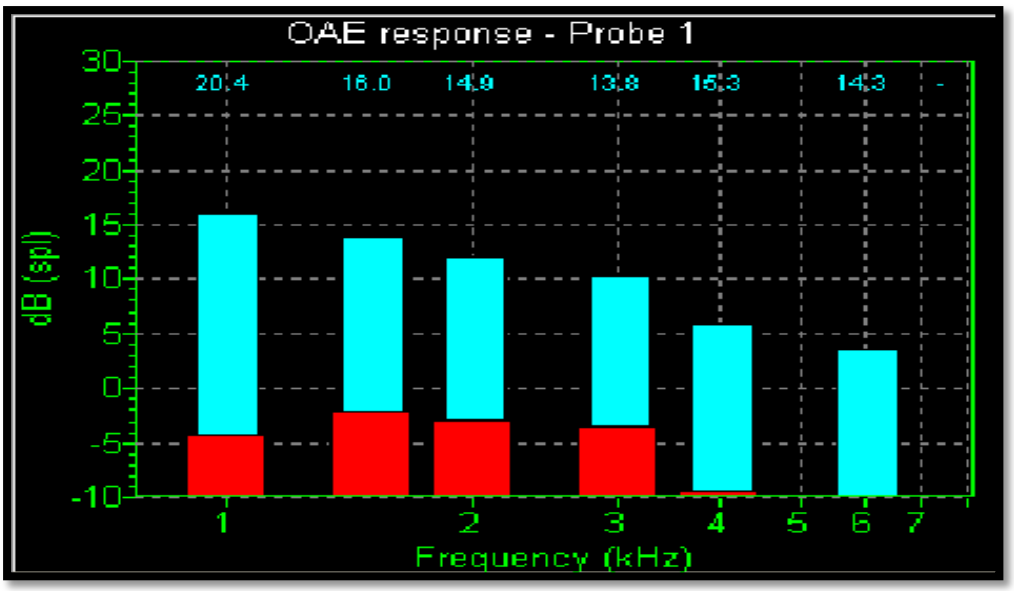

Figure 3. Representative example of DP gram of one of the participant in post (ABR) exposure condition.

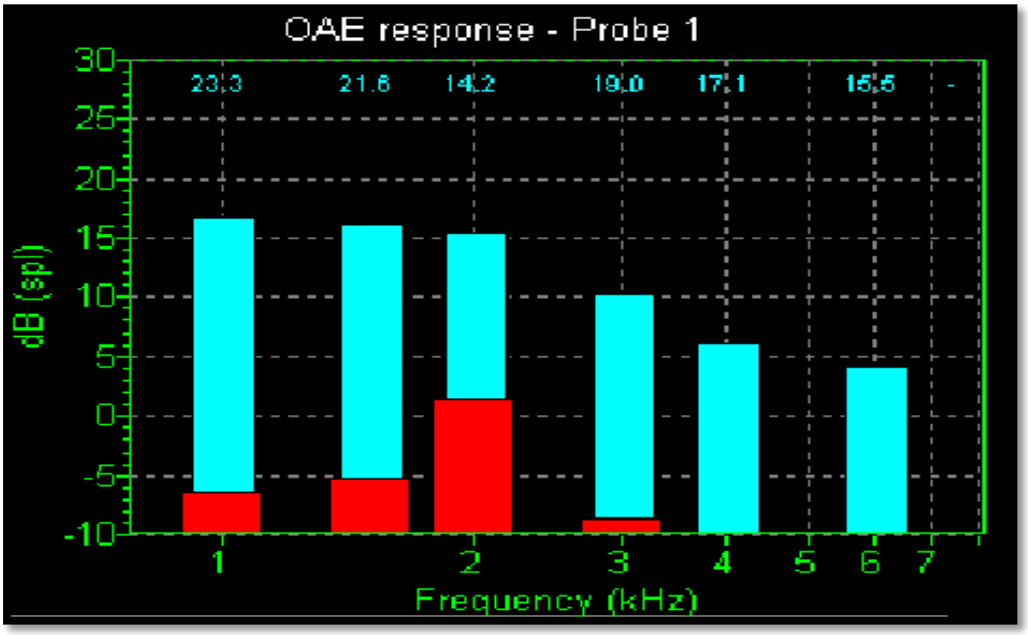

Figure 4. Representative example of DP gram of one of the participant in one hour after (ABR) exposure condition.

