THE RELATIONSHIP BETWEEN DPOAE FINE-STRUCTURE AND HEARING SENSITIVITY ACROSS DIFFERENT AGE GROUPS AND GENDER.

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JUNE - 2011

Certificate

This is to certify that this dissertation entitled ***“The relationship between DPOAE Fine-Structure and Hearing Sensitivity across different Age groups and Gender”*** is a bonafide work in part fulfilment for degree of Masters of Science (Audiology) of the student Registration No. 09AUD009. This has been carried out under the guidance of a faculty of this institute and has not been submitted earlier to any other university for the award of any other Diploma or Degree.

Mysore

June, 2011

Prof. S. R. Savithri

Director

All India Institute of Speech and Hearing

Manasagangothri

Mysore 570006

Certificate

This is to certify that this dissertation entitled ***“The relationship between DPOAE Fine-Structure and Hearing Sensitivity across different Age groups and Gender”*** has been carried out under my guidance and has not been submitted earlier to any other university for the award of any other Diploma or Degree.

Mysore

June, 2011

Mr. Sujeet Kumar Sinha

Lecturer in Audiology

All India Institute of Speech and Hearing

Manasagangothri

Mysore 570006

DECLARATION

This dissertation entitled ***"The relationship between DPOAE Fine-Structure and Hearing Sensitivity across different Age groups and Gender"*** is a result of my own study under the guidance of Mr. Sujeet Kumar Sinha, Lecturer in Audiology, All India Institute of Speech and Hearing, Mysore and has not been submitted earlier to any other university for the award of any other Diploma or Degree.

Mysore Register No. **09AUD009**

June, 2011

वक्रतुण्ड महाकाय सूर्यकोटि समप्रभ ।
निर्विघ्नं कुरू मे देव सवकार्येषु सर्वदा ॥

Dedicated to

papa

mummee

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Chapter-1

INTRODUCTION

The origin of otoacoustic emissions (OAEs) is ascribed to processes associated with active cochlear processes and the mechanical motion of the outer hair cells, thought to be controlled through the efferent auditory pathways via the olivocochlear system (Kemp, 1978; Kemp & Chum, 1980). Oto-acoustic emissions are sounds of cochlear origin, which can be recorded by a microphone fitted into the ear canal. They are caused by the motion of the cochlea's sensory hair cells i.e. the reverse travelling wave gives rise to the OAEs. There are mainly two types of OAEs: spontaneous and evoked.

- Spontaneous OAEs occurs in the absence of any external acoustic stimulation. SOAEs are pure-tones of about 20dB SPL that occur in the absence of stimulus.
- Evoked OAEs are those which are elicited or evoked with some kind of acoustic stimulation. They are further divided into three types depending on the type of stimulus eliciting it. They are stimulus frequency OAEs, transient evoked OAEs and distortion product OAEs.

Stimulus Frequency OAEs are evoked with a continuous pure tone stimulus. They are least studied experimentally and clinically. On the other hand, Transient evoked otoacoustic emissions (TEOAEs) are widely used clinically and can be generated by click or tone-burst stimulation (Robinette & Glattke, 2007).

Distortion product otoacoustic emissions (DPOAEs) are elicited by the simultaneous presentation of two pure-tones, closely spaced in frequency. Distortion is always generated when there is mechanical non-linearity, and healthy outer hair cells are mechanically non-linear. DPOAE is an intermodulation distortion response produced by the ear in response to two simultaneous puretone stimuli or two primary tones that are nearby in frequency. This DPOAE response is referred to as distorted as it originates from the cochlea at a tone signal that is not present in the eliciting pure tone stimuli. Two stimuli at different frequency (f1 and f2) and levels (L1 and L2) are used where f2>f1 and L1>L2. Mainly, the two frequencies are related to each other with a ratio of 1.2 and frequently measured distortion product is at the frequency 2f1-f2 as it is the largest distortion product found in all mammals (Kemp, 1978).

In humans, when the distortion products are measured in small frequency increments, it exhibits a fine structure characterised by a series of amplitude peaks and valleys across frequency with peak to valley amplitude ratios as great as 20 dB (Gaskill & Brown, 1990; He and Schemiedt, 1993). The peak to peak frequency interval is about 3-32 octave (He and Schemiedt, 1993) and is numerically comparable with similar rippling patterns that have been observed in stimulus frequency emissions and the fine structure of the behavioural threshold (Zwicker and Schloth, 1984; Zwicker, 1990).

The distortion product otoacoustic emissions have been recorded in various age groups and there is always some debate about the age-related changes in otoacoustic emissions. Some studies of distortion product otoacoustic emissions in humans concluded that there was a statistically significant effect of age on the distortion product otoacoustic emission amplitude (Bonfils *et al.*, 1988; Bonfils, 1989; Collet *et al.*, 1990; Lonsbury-Martin *et al.*, 1990). However, in a recent study by Stover and Norton, (1993) using a statistical analysis of variance and covariance on several types of emissions argued that these differences can be attributed to the sensitivity changes, rather than aging itself. Other studies with hearing-impaired subjects concluded that otoacoustic emissions were either significantly reduced in level or not measurable when thresholds were poorer than 30 dB HL (Bonfils *et al.*, 1988; Kemp, 1978; Harris, 1990; Nelson and Kimberley, 1992). Similarly age related changes for DPOAE fine structure have also been reported in the literature. Regarding the age effect on the DPOAE fine structure there are few studies which have reported a decline in the DPOAE fine structure whereas few studies have reported no change in the DPOAE fine structure (He & Schemiedt, 1996; Uchida et al., 2008)

DPOAE has also been used as a tool to predict the hearing threshold. Several studies have reported a relation between DPOAE levels and hearing thresholds. Harris (1988, 1990) and, Harris and Glattke (1988) have found a very good agreement between low DPOAE levels and high auditory thresholds in some of their subjects. However, in other subjects this relationship did not hold good. Gaskill and Brown (1990) reported the existence of 80% correspondence between DPOAE levels and behavioural audiograms and they also showed statistically significant correlation between DPOAE levels and auditory thresholds across the audiometric frequency range in about 50% of the ears.

Also, there are studies which report a weak correlation between auditory thresholds and DPOAE level. Kimberley et al. (1997) reported that prediction of an individual’s hearing threshold with OAE is not possible to any useful degree of accuracy. Martin, Ohlms, Franklin, Harris and Lonsbury-Martin (1990) demonstrated strong negative relation between DPOAE level and auditory threshold in subjects with noise induced hearing loss. Similarly, for the fine structure of the DPOAE, there are equivocal findings regarding the correlation between the puretone threshold and the DPOAE fine structure, whereas few studies report a good correlation between the fine structure and the hearing threshold other reports a weak correlation between the fine structure of DPOAE and the hearing threshold in children as well adults (Dhar & Abdala, 2007; Uchida et al., 2008; Wagner, Plinkert, Vonthein & Plonkte, 2008)

Need for the study:

- DPOAE is a quick and reliable measure of measuring the functioning of the outer hair cells. It requires lesser time to evaluate the functioning of outer hair cells in an individual.
- There are no normative for DPOAE fine structure across different age groups for the Indian population. As reported earlier the amplitude of the DPOAE can vary from race to race (Whitehead et al. 1993; Shanaz, 2006). So there is a need to establish the normative values of DPOAE fine structure for the Indian population.
- There are equivocal findings regarding the correlation between the puretone threshold and the DPOAE. Thus, there is a need to further investigate the correlation between the DPOAE fine structure and the hearing threshold.
- Subjective tests such as puretone audiometry requires behavioural cooperation from the client, whereas, DPOAE does not require any behavioural co-operation to record and can be recorded reliably in lesser time. Thus, there is a need to study the correlation with the puretone threshold, so that it can be recorded easily and can be a reliable tool to predict the hearing threshold in individuals.

- There are equivocal findings regarding the effect of aging on the amplitude of the DPOAE fine structure (Bonfils, 1988; Collet *et al.*, 1990; Stover & Norton, 1993). Thus, there is a need to further investigate the effect of age on the amplitude of DPOAE fine structure.

Objectives of the study:

- To develop norms for DPOAE fine-structure across three age groups i.e. young age group (8-18 years), middle age group (30-40 years) and the elderly age group (50- 60 years).
- To analyze the gender differences, if any, in fine-structure of the DPOAE.
- To correlate DPOAE fine structure with the behavioural thresholds.