Later repeated measure ANOVA was performed to analyse the significant difference in SNR across three conditions, and it showed that time of measurement (pre, post and after one hour) and frequency has a significant effect on DPOAE SNR values, where significant difference in SNR was seen across all the frequencies for all

the 3 conditions (p<.05). Results also revealed that frequency was a significant variable indicating that pattern of attenuation and recovery was not similar for all the frequencies, which can be seen in Table 4.To analyse the difference across conditions pair wise comparison was done using Bonferroni multiple comparison. It revealed the significant difference between pre and post (p<.01) and also between post and one hour recovery (p<.01) (Table 5). The significant p values for difference between pre, post and one hour after ABR testing for individual frequencies are given in Table 5 where shaded values show no significant changes.

Table 4

F values of DPOAE across each frequency.

Frequency (Hz)	**1001**	**1501**	**2002**	**3003**	**4004**	**6006**
F (2,98)	40.183*	24.494*	13.299*	13.687*	6.842*	8.280*
*=p<.01						

Table 5

Statistical significant difference (p-value) among three conditions across each frequency of DPOAE.

Frequency (Hz)	**PE vs PO**	**PO vs HR**	**PE vs HR**
1001	0.000	0.000	0.001
1501	0.000	0.038	0.000

2002	0.000	0.135	0.031
3003	0.000	0.011	0.238
4004	0.001	1.000	0.024
6006	0.000	0.063	0.690

From the above tables it is evident that ABR induced DPOAE reduction in terms of SNR was seen in all the subjects with some inter subject variability. It is also evident that attenuation in DPOAE is more significant at lower frequencies (1001 Hz to 3003 Hz) than higher frequencies (4004 to 6006) indicating the effect of ABR exposure was more at the frequencies which fall under click frequency spectrum.

Effect of ABR on DP amplitude

The mean and standard deviation of DPOAE amplitude across each frequency was calculated. It was found that standard deviation for DP amplitude across frequency was higher than the mean, so median was considered for the analysis. The nonparametric analysis was done using Friedman test for all the frequencies. Table 6 shows the median and SD of DP amplitude.

Table 6

Median and SD for absolute amplitude of DPOAE at different frequencies obtained for three different conditions (PE-pre exposure, PO-post exposure, HR-one hour after exposure).

Frequency (Hz)	**Conditions**	**Median**	**SD**
1001	PE	6.3167	5.65569
	PO	4.3833	7.13773
	HR	5.3667	5.75321
1501	PE	12.8833	4.86326
	PO	10.3500	5.18906
	HR	11.9000	4.45523
2002	PE	11.4167	5.63697
	PO	10.6667	5.86001
	HR	10.4000	5.16509
3003	PE	5.3167	4.74624
	PO	6.1500	5.38328
	HR	6.0500	4.87059
4004	PE	6.7500	5.35886
	PO	5.6833	5.36445
	HR	6.7833	5.31927
6006	PE	2.0667	6.76002
	PO	1.6500	7.55610
	HR	2.2500	6.68280

The magnitude of difference between three conditions for individual frequencies of DPOAE is presented in the form of bar graph in Figure 5.

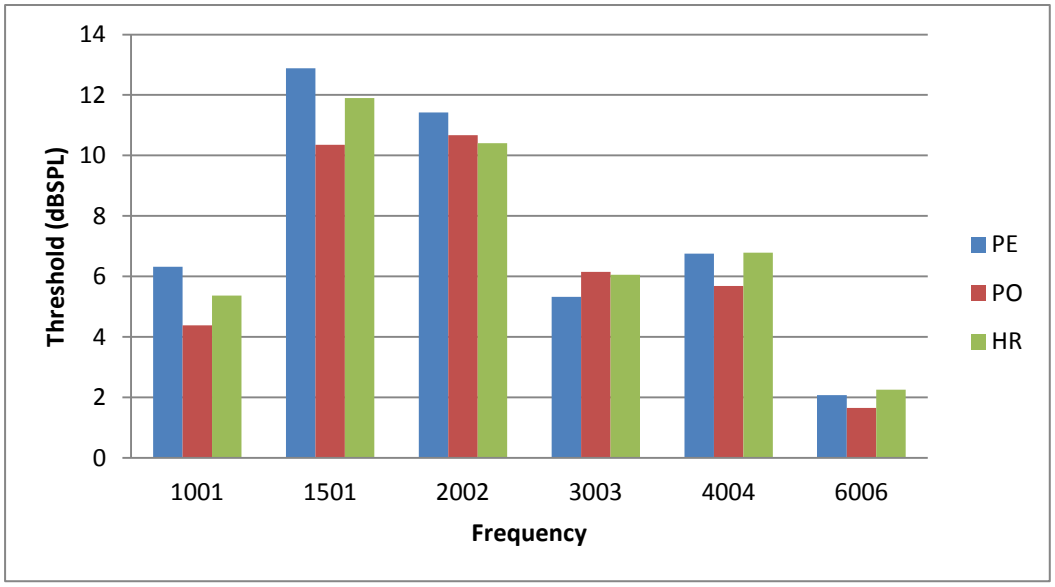

Figure 5. Median value of DPOAE amplitude before, after and one hour after ABR testing in individuals with normal hearing.

The Friedman test was performed to see the difference in DP amplitude across three conditions (pre, post and after one hour). Table 7 shows the Chi-square value of all the frequencies of DPOAE & it can be noted that the DP amplitude of low frequencies is significantly affected ($p<0.05$) compared to high frequencies post ABR testing. Later Wilcoxon Signed Ranks Test was performed for lower frequencies to analyse the significant difference and it revealed that time of measurement had a significant effect on DPOAE amplitude. Also frequency was a significant variable indicating that the effect of ABR and recovery was not equal at all frequencies, where significant difference in DP amplitude was seen for frequencies between 1001 Hz and 1501 Hz for all the 3 conditions. The significant Z values for difference between pre, post and one hour after ABR testing for individual frequencies are given in the Table 8.

Table 7

Chi-square values across different frequencies of DPOAE.

FREQUENCY (Hz)	Chi-square (2)
1001	39.520*
1501	17.760*
2002	2.000
3003	0.131
4004	1.095
6006	4.357
*=p<.05	

Table 8

Z-values among three conditions at 1001 Hz and 1501 Hz frequencies.

FREQUENCY (Hz)	PE vs PO	PO vs HR	PE vs HR
	Z	Z	Z
1001	5.502*	4.175*	-3.137*
1501	3.823*	-2.466*	-2.457*
*=p<.05			

The purpose of this study was to evaluate the change in the amplitude and SNR of DPOAE in response to non hazardous sound stimulus, clicks, commonly used in routine clinics to assess hearing sensitivity (standard ABR test), which was previously not reported on humans. The temporary shift in DP amplitude and SNR

was seen in 50 individuals with normal hearing sensitivity, which recovered after one hour rest period.

The DPOAE amplitude reduction following ABR testing may reveal a direct effect on the sensory hair cells in response to constant acoustic stimulation. On the other hand, central control may also be accountable for the reduction in OHC activity as Medial olivocochlear (MOC) neurons project to outer hair cells (OHCs). Abdala, Mishra and Williams (2009) & Deeter, Abel, Calandruccio and Dhar (2009) have revealed that activation of the MOC neurons leads to diminished DPOAEs. Thus, it is possible that the ABR stimuli could activate the MOC neurons that bring suppressive effect over OHC and their OAEs results.