Chapter -2

REVIEW OF LITERATURE

Distortion product otoacoustic emissions (DPOAE) can be recorded from the ear canal, during continuous stimulation with pure tones at f1 and f2 frequencies where f1<f2 and the intensity level L1>L2. The DPOAE has been linked to the functioning of outer hair cells on the basilar membrane corresponding to the locus 2f1-f2 (Dallos, Harris, Relkin & Chetham, 1980; Kim, Matthews & Molnar, 1980; Siegel & Kim, 1982; Horner, Lenoir & Block, 1985; Zurek 1985; Fahey & Allen, 1986; Ruggero, Rich & Freyman, 1986; Norton & Mott, 1987; Furst, Rabinowitz & Zurek, 1988). The strongest 2f1- f2 DPOAE were produced by the stimulus frequencies about 20% apart in frequency and f1/f2 ratio of 1.22.

The DPOAE fine structure is characterized by consistent maxima and minima in dependence of frequency with depth of the notches up to 20 dB (Gaskill & Brown, 1990; He & Schmiedt, 1993; Heitmann *et al.*, 1996) and a periodicity of 3/32 octave (He & Schmiedt, 1993; Mauermann *et al.*, 1997). When the stimulus frequencies f1 and f2 are varied in small steps, distinct peaks and valleys in DPOAE level versus fine structure are observed which is referred to as DPOAE fine structure. The fine structure or the microstructure is characterized by peak to peak distance of 10 peaks/octave and peak to valley excursion of 20 dB. The DPOAE fine structure is less apparent above 4000Hz. DPOAE fine structure has been used as a tool to predict the subtle changes in the cochlear function in individuals with normal hearing occurring under various clinical and environmental conditions.

Factors affecting recording of DPOAE

Stimulus related factors:

Frequency:

The three main frequencies for DPOAE measurement are f1, f2 and 2f1-f2 which are closely related to the cochlear place that is being stimulated. DPOAE frequencies f1 and 2f1-f2 are of less importance as they are not related to the audiogram. 2f1-f2 provides no information about the status of the cochlea in that region. However, decreasing the f2 actually decreases the overlap, which results in reduction of DPOAE amplitudes (Whitehead et al., 1995a; Whitehead et al., 1995b). f1/f2 ratio is critical in DPOAE measurement (Wilson, 1980; Brown & Kemp, 1985; Harris, Lonsbury-Martin, Stagner, Coats & Martin, 1989). A distortion product will not be recorded if the f1/f2 ratio is too far apart or too close. DP amplitude drops sharply as the frequency ratio is increased or decreased from a value of 1.20 (Allen & Fahey, 1993; Brown, Williams & Gaskill, 1993). Neilson, Popelka, Rasmussen and Osterhammel (1993) studied the effect of frequency region and f1/f2 ratio on the DP amplitudes. The authors found that for frequency region of 1000 to 3000Hz maximum amplitude was seen for f1/f2 ratio of 1.30, while for frequency regions above or below this had maximum amplitude for f1/f2 ratio of 1.20. Also at higher frequency regions reduced DPOAE amplitudes are seen due to the effect of changes in f1/f2 ratio (Gaskill & Brown, 1990).

However several studies have reported that the f1/f2 ratio of 1.20 produces robust DP amplitude across all the ages. Abdala (1996) recorded the 2f1-f2 DPOAE in adults, term and premature neonates to define the optimal f2/f1 ratio. Two f2 frequencies (1500 and 6000 Hz) were investigated. f2 was held constant while f1 was varied to produce 13 frequency ratios. Results revealed that the mean optimal frequency ratio for DPOAE generation is comparable in adults and neonates. The f2/f1 frequency ratio functions were similar in shape, slope, and bandwidth for adults and neonates, suggesting adult-like cochlear filtering prior to term birth. There are several other reports that suggest that f1/f2 ratio of 1.2 produces robust DPOAE amplitude (Dhar, Long, Talmadge & Tubis, 2005; Neilsonet al. 1993).

There are reports that suggest that f1/f2 ratio depends on the primary frequencies. Harris et al. (1989) studied acoustic-distortion products at 1, 2.5, and 4 kHz. f2/f1 ratios were varied in 0.02 increments from 1.01–1.41 (4 kHz), 1.01–1.59 (2.5 kHz), or 1.01–1.79 (1 kHz). The authors reported that despite of amplitude non-monotonicity, there was clearly a region of f1 and f2 separation that generated a maximum DP emission. Larger ratios reflecting a greater separation of f1 and f2 were more effective in generating DPEs at 1 kHz rather than at 4 kHz. The optimal ratio for 2.5 kHz fell at an intermediate value.

Several authors have reported that DPOAEs should include multiple internal reflections along with the generation sources. Dhar, Talmadge, Long and Tubis (2002) studied DPOAE fine structure at frequency increments between 4 and 8 Hz, at fixed f2/f1 ratios of 1.053, 1.065, 1.08, 1.11, 1.14, 1.18, 1.22, 1.26, 1.30, 1.32, 1.34, and 1.36 from four subjects. The resulting patterns of DPOAE amplitude and group delay revealed several patterns. Multiple internal reflections were observed more commonly for high primary ratios (f2/f1≥ 1.3). These results indicate that a full interpretation of the DPOAE level and phase (group delay) must include not only the two generation sources, but also multiple internal reflections.

Gorga, Nelson, Davis, Dorn and Neely (2000) measured DPOAE amplitude and noise amplitude at 2f1-f2 and 2f2-f1 for 12 primary levels for 70 normal hearing individuals and 80 hearing impaired individuals. The authors found that DPOAEs were larger for 2 *f1-f2* compared to 2 *f2-f1* in subjects with normal hearing. Also, noise amplitudes were smaller for 2 *f2-f1,* but this effect was restricted to the lowest f2 frequencies. The authors also found that multivariate analysis and multiple distortion products improve the measurement of DPOAEs.

Intensity level:

Intensity levels of f1 and f2 are L1 and L2 respectively. There have been various studies reported in literature which studied the effect of intensity level on the DPOAE amplitude. Earlier until about 1995 the researchers used equal intensity levels (L1=L2) to measure DPOAEs clinically (Lonsbury-Martin et al., 1990; Spektor, Leonard, Kim, Jung & Smurzynski, 1991; Hall, 1993).

Several authors compared L1=L2 and L1>L2 conditions with respect to DPOAE amplitude and found that L1>L2 yields better DP amplitude. Gaskill and Brown (1990) compared the two conditions (L1=L2 and L1>L2) and found that L1>L2 condition results in better amplitude of about 3dB. Several other authors support these findings (Hauser & Probst, 1991; Whitehead, Lonsbury-Martin & Martin, 1992; Neilson et al., 1993; Whitehead et al., 1995).

However, there are studies in contrary too. Neilson et al. (1993) studied DPOAE amplitude in seven normal ears. They kept the f1/f2 ratio constant (1.23) and varied L1 and L2 from -10dB to +10 dB systematically. The L2 was held constant at 75 dB SPL for negative value and L1 kept constant at 75 dB SPL for positive values. They found that DPOAE amplitude was maximum for L1=L2 followed by L1>L2 and least amplitude for L2>L1.

There are several reports that suggest that primary tone level depends on the f1/f2 ratio itself. Harris et al., (1989) studied acoustic distortion-product amplitude as a function of primary-tone level. They found that it was directly related to the frequency separation of the primary tones. Regardless of the frequency region of the primary tones, smaller f2/f1 ratios were superior in generating DP emissions in response to 65-dB stimuli, whereas larger ratios elicited bigger DP emissions with primaries at 75 and 85 dB SPL.

Subject related parameters:

Age differences:

Age differences are seen due to the developmental changes that take place as the age increases and also the changes that are associated with advanced aging. There are studies which suggest that DPOAE amplitude is larger for children than adults. Several reports (Bonfils et al., 1992; Lasky et al., 1992; Brown et al., 1995) suggest that with increase in age the amplitude of DPOAEs decrease. Highest amplitude of DPOAEs is seen for infants less than 1 year. The amplitude decreases from 1 to 3 years and decreases further with age until reaches an adult value.