The middle ear muscle (MEM) reflex (which can be elicited by non hazardous ABR testing), can also affect OHC activity (Goodman & Keefe, 2006). Elicitation of the MEM reflex results in a stapedius muscle contraction which can alter the sound pressure in the ear canal, and thus will reduce the OHC response which intern can attenuate DPOAE response.

However, reduction in DP response induced by ABR is highly variable. Differences across subjects were seen in (1) magnitude of the DPOAE shift; (2) frequency specificity of DP shift (3) recovery pattern. Studies have shown that usually a high inter subject variability is seen on DPOAE shift because of noise exposure (Engdahl & Kemp, 1996). In the present study the variability can be attributed to individual susceptibility to sound exposure.

In the present study the DPOAE response was maximally affected from frequencies between 1-3 kHz. It could be because ABR was measured using click stimulus and the click has its frequency concentration between the same frequency

ranges. This finding is also consistent with Gupta (2002) who observed that most threshold shift occurred at and above the frequency of their TTS-inducing stimulus. Previous studies have also shown that frequency of the noise exposure has an effect on TTS. Reuter et al, (2007) investigated the effect of 1 kHz pure tone exposure (lasting for 3 min at a SPL of 105.5 dB) on DPOAE properties in 39 individuals with normal hearing. The results showed a similarity between DPOAE and TTS which were found in the affected frequency region and the time course of recovery.

Although findings in the present study and that performed earlier by Mhatre et al (2010) are similar with respect to the effect of ABR stimulus exposure over DPOAE amplitude and SNR. However it was reported that effect produced by ABR exposure was more at higher frequencies on multiple mouse strain in a study by Mhatre et al (2010). Whereas in present study reduction in DPOAE response was seen across all test frequencies but effect was more significant at lower frequencies between 1001 Hz to 3003 Hz. This difference could be attributed to the difference in stimulus used for ABR test. In the present study click were used as a stimulus for ABR assessment, whereas in their study click and tone burst (8, 16, 24, 32 KHz) were used as a stimulus for ABR testing.

Moreover in the present study difference in DP amplitude was seen only at lower frequencies (1 KHz and 1.5 KHz) in all the three conditions (PE, PO and HR) whereas for SNR the difference was seen for all the frequencies in all the three conditions. However for SNR the difference was more significant at lower frequencies. The reason for DP amplitude variation could be attributed to the fact that higher frequencies had lower amplitude in pre exposure condition itself. Also the reason as to why SNR variation was seen at all frequencies could be due to the higher contamination of noise at low frequencies (Sliwinska-Kowalska & Kotylo, 1997).

Recovery patterns of DPOAE

After exposure to continuous stimulus of ABR there was a reduction in DPOAE amplitude and in SNR. However after a rest period of one hour, three different types of DPOAE recovery patterns were seen. The group-recovery DPOAE-shift shows the greatest DPOAE shift seen in the frequency range between 1 kHz to 3 kHz, with a maximum value of 4.4 dB. The recovery patterns of DPOAE post ABR exposure is discussed under 3 headings of Partial recovery, complete recovery, no recovery.

Partial recovery

In most of the participants, only a partial recovery was seen i.e. the DPOAE amplitude and SNR did not return to pre exposure level. An example from one participant with partial recovery is shown in Figure 6 and 7 which were characterized by a progressive decline and loss of DPOAEs at test frequencies lower than 3003 Hz, and weakly diminished DPOAEs at frequencies of 4004 to 6006 Hz.