Prieve, Fitzgerald, Schulte and Kemp (1997) studied 196 normal hearing individuals aged between 4 weeks to 29 years. DPOAE input/output function at seven f2 frequencies was measured. Children aged less than 1 year had significantly higher mean DPOAE levels than older children and adults, and children aged 1–3 yr had higher mean DPOAE levels than teens and adults.

There are studies which suggest that DPOAEs are most prominent at high frequencies across the ages. Kon, Inagaki and Kaga (2000) studied the developmental changes of distortion product otoacoustic emissions (DPOAEs) and transient evoked otoacoustic emissions (TEOAEs) in 275 normal subjects aged from 1 month to 39 years. The DP-grams of the subjects were evaluated. In subjects younger than 3 years, low frequency DPOAEs did not rise above the noise floor. At high frequencies the DP levels did not change much across the age range, however, those at low and middle frequency there was significant decrease with age. The DPOAEs were predominant at high frequencies.

With the advanced age the amplitude of DPOAEs decreases as the thresholds increases with age. This reduction in the amplitude of DPOAEs is mainly seen for the higher frequencies. Lonsbury-Martin and Martin (1990) studied 44 ears of 22 adults, ranging in age from 21-30 years. It was found that five ears displayed significant decrements in DPOAE amplitudes. Four of the five ears exhibiting the high-frequency deficits in DPOAE magnitudes were from the oldest individuals who were 30 years old. Thus, in these older subjects it was the reductions in the amplitudes of the high-frequency DPOAEs and the concomitant increases in detection thresholds to aging effects. Also, in young subjects DPOAE amplitudes tended to decrease and detection thresholds increase, with age, for the two highest test frequencies at 6 and 8 kHz. Several other studies report the reduction in amplitude with age (Lonsbury-Martin, Cutler & Martin, 1991; Dorn et al., 1998; Oeken, Lenk & Bootz, 2000).

However, it has also been reported that DPOAEs are not affected by advancing age if the hearing thresholds are within the normal range. Karzon, Philip, Peterein and Gates (1994) studied DPOAEs in 71 elderly individuals in the age range of 56-93 years and 8 young individuals in the age range of 19-26 years. They found that the DPOAE amplitude did not decrease significantly with age if the hearing thresholds were within the normal limits. Several other reports suggest the same findings (Strouse, Ochs & Hall, 1996; He & Schmiedt 1996; Wagner, Plinkert, Vonthein & Plontke, 2008).

Torre, Cruickshanks, Nondahl, and Wiley (2003) studied 937 individuals for DPOAEs and noise response characteristics in adults aged between 48-92 years. The DPOAE and noise responses were measured at 1000, 2000, 4000 and 8000 Hz and were compared with respective pure tone frequencies. The receiver operator characteristic analyses demonstrated -6 dB SPL at 2000 Hz, -14 dB SPL at 4000 Hz and -22 dB SPL at 8000 Hz and a +9 dB DPOAE/Noise ratio at each of these frequencies. Therefore, the authors support the use of DPOAEs as a clinical measure for older adults.

DPOAE fine structure across age groups

There are reports that suggest that DPOAE fine structure has more depth and wider spacing in newborns when compared with adults. Dhar and Abdala (2007) compared DPOAE fine structure in ten human newborns and ten adults with normal hearing. They found that the DPOAE fine structure in newborns were not adult-like. The newborns showed higher DPOAE levels, greater fine structure depth and wider fine structure spacing.

However, several other reports suggest that DPOAE fine structure is independent of age. Wagner et al. (2008) studied the dependence of DPOAE fine structure on age. The authors studied 102 participants in the age range of 17-81 years. First, the authors screened for fine structure using two tone stimulation (L1/L2 = 55/45 dB SPL, f2/f1 = 1.22) and frequency steps of 40 Hz in the frequency range of 1.8–4.2 kHz. DPOAE fine structure was then recorded in 1/3 octave-bands centered around f2 equals 2, 3 and 4 kHz with a frequency resolution of 12.5, 20 and 25 Hz, respectively. They found no significant age effect on DPOAE fine structure.

Also, some studies report that only at few frequencies the DPOAE fine structure is affected. He and Schmeidt (1996) studied DPOAE fine structure for twenty young and adult normal. A distortion product fine structure was measured over four 1/3-octave frequency ranges centred at 2000, 3000, 4000, and 6000 Hz, respectively. Equivalent primaries of 50 dB SPL were used. They found significant difference in fine structure only at 3000Hz region. Other frequencies no significant difference in the DPOAE fine structure was noticed.

Gender differences:

Gender differences are seen in DPOAEs but compared to other evoked OAEs it is minimally noted. Longer DPOAE latency (phase) values, smaller DPOAE amplitude for males is noted. Gaskill and Brown (1990) found that DPOAEs were significantly larger in females than males for majority of test frequencies ranging 1000-5000 Hz. Several other studies reports of higher amplitude DPOAEs in females (Lonsbury- Martin, Curtler & Martin, 1991; Moulin et al., 1993; Cacace et al., 1996; Bowman, Brown & Kimberley, 1999).

However, some studies suggest that the longer latencies and smaller amplitudes are seen from low to mid frequency and not seen at all frequencies. Cacace et al (1996) studied 8 males with mean age 25 years and 8 females with mean age 24 years. They studied DPgram for 12 pairs of puretone primary frequency. The f2 ranged from 1245Hz- 6201Hz at 4points/octave and the auditory thresholds were measured from 250Hz-8000Hz. The study concluded that females had an average of 2.4 dB more sensitive thresholds than age matched males for octave frequencies from 250-4000 Hz.

Uchida et al. (2008) studied the effect of aging on normal hearing adult individuals. The authors studied 331 individuals (136 men and 195 women) aged 40-82 years. 22 frequencies were studied for DPOAE amplitude and puretone threshold. The authors found that out of the 22 test frequencies, DPOAE amplitudes were significantly different for four test frequencies (4761-6165) for males and for all frequencies except 3088 Hz for females. Also, a significant negative effect of age on DPOAE levels at 1086 Hz in males and at the 1184, 2002, 2185, 4004, and 4358 Hz in females. They concluded saying that aging effect was observed more in women than in men.

Dunckley and Dreisbach (2004) measured DPOAEs in 20 females and 17 males to see the effect of gender on high frequency DPOAEs. DPOAEs were measured at f2 frequencies of 1, 2, 4, 8, 10, 12, 14, and 16 kHz, with L1 = 60 and L2 = 45 dB SPL, with f2/f1 varied from 1.2. The authors reported significant interactions for frequency and gender for group delay for frequencies 1 to 8 kHz and level for frequencies 9 to 15 kHz. The authors concluded saying that significant interactions exist between gender and DPOAE group delay values at low frequencies and for DPOAE levels at high frequencies.

McFadden, Martin, Stagner and Maloney (2008) studied 51 females and 57 males in the age range of 15-35 years. The DPOAE was measured for frequencies ranging from 800 Hz -8000 Hz. The authors reported gender differences but no ear differences for DPOAEs. The gender differences seen for DPOAEs were lesser when compared to TEOAEs.

Engdahl (2002) studied DPOAEs for f2 frequencies of 2, 3, 4, 6 and 8 kHz. The author studied the effect of age, gender and ear on adult population of Norway. He studied 2823 males and 3592 females in the age range of 20-97 years. The author reported of significant differences across the age, gender and ears. Females for right ear had higher DPOAE levels.

Dreisbach, Kramer, Cobos and Cowart (2007) studied racial and gender effects on behavioral thresholds and DPOAEs. The authors studied an age range of

20-39 years. 60 young normal-hearing adult subjects which includes 20 Caucasian, 20 Asian, 20 African-American, with ten females and ten males in each group. Behavioural thresholds were measured from 1000 through 16000 Hz using Bekesy tracking and DPOAEs were measured for f2 frequencies ranging from 2000-12000 Hz with L1/L2 equivalent to 60/45 dB SPL, and f2/f1ratio of 1.2. The authors reported significant racial and gender differences in behavioural thresholds were found at 14000 and 16000 Hz, with the African Americans and females having better hearing sensitivity at these frequencies.