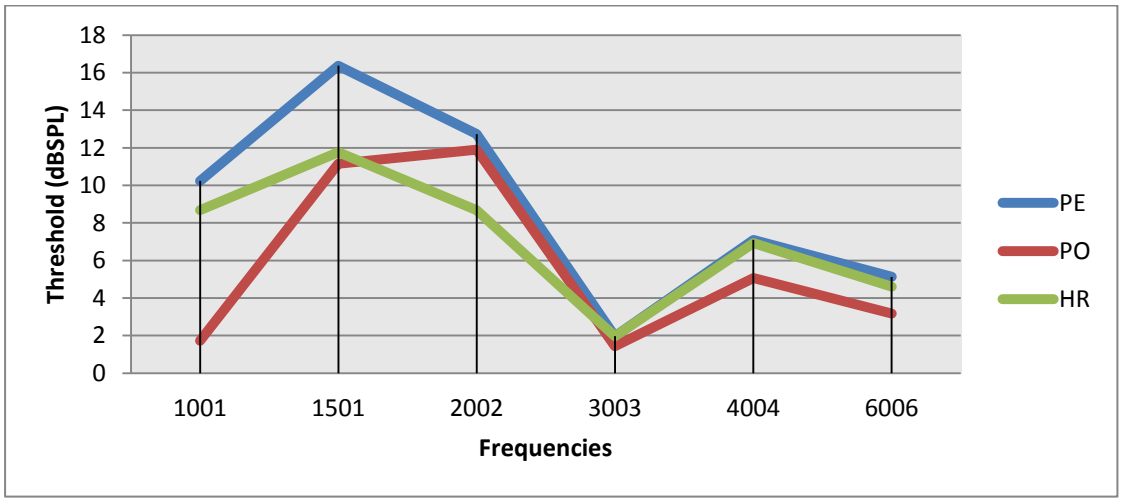

Figure 6. Representative example of partial recovery of DPOAE amplitude after one hour exposure to ABR stimulus.

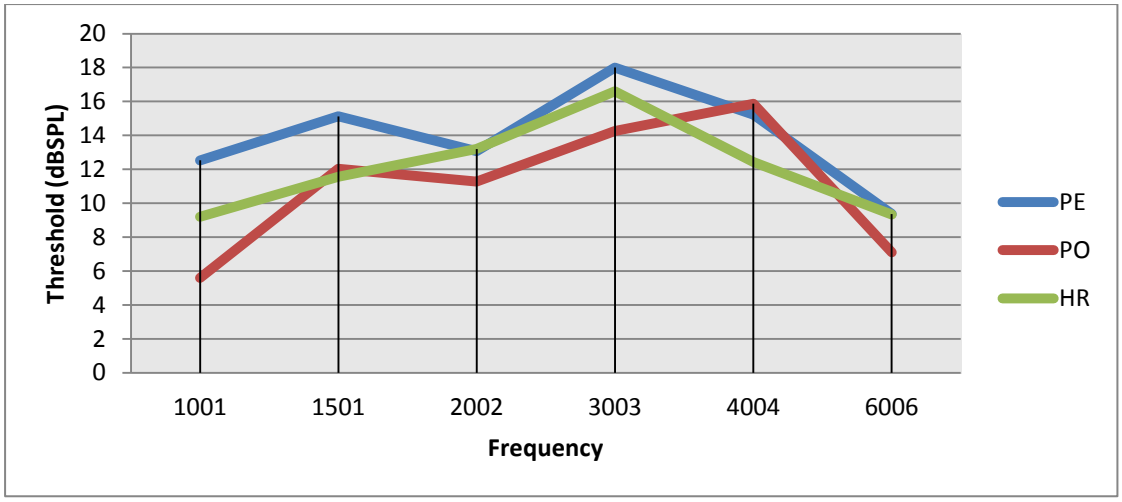

Figure 7. Representative example of partial recovery of DPOAE SNR after one hour exposure to ABR stimulus.

Overshooting/complete recovery

In some of the participants the initial loss of DPOAE amplitude and SNR was very short lived which was returned to pre exposure level completely within one hour post exposure. This overshoot or complete recovery was seen at higher frequencies between 3003 Hz to 6006 Hz in the same participants as shown in Figure 6 and 7.