Johanasson, Magnus and Arlinger (2003) studied the effect of age, gender and middle ear pressure on 493 individuals in the age range of 20-79 years. The authors studied DPOAE level for frequencies 0.75, 1, 1.5, 2, 3, 4, 6 and 8 kHz. The authors reported of significant effect of gender and age. Females showed 2-3 dB higher levels of DPOAE. No significant effects of middle ear pressure and ear differences were noted on DPOAE level.

Ear differences:

The right ear is more sensitive than the left to simple sounds (peripheral right-ear advantage) and to processing complex sounds such as speech (central right-ear advantage). This holds good for transient evoked otoacoustic emission (TEOAE) and distortion product otoacoustic emission amplitudes also. Tadros et al., (2005) studied young adults with normal hearing and older presbycusis group. The young adults showed significantly higher otoacoustic emission amplitudes for the right ear compared to the left ear. However, this finding was reversed in the presbycusic group that showed higher left-ear emission amplitudes.

However, there are reports that suggest that no significant ear differences are seen for DPOAEs. Pavlovcinova et al (2010) studied DPOAEs in hundred and twenty-nine 12-year-old children with normal hearing for ear asymmetry and gender. They found that DPOAEs are independent of gender and ear effects

Body temperature:

Body temperature is one of the factors that influence endocochlear potential, mechano-electric transduction properties, outer hair cell length, shape, and mechanics, and hair cell afferent synapses (Gitter, 1992; Ohlemiller & Siegel, 1994; LeCates et al., 1995 Chen & Brownell, 1999). Several studies have reported no effect of body temperature on DPOAE levels. Cacace, McClelland, Weiner and McFarland (1996) studied the effect of body temperature and resting pulse on DPOAE amplitude and found no effect. Several other reports suggest no significant effect of temperature on DPOAE amplitude (Noyes et al., 1996).

However, there are studies that report that in a particular temperature range there is no effect of body temperature on DPOAE amplitude while above and below that range the amplitude reduces. Khvolves, Freeman and Sohmer (1998) studied DPOAE and TEOAE amplitudes within the temperature range of 33 to 39 degrees. They found that the amplitudes remained constant in this temperature range. However, above or below this range the amplitudes are significantly reduced, especially for lower intensity stimuli.

Body position:

It has been postulated that the fine structure was less pronounced as the body tilts backward from an upright position and disappears in horizontal position (Wilson, 1980). Heinlen (2008) studied the effect of three body positions namely lying on the left side, supine, and head raised at 45 degrees from supine for 47 full term newborn babies. No significant difference was noticed among the different body positions.

Several other authors reported the effect of body position on DPOAEs. Driscoll et al (2004) studied 60 normal hearing adults for the effect of body position on DP amplitude, signal to noise ratio and noise. A significant effect of body position was observed on all the three parameters.

State of arousal:

The state of arousal and the evoked oto-acoustic emissions are independent of each other. Several studies have reported the effect of various drugs on DPOAE. Various studies reported no change in the amplitude of DPOAEs for sodium pentobarbital and ketamine (Harel et al., 1997; Zheng et al., 1997). However, several studies reported reduced DPOAEs for barbiturate aneasthesia (Zheng et al., 1997).

Pathological factors:

Pathological conditions like middle ear dysfunction and hearing loss affects the DPOAE results. Several reports suggest that the presence of middle ear dysfunction decreases the amplitude of DPOAEs or total absence of DPOAEs (Wiederhold, 1990; Owens et al., 1993; Gorga et al., 2000; Keefe, 2002)

As the hearing loss reaches mild degree the DPOAEs are absent. For mild and minimal hearing loss reduced DPOAEs are seen. Above mild degree of hearing loss no DPOAEs are seen. Several studies report a reduction of DPOAE fine structure in cochlear hearing losses such as sudden hearing loss (Mauermann, Uppenkamp, Van Hengel & Kollmeier, 1999), ototoxicity (Rao *et al., 1996*) and noise induced temporary threshold shifts (Engdahl & Kemp, 1996).

Evoked OAEs have been found to be a useful tool in understanding the role of various genes in hearing (Hood & Berlin, 2001). Evoked OAE can be helpful in detecting carriers of hereditary hearing loss in absence of audiometric evidence.

Several studies reported reduced evoked OAEs in genetic carriers despite of normal hearing sensitivity. Hood and Berlin (2001) reported reduced Evoked OAE in carriers of Cx26 mutations. Several other studies also found reduced evoked OAEs in genetic carriers (Morell et al., 1998; Engel-Yeger et al., 2002, 2003).

Several authors reported of notched DPOAEs in syndromic patients with normal hearing sensitivity. Liu & Newton (1997) found abnormal notches in DPOAEs in patients with Waardenburg syndrome despite having normal audiometric threshold. Nieschalk, Hustert and Stoll (1998) studied DPOAEs using DPgram and DPOAE input- output function for 20 normal hearing adults and 20 age matched sensorineural high frequency loss. DPgram was recorded in ¼ octave steps at 70dB SPL over a frequency range of 1001-6299Hz. DPOAE input-output function was measured for stumulus level ranging from 20-71 dB SPL in 3 dB steps for f2 frequency of 1, 1.5, 2, 4 and 6 kHz. The normal hearing adults showed 2 distinct behaviours representing the normal functioning of cochlea with saturating behaviour till 60 dB and linear above 60 dB. This represents the active and passive processes in cochlea. While the hearing impaired adults showed more of linear behaviour.

Wagner and Plinkert (1999) compared transiently evoked otoacoustic emissions (TEOAE) and distortion product otoacoustic emissions (DPOAE) in 44 normal hearing ears and 149 ears with cochlear hearing loss. The authors found that hearing-impaired individuals showed 50% reduction of OAE by a mean hearing loss of 10.5 dB for TEOAE compared to 27 dB SPL for DPOAE. Also, 90% incidence reduction was found at a mean threshold elevation of 33 dB for TEOAE and 51 dB for DPOAE. The authors found that the correlation between TEOAE amplitudes and hearing loss was low, while DPOAE amplitudes showed a slightly better correlation with hearing loss. In general, efforts to derive an audiogram from evoked OAE have been more promising for DPOAE than for TEOAE.

Threshold estimation using DPOAEs

Few studies found no direct correlations between frequencies of DPOAE maxima and minima and the threshold fine structure in humans which is thought to be due to the fact that the DPOAE does not simply reflect properties of cochlear status near *f*2 (Mauermann *et al.*, 1997; Talmadge, Tubis, Long &Piskorski, 1998). Mauermann, Long and Kollmeier (2004) suggested that the fine structure might serve for the identification of early hearing loss on account of high sensitivity of fine structure on cochlear hearing loss.

Correlation between DPOAE and ASSR:

Several studies have reported a significant correlation between the ASSR and DPOAEs especially in the lower frequencies. Hatzopoulos et al. (2009) studied distortion product otoacoustic emission input/output-functions and auditory steady state responses (ASSR) in 53 subjects. The comparison between DPOAE and ASSR threshold values indicated significant mean differences across all tested frequencies. Significant relationships were observed between the behavioural and the DPOAE measurements in the lower frequencies (1.5 and 2.0 kHz).

Rosner, Kandzia, Oswald and Janssen (2011) developed a parameter-setting and test-protocol to measure DPOAEs and ASSRs binaurally and simultaneously at multiple frequencies. The authors studied ten normal hearing individuals and twenty three hearing impaired individuals for interactions of DPOAE and ASSR for frequencies between 0.25 and 6 kHz. Frequency distance between ASSR carrier frequency and DPOAE primary tone f2 was kept 1.5 octaves atleast and ASSR stimulus level below 70 dB SPL. The authors found a significant correlation between pure-tone and DPOAE/ASSR-thresholds for hearing impaired individuals.

Correlation between DPOAE and ABR:

DPOAEs and ABR shows similar trends for threshold estimation. Several reports suggest that DPOAE detection threshold shows trends with ABR measures when DPOAE measures are referred to f2 (Parham, 1997; Le Calvez et al., 1998; Parham et al., 1999)

However, there are reports that suggest no significant correlation between the DPOAEs and ABR. Kakiqi, Hirakawa, Harel, Mount and Harrison (1998) compared distortion product otoacoustic emissions, transient evoked otoacoustic emissions and ABR threshold shifts in chinchillas with cochlear hearing loss. ABR thresholds to tone pip stimuli were determined. Both types of emission were compared with corresponding ABR thresholds. There was no significant linear correlation between these different measures of cochlear function.