No recovery

In few participants a complete and persistent loss of DPOAE was observed even after one hour of recovery period. This loss of DPOAE was persistent in all the test frequencies as shown in Figure 8 and 9.

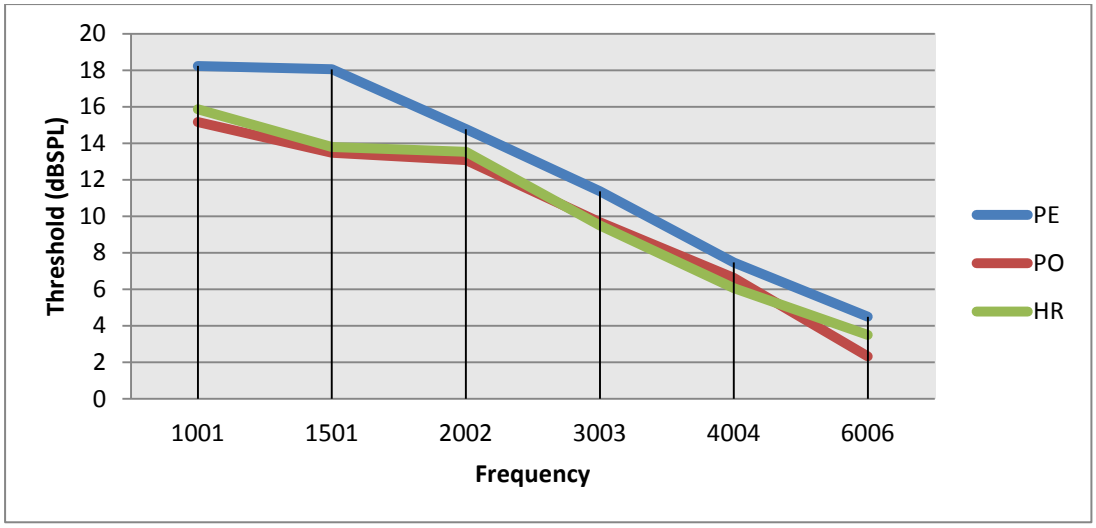

Figure 8. Representative example of no recovery of DPOAE amplitude after one hour exposure to ABR stimulus.

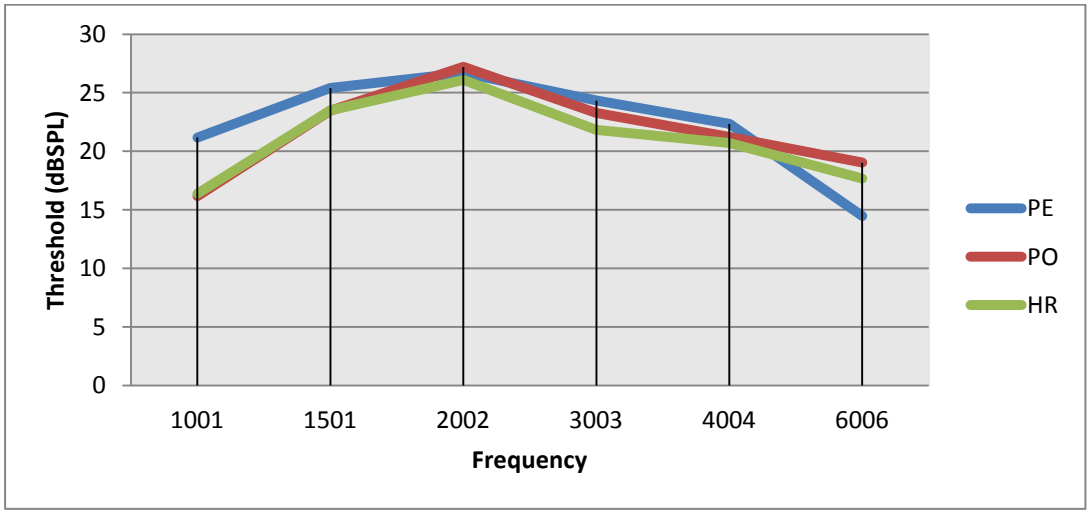

Figure 9. Representative example of no recovery of DPOAE SNR after one hour exposure to ABR stimulus.