Correlation between DPOAE and PTA:

The relationship between the DPOAE levels and behavioural thresholds has been argued since years. Several studies report no correlation between the audiometric thresholds and the DPOAE levels. Boege and Janssen (2002) studied DPOAE input/output function to predict behavioural thresholds. They studied 30 normal hearing individuals and used DPOAE input/output function to extrapolate DPOAE thresholds. A correlation of 0.6 was obtained between the predicted thresholds and the audiometric thresholds. Although the data was variable but there was a relationship between the two.

He and Schmiedt (1996) studied DPOAE fine structure for 20 aged subjects and 14 young subjects with normal hearing sensitivity. They found DPOAE fine structure for 1/3 octave per frequency for 2000, 3000, 4000 and 6000 Hz frequencies. They found that DPOAE fine structure was observable when the hearing thresholds were within normal limits. They also found a positive correlation between DPOAE fine structure and hearing thresholds.

Several other studies report that there is a correlation between DPOAE levels and audiometric thresholds but the highest correlation was seen at mid and high frequencies. Gorga et al (2003) used DPOAE input/output function to predict behavioural thresholds. They found that there exists a relation between the audiometric thresholds and DPOAE thresholds. The correlation between the two was highest for mid to high frequencies. A correlation of 0.85 for 4000 Hz was found.

There are several reports that suggest that hearing thresholds are predicted best using input-output method. Boege and Janssen (2002) measured DPOAE input-output function and pure tone thresholds for 51 frequencies ranging from 500Hz to 8000Hz in 30 normal hearing individuals and 119 sensorineural hearing loss individuals. The researchers predicted DPOAE thresholds using DPOAE input-output function. They found a correlation of 0.8 in majority of DPOAE input-output functions.

Various other studies report a weak or a poor correlation between the DPOAE levels and audiometric thresholds. Heitmann, Waldmann & Plinkert (2004) have reported a weak correlation between the hearing thresholds and DPOAE fine-structure. They also found that the behavioural thresholds cannot be accurately predicted using the fine-structure. Several other studies suggest the same.

Talmadge, et al., (1998) studied the relationship between the fine structures of the hearing threshold, synchronous and click-evoked emissions, distortion-product emissions, and spontaneous emissions. They found that the frequency spacing for spontaneous emissions and threshold microstructure are predicted to be the same, but some deviations were predicted for synchronous and click-evoked and distortion-product emissions.

Reuter and Hammershoi (2006) studied DPOAE fine structure for 50 normal hearing individuals aged between 20-29 years. DPOAE fine structure was measured for frequencies ranging between 903 Hz-6201 Hz. They studied three parameters namely ripple spacing, ripple height and ripple prevalence. They found that ripple spacing decreases with increase in frequency from 1/8 octave at 1 kHz to 3/32 octave at 5kHz. Ripple prevalence was found to be 2-3 ripples per 1/3 octave. Ripple height of 32 dB was detected.

So, there are studies which are in consonance with the thought of prediction of hearing thresholds with the DPOAE fine structure while there is also some literature opposing this school of thought. Hence, there is a need to probe further in to this area of research in order to cull some implications, if possible.

Chapter-3

METHOD

The present study was conducted with the aim of studying the relationship between amplitude of the distortion product oto-acoustic emission fine structure and hearing sensitivity across different age groups and gender.

Participants

A total of 98 subjects in the age range of 8 yrs to 60 years participated for the study. The participants were further sub-grouped into three subgroups:

Group I: 50 young individuals (8 to 18 years, mean age: 12.6 years) – (25 males and 25 females)

Group II: 30 middle aged individuals (30 to 40 years, mean age: 34.0 years) – (15 males and 15 females)

Group III: 18 elderly individuals (50 to 60 years, mean age: 52.3 years) – (9 males and 9 females)

Participant's selection criteria:

- Normal hearing sensitivity in both the ears as defined by pure tone threshold of less than or equal to 15 dB HL in the octave frequency from 250 Hz to 8000 Hz for air conduction and less than or equal to 15 dB HL for bone conduction thresholds in the octave frequencies from 250 Hz to 4000 Hz.
- Speech identification scores of greater than or equal to 90% in quiet.

- Normal middle ear functions as revealed by immittance measures and ENT evaluations. Individuals with type 'A' tympanogram and presence of acoustic reflexes (ipsilateral and contralateral) were selected for the study.

- Presence of DPOAE as defined by signal to noise ratio of 6 dB or greater in the frequencies between 1000 Hz to 8000 Hz.
- No family history of hearing loss.
- Presence of no diabetes.
- Presence of no hypertension.
- No exposure to occupational noise.
- No illness on the day of testing.
- No evidence of any neurological problem.
- No other otological problem such as earache, ear discharge, past history of ear discharge and tinnitus.

Instrumentation

- A calibrated dual channel audiometer (Orbiter 922), with TDH-39 headphones housed in MX-41AR supraural cushion, was utilized for pure tone testing. Radio Ear B-71 bone vibrator for bone conduction threshold was utilized. The same audiometer was utilised for speech audiometry as well.
- A calibrated immittance meter for tympanometry and reflex measurements.
- ILO V6 was used for recording DPOAE and DPOAE fine-structure.

Testing environment

All the evaluations were carried out in an acoustically treated two-room situation with permissible noise levels as per ANSI S3.1 (1999).

Procedure

- *Detailed case history:*

  A detailed case history was taken. It included information on family history of hearing loss, presence of diabetes, any exposure to occupational noise, any other neurological or otological problems.

- *Behavioural testing (Auditory microstructure):*

  Hearing thresholds were obtained at frequencies same as the f2 frequencies of DPOAE, as the 2f1-f2 DPOAE is thought to be generated in the region of f2 (Brown & Kemp, 1984; Martin et al., 1987, 1998; Lonsbury-Martin & Martin, 2007). Hence, for the puretone audiometry the frequencies for testing chosen were 1001, 1086, 1184, 1294, 1416, 1538, 1685, 1831, 2002, 2185, 2380, 2600, 2832, 3088, 3369, 3662, 4004, 4358, 4761, 5188, 5652, 6165, 6726, 7336 and 7996 Hz. The threshold was measured in 1dB step using the Modified Hughson-Westlake Method (Carhart & Jerger, 1959). Hearing thresholds at 8 points between octaves 1000 Hz to 8000 Hz were established to obtain the "auditory microstructure".

- *Speech identification scores(SIS):*

  SIS was measured in quiet using word list given by Vandana and Yathiraj (1998). It consists of 2 word lists of 20 phonetically balanced words. The speech identification scores were noted at 40 dB above the speech recognition threshold.

- *Immittance evaluation:*

  Tympanometry was done using 226 Hz probe tone frequency and acoustic reflexes were elicited ipsilaterally and contralaterally for 500 Hz and 1000 Hz, 200 Hz and 4000 Hz.

- *DPOAE:*

  DPOAEs were measured for f2 frequency of 1001 Hz, 2002 Hz, 4004 Hz and 7996 Hz. The f1/f2 ratio equals 1.22 which was kept constant. The intensity of the two stimuli (L1 and L2) was kept constant as 65 dB and 55 dB respectively.

- *DPOAE fine-structure:*

  DPOAE fine-structure amplitude was obtained for 25 frequencies where f2 frequency was varied from 1001 Hz to 7996 Hz at 8 point per octave (1001, 1086, 1184, 1294, 1416, 1538, 1685, 1831, 2002, 2185, 2380, 2600, 2832, 3088, 3369, 3662, 4004, 4358, 4761, 5188, 5652, 6165, 6726, 7336 and 7996 Hz). The primary tone frequency ratio (f2/f1) was kept constant at 1.22 as the transmission of 2f1-f2 basally occurs maximally at this ratio (Kemp, 2007). The presentation levels for f1 and f2 were kept at 65 dB HL and 55dB HL, respectively.

Analyses

- Absolute amplitude of the DPOAE fine structure was measured.
- Auditory microstructure for the behavioural testing was established.
- The DPOAE fine structure amplitude across the different age groups was analyzed.
- The auditory microstructure and the amplitude of the DPOAE fine structure were correlated**.**

Chapter-4

RESULTS AND DISCUSSION

The present study aimed at developing norms for DPOAE fine structure for the three age groups (8-18yrs, 30-40yrs and 50-60yrs). The study also aimed at correlation between DPOAE fine structure and behavioural thresholds. To analyse the data following statistical analyses were carried out:

1) Descriptive statistics to find out the mean and standard deviation of amplitude of DPOAE fine structure
2) Mixed ANOVA to see the interactions among the frequency, age, gender and ear.
3) Bonferroni's post hoc for pairwise comparison across the frequencies.
4) Duncan's post hoc analysis to see the significant differences across different age groups.
5) A repeated measure of ANOVA was done for variables that showed interaction in the Mixed ANOVA test.
6) Pearson's Correlation to find out the correlation among the DPOAE fine structure amplitude and Puretone threshold.

Amplitude of DPOAE fine structure

Descriptive statistics was done to obtain the mean and standard deviation for the amplitude of DPOAE fine structure across the different age groups. The details of the mean and standard deviation of the amplitude of DPOAE fine structure for the three different age groups across age, ear and gender are given in table 4.1.1, 4.1.2 and 4.1.3.

Table 4.1.1.

Mean and Standard deviation for age 8-18 years across ear and gender.

DP Fq	Ear	Gender	Mean	S.D.	DP Fq	Ear	Gender	Mean	S.D.	DP Fq	Ear	Gender	Mean	S.D.	DP Fq	Ear	Gender	Mean	S.D.
1001	R	M	5.68	5.09	1831	R	M	9.15	4.82	3369	R	M	7.25	4.89	6165	R	M	6.11	6.23
		F	4.17	4.81			F	11.40	5.56			F	9.87	4.91			F	8.23	6.55
	L	M	5.71	5.17		L	M	9.66	4.39		L	M	7.35	5.40		L	M	7.53	5.82
		F	4.72	4.63			F	9.86	4.26			F	8.28	4.31			F	6.83	5.27
1086	R	M	2.60	8.72	2002	R	M	8.73	5.16	3662	R	M	7.33	4.74	6726	R	M	2.58	5.80
		F	5.21	4.61			F	11.48	4.30			F	9.91	4.97			F	6.27	6.52
	L	M	2.80	6.54		L	M	8.02	4.84		L	M	8.40	4.73		L	M	3.61	6.88
		F	4.84	5.09			F	9.81	4.75			F	8.32	4.30			F	4.71	8.20
1184	R	M	7.15	6.04	2185	R	M	8.56	5.77	4004	R	M	8.58	5.08	7336	R	M	-.42	6.10
		F	6.77	3.84			F	11.90	3.52			F	9.32	4.97			F	3.25	5.54
	L	M	5.91	6.67		L	M	8.35	4.84		L	M	7.95	5.44		L	M	-.84	7.28
		F	5.17	4.84			F	9.18	4.49			F	7.72	5.43			F	.01	5.96
1294	R	M	7.98	5.67	2380	R	M	9.40	5.08	4358	R	M	9.55	4.27	7996	R	M	-4.08	9.18
		F	7.65	5.53			F	11.12	3.25			F	9.85	4.38			F	-3.91	7.51
	L	M	8.24	4.99		L	M	7.94	4.84		L	M	8.57	5.53		L	M	-3.75	5.27
		F	7.57	4.35			F	8.93	5.00			F	9.21	4.56			F	-3.35	6.94
1416	R	M	7.65	6.37	2600	R	M	8.09	6.11	4761	R	M	8.45	5.00					
		F	8.70	4.08			F	11.86	4.16			F	10.37	5.07					
	L	M	7.50	4.76		L	M	7.82	5.18		L	M	8.27	6.17					
		F	8.00	4.40			F	8.70	4.50			F	9.07	5.11					
1538	R	M	9.26	5.12	2832	R	M	8.15	4.33	5188	R	M	8.27	5.66					
		F	9.24	4.86			F	10.99	4.18			F	9.75	4.56					
	L	M	8.83	4.84		L	M	8.52	4.54		L	M	9.19	6.52					
		F	8.25	4.31			F	8.79	4.58			F	9.89	4.96					
1685	R	M	9.54	4.69	3088	R	M	7.94	4.22	5652	R	M	7.23	5.69					
		F	10.48	5.30			F	11.05	4.79			F	9.42	4.73					
	L	M	9.20	4.96		L	M	7.35	5.23		L	M	8.63	5.86					
		F	10.34	5.00			F	8.55	4.00			F	8.69	4.62					

Table 4.1.2.

Mean and Standard deviation for age 30-40 years across ear and gender.

DP Fq	Ear	Gender	Mean	S.D.	DP Fq	Ear	Gender	Mean	S.D.	DP Fq	Ear	Gender	Mean	S.D.	DP Fq	Ear	Gender	Mean	S.D.
1001	R	M	5.01	4.29	1831	R	M	9.56	2.84	3369	R	M	7.68	3.00	6165	R	M	3.23	3.81
		F	4.17	4.81			F	11.64	5.52			F	9.56	5.36			F	5.25	5.56
	L	M	5.71	5.17		L	M	9.23	2.64		L	M	7.22	2.83		L	M	.51	4.27
		F	4.72	4.63			F	9.96	4.43			F	7.19	4.53			F	3.69	7.43
1086	R	M	4.63	5.54	2002	R	M	9.05	4.00	3662	R	M	7.86	3.35	6726	R	M	-.79	3.99
		F	6.19	5.49			F	10.79	5.05			F	8.83	4.90			F	2.76	4.53
	L	M	5.46	4.17		L	M	8.63	2.06		L	M	7.26	2.37		L	M	1.75	11.89
		F	5.22	4.52			F	9.91	3.91			F	6.76	5.67			F	.12	9.33
1184	R	M	5.63	5.04	2185	R	M	7.64	3.49	4004	R	M	7.05	3.34	7336	R	M	-1.92	3.72
		F	6.34	6.18			F	9.94	5.18			F	9.79	5.25			F	-4.14	6.81
	L	M	6.06	3.34		L	M	6.53	2.23		L	M	7.03	2.95		L	M	-4.01	6.58
		F	5.72	5.62			F	8.36	3.30			F	7.43	5.09			F	-4.44	7.74
1294	R	M	6.29	4.37	2380	R	M	7.24	2.42	4358	R	M	7.58	3.79	7996	R	M	-6.23	3.75
		F	8.70	6.23			F	10.09	4.17			F	10.17	4.19			F	-7.67	4.71
	L	M	8.44	7.06		L	M	6.28	2.44		L	M	6.03	3.05		L	M	-4.46	6.30
		F	8.46	4.90			F	6.87	4.95			F	8.81	4.63			F	-7.39	5.15
1416	R	M	8.00	4.43	2600	R	M	7.07	3.27	4761	R	M	7.69	3.44					
		F	9.50	5.38			F	9.34	4.06			F	9.31	3.76					
	L	M	6.65	4.26		L	M	7.28	2.31		L	M	5.73	2.66					
		F	9.25	5.27			F	7.35	4.93			F	7.81	3.81					
1538	R	M	8.92	3.61	2832	R	M	6.78	3.38	5188	R	M	5.90	3.99					
		F	10.89	4.68			F	10.24	5.06			F	9.02	3.07					
	L	M	7.23	2.52		L	M	6.84	2.58		L	M	3.45	3.05					
		F	9.32	4.20			F	6.39	4.34			F	6.64	4.05					
1685	R	M	9.36	3.36	3088	R	M	7.18	3.14	5652	R	M	5.15	4.37					
		F	11.84	6.37			F	10.80	5.22			F	5.11	4.46					
	L	M	9.12	2.82		L	M	6.44	2.64		L	M	2.35	2.65					
		F	10.79	4.04			F	6.64	4.86			F	3.96	4.86					

Table 4.1.3.

Mean and Standard deviation for age 50-60 years across ear and gender.