Thus it is evident that continuous but short exposure of click stimulus produced variable outcomes both in terms of attenuation of DPOAE and recovery patterns. Some participant's DPOAE recovered quicker and completely than others whereas some didn't show a significant recovery in DPOAE. Similar recovery patterns were obtained in a study done by Emmerich, Richter, Reinhold, Linss and

Linss (2000). They studied DPOAE level shifts before and after noise exposure and found 70% partial recovery of the DPOAEs within 4 months after noise exposure and in 16% of the investigated ears no recovery of DPOAEs was observed. It has been observed that recovery pattern depends on individual susceptibility to noise damage, which probably differ as a function of age and health of the individual (Dancer, 1995).

Even though some inter subject variability was seen in terms of reduction and recovery of DPOAE, the present findings support the assumption that routine ABR testing causes some amount of fatigue to the hair cells which in turn can lead to temporary and partial attenuation of DPOAE, which is in agreement with the study done by Mhatre et al (2010). The results form presents study demonstrate that indeed ABR testing when performed before OAE evaluation can lead to misdiagnosis. Thus, present study would help in deciding the protocol whether there should be reversal of the traditional order for carrying out auditory tests with the OAE measurements preceding ABR assessment, thus ensuring that the DPOAE response is unaffected, leading to proper diagnosis of hearing sensitivity.

CHAPTER 5

Summary and Conclusion

OAE is one of the objective measures of the ear's ability to process acoustic stimuli. They are low-level sounds reflecting the non-linear active processes of the cochlea. These processes are responsible for the high sensitivity, sharp frequency selectivity and wide dynamic range of the human auditory system (Norton, 1992). OAE is a very useful clinical tool in hearing screening and gets affected by various factors such as noise exposure. OAE amplitude and SNR gets affected in individuals with temporary threshold shift.

The hearing assessment of clinical population and infant screening is usually assessed by the combined use of auditory brainstem response and distortion product otoacoustic emissions, carried out in succession, with the former assay preceding the latter. The use of this course of assessment can yield reduced DPOAE response.

In the present study DPOAE amplitude and SNR was measured across frequencies before, immediately and one hour after ABR recording. To fulfil the aim of the present study total 50 participants with normal hearing sensitivity in both the ears which was confirmed by routine behavioural audiometric testing and immittance evaluation were selected. Data was analysed using repeated measure ANOVA and Friedman test. The results of the present study were discussed under the following three headings:

a. Effect of ABR on SNR.
b. Effect of ABR on amplitude.
c. Recovery patterns of DPOAE.

Results revealed that a significant inter subject variation was present. Mean absolute DPOAE SNR value obtained for lower frequencies after ABR exposure was

lower than at higher frequencies and time of measurement (pre, post and after one hour) and frequency had a significant effect on DPOAE SNR values, where significant difference in SNR was seen across all the frequencies for all the 3 conditions ($P<.05$). Friedman test was performed to see the difference in DP amplitude across three conditions (pre, post and after one hour) and it showed that the DP amplitude of low frequencies (1001 Hz to 1501 Hz) was significantly affected ($p<0.05$) compared to high frequencies post ABR testing. Even though there was a reduction in DPOAE amplitude and SNR after exposure to continuous stimulus of ABR, however after a rest period of one hour, three different types of DPOAE recovery patterns were seen i.e. partial, complete and no recovery.

OAE and ABR evaluation are very important in the assessment of the hearing acuity and hearing screening in children. A functional outcome of this study is the recommendation for reversal of the order for carrying out the audiological tests. Thus the OAE measurements should be done prior to the ABR assessment which will ensure that the DPOAE responses are unaffected. However if ABR recording has to be done before OAE measurement, then at least one to two hours of gap is recommended between these tests.

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