DP Fq	Ear	Gender	Mean	S.D.	DP Fq	Ear	Gender	Mean	S.D.	DP Fq	Ear	Gender	Mean	S.D.	DP Fq	Ear	Gender	Mean	S.D.
1001	R	M	-1.43	3.60	1831	R	M	4.00	2.70	3369	R	M	2.26	2.06	6165	R	M	-7.67	5.92
		F	1.56	4.89			F	5.52	1.63			F	3.26	3.08			F	-3.54	5.56
	L	M	-2.34	3.84		L	M	4.16	3.79		L	M	2.09	5.25		L	M	-10.70	4.33
		F	2.24	3.55			F	6.37	1.80			F	3.39	1.82			F	-11.68	28.11
1086	R	M	-2.84	4.89	2002	R	M	2.84	2.71	3662	R	M	2.16	3.73	6726	R	M	-10.22	5.91
		F	.31	6.39			F	6.23	2.33			F	3.21	1.25			F	-4.23	5.77
	L	M	-2.08	5.03		L	M	4.30	3.77		L	M	.71	5.60		L	M	-11.54	2.57
		F	3.89	3.76			F	5.24	1.64			F	4.39	3.10			F	-6.51	6.10
1184	R	M	-2.84	7.81	2185	R	M	4.12	3.30	4004	R	M	1.99	2.46	7336	R	M	-6.81	13.71
		F	4.44	4.01			F	4.18	2.43			F	4.08	1.91			F	-9.29	4.11
	L	M	1.02	1.66		L	M	4.26	4.08		L	M	-.09	5.54		L	M	-12.42	1.12
		F	5.04	3.07			F	5.81	2.41			F	4.68	3.76			F	-10.86	5.99
1294	R	M	1.60	4.45	2380	R	M	4.26	3.67	4358	R	M	-.06	2.19	7996	R	M	-12.72	4.87
		F	4.49	5.63			F	3.97	2.49			F	4.53	3.09			F	-12.34	4.06
	L	M	.63	3.85		L	M	2.39	3.95		L	M	-2.14	7.11		L	M	-14.52	3.96
		F	6.00	4.01			F	4.53	2.29			F	5.26	4.72			F	-14.29	3.99
1416	R	M	3.92	2.49	2600	R	M	4.93	2.21	4761	R	M	-1.60	2.99					
		F	5.69	4.94			F	4.03	2.28			F	4.70	4.14					
	L	M	1.16	4.93		L	M	4.73	2.50		L	M	-4.44	7.37					
		F	7.57	3.67			F	6.20	2.79			F	3.71	5.11					
1538	R	M	4.62	2.96	2832	R	M	4.77	1.76	5188	R	M	-3.89	2.27					
		F	5.99	2.77			F	3.89	1.74			F	3.70	4.11					
	L	M	3.54	2.98		L	M	3.50	1.56		L	M	-7.80	7.50					
		F	7.71	2.95			F	4.07	2.76			F	3.189	6.03					
1685	R	M	4.44	2.75	3088	R	M	1.81	2.18	5652	R	M	-5.27	4.22					
		F	5.22	2.82			F	2.97	1.85			F	.17	5.51					
	L	M	4.38	3.18		L	M	3.03	2.58		L	M	-8.56	4.79					
		F	6.21	2.63			F	2.70	2.31			F	-.81	7.00					

It can be seen from table 4.1.1, 4.1.2 and 4.1.3 that the amplitude of the DPOAE fine structure is almost similar for 8-18 years and 30-40 years of age groups. It can also be seen that the amplitude of DPOAE fine structure reduces for the third age group (i.e. 50-60 years) for all the frequencies compared to the first two age groups for the right ear. On comparing the three age groups it can also be seen from table 4.1.1, 4.1.2 and 4.1.3 that even for the 2nd age group there was a reduction in the amplitude of the DPOAE fine structures above 5188 Hz frequencies for the right ear. The same can be seen in figure -4.1.

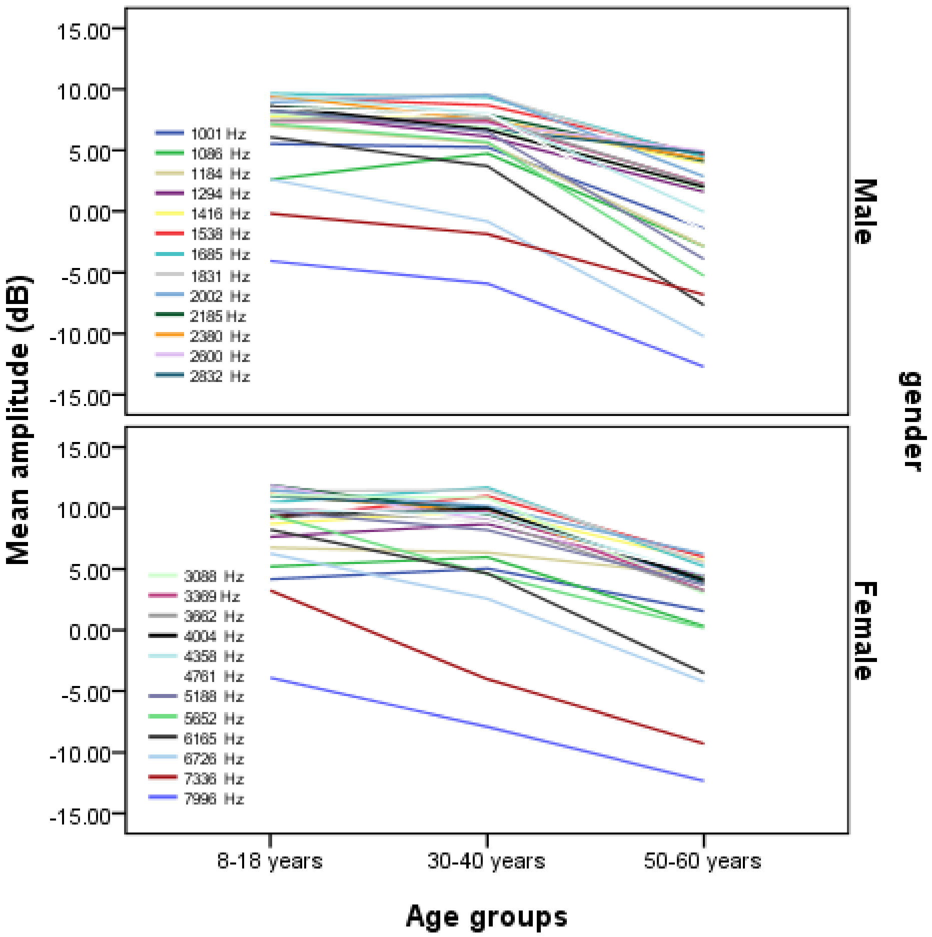

Figure 4.1. Amplitude of the DPOAE fine structure across three age groups for the right ear for males and females

It can also be seen form table 4.1, 4.2 and 4.3 that the amplitude of DPOAE fine structure reduces for the third age group (i.e. 50-60 years) for all the frequencies compared to the first two age groups for the left ear. On comparing the three age groups it can also be seen from table 4.1.1, 4.1.2 and 4.1.3 that even for the 2nd age group there was a reduction in the amplitude of the DPOAE fine structure above 5188 Hz frequencies for the left ear.

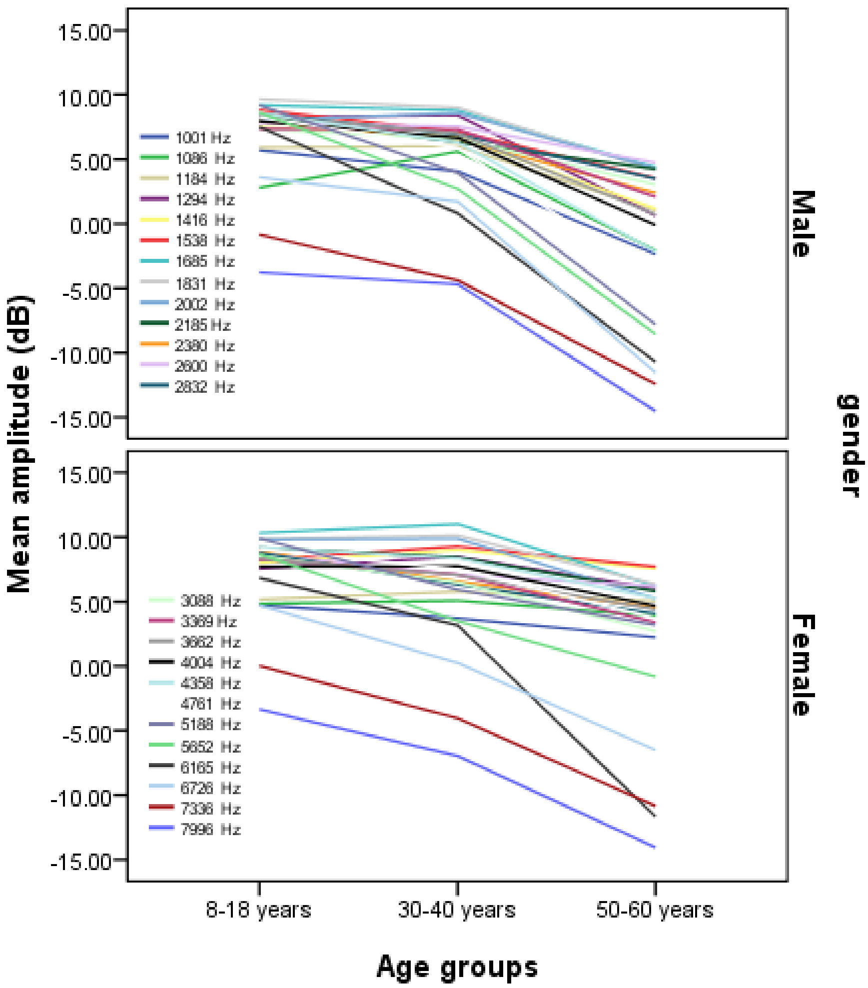

Figure 4.2. Amplitude of the DPOAE fine structure across three age groups for the left ear for males and females

Mixed ANOVA was done to see the interactions for frequency, gender, ear and age. Mixed ANOVA revealed a significant main effect for frequency [F(24, 2184)=112.05, p<0.01], gender [F(1,91)=9.82, p<0.01], ear [F(1,91)=6.71, p<0.05] and age [F(2,91)=45.48, p<0.01]. Also, significant interactions were seen for frequency and gender [F(24,2184)=1.88,p<0.01], frequency and age [F(48,2184)=6.45, p<0.01], frequency, gender and age [F(48,2184)=1.61, p<0.01], frequency and ear [F(24,2184)=1.91, p<0.01] and frequency, ear and age [F(48,2184)=1.44, p<0.05]. However, no significant interactions were seen for ear and gender [F(1,91)=.39, P>0.05], ear and age [F(2,91)=.35, p>0.05], ear, gender and age [F(2,91)=1.50, p>0.05], frequency, ear and gender [F(24,2184)=1.20, p>0.05], frequency, ear, gender and age [F(48,2184)=0.76, p>0.05] and gender and age [F(2,91)= .98, p>0.05].

Duncan’s post hoc test was done to see the significant differences for the three age groups. The Duncan’s post hoc test did not reveal any significant differences between the group I and II (p>0.05), whereas group I and II showed a significant differences with the III group (p<0.05). Further, Bonferroni’s post hoc test was done to see the pairwise differences for the different frequencies of the DPOAE fine structure. The details of the Bonferroni’s post hoc analysis are given in table 4.2

Table-4.2

Bonferroni's pairwise comparisons for the different frequencies

Freq	1086	1184	1294	1416	1538	1685	1831	2002	2185	2380	2600	2832	3088	3369	3662	4004	4358	4761	5188	5652	6165	6726	7336	7996
1001	NS	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	NS	NS	NS	S	S	S
1086		NS	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	NS	NS	NS	NS	S	S	S
1184			S	S	S	S	S	S	S	S	S	NS	NS	NS	NS	NS	NS	NS	NS	NS	S	S	S	S
1294				NS	S	S	S	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	S	S	S	S	S
1416					NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	S	S	S	S	S
1538						NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	S	S	S	S	S	S	S
1685							NS	NS	NS	NS	NS	NS	S	S	S	S	S	S	S	S	S	S	S	S
1831								NS	NS	S	NS	S	S	S	S	S	S	S	S	S	S	S	S	S
2002									NS	NS	NS	NS	S	S	S	NS	NS	S	S	S	S	S	S	S
2185										NS	NS	NS	NS	NS	NS	NS	NS	NS	S	S	S	S	S	S
2380											NS	NS	NS	NS	NS	NS	NS	NS	S	S	S	S	S	S
2600												NS	NS	NS	NS	NS	NS	NS	S	S	S	S	S	S
2832													NS	NS	NS	NS	NS	NS	S	S	S	S	S	S
3088														NS	NS	NS	NS	NS	NS	S	S	S	S	S
3369															NS	NS	NS	NS	NS	S	S	S	S	S
3662																NS	NS	NS	NS	S	S	S	S	S
4004																	NS	NS	S	S	S	S	S	S
4358																		NS	S	S	S	S	S	S
4761																			NS	S	S	S	S	S
5188																				S	S	S	S	S
5652																					S	S	S	S
6165																						NS	S	S
6726																							S	S
7336																								S
7996																								

S=Significant, $p<0.05$, NS- Not significant, $p>0.05$

Mixed ANOVA showed significant interactions between age, gender, ear and frequency, hence, repeated measure ANOVA was done to see the significant differences for age, gender and frequency. Repeated measure ANOVA showed a significant differences for age group I (8-18years) males for right ear [$F(24,576)$- =13.32, $p<0.01$] and left ear [$F(24,552)=12.87$, $p<0.01$]. Also, females in age group I showed significant difference for the right ear [$F(24,576)=21.86$, $p<0.01$] and for the left ear [$F(24,576)=15.70$, $p<0.01$]. Age group II (30-40years) also showed significant difference for males for the right ear [$F(24,336)=16.35$, $p<0.01$] and for the left ear [$F(24,336)=9.93$, $p<0.01$]. Females in age group II showed significant differences for right ear [$F(24,336)=21.82$, $p<0.01$] and left ear [$F(24,336)=14.16$, $p<0.01$]. Age group III (50-60years) showed significant differences for males for right ear [$F(24,192)=11.58$, $p<0.01$] and left ear [$F(24,336)=14.16$, $p<0.01$]. Age group III females also showed significant differences for right ear [$F(24,192)=11.58$, $p<0.01$] and left ear [$F(24,192)=8.63$, $p<0.01$].

Bonferroni's pairwise analysis was done to see the group wise differences. The details of Bonferroni's pairwise comparison are given in table 4.3.1, 4.3.2 and 4.3.3 below. One thing to be noted in the table, frequencies which were significantly different from each other in the particular age groups are given. While those frequencies that were not significant has not been represented in the table.

Table-4.3.2

Table *Bonferroni's pairwise comparison for the II age group.*

Freq	Age group II

Freq	Age group I																			
	Males						Females													
	Right			Left			Right								Left					
	6726	7336	7996	1831	7336	7996	1001	1086	1184	1831	2185	6726	7336	7996	1001	1086	1184	7336	7996
1001			S	S		S					S			S					
1086											S			S					
1184		S	S			S	S				S			S					S
1294		S	S		S	S	S	S		S	S			S		S		S	S
1416		S	S		S	S	S	S			S		S	S			S	S	S
1538	S	S	S		S	S	S	S			S			S	S	S		S	S
1685	S	S	S		S	S	S	S					S	S	S	S	S	S	S
1831	S	S	S		S	S	S	S					S	S	S	S	S	S	S
2002	S	S	S		S	S	S	S	S				S	S	S			S	S
2185		S	S		S	S	S	S	S			S	S	S	S			S	S
2380	S	S	S		S	S	S	S	S				S	S	S			S	S
2600		S	S		S	S	S	S	S				S	S				S	S
2832	S	S	S		S	S	S	S					S	S				S	S
3088	S	S	S		S	S	S	S					S	S				S	S
3369	S	S	S		S	S							S	S				S	S
3662		S	S		S	S	S						S	S				S	S
4004	S	S	S		S	S							S	S				S	S
4358	S	S	S		S	S	S						S	S				S	S
4761	S	S	S		S	S	S						S	S				S	S
5188	S	S	S		S	S	S						S	S	S			S	S
5652	S	S	S		S	S	S						S	S	S			S	S
6165	S	S	S		S	S								S				S	S
6726			S			S								S					S
7336														S					

Bonferroni's pairwise comparison for the I age group.

	Males												Females							
	Right					Left							Right				Left			
	1538	6165	6726	7336	7996	1685	1831	5188	5652	6165	7336	7996	1538	6726	7336	7996	1001	1086	7336	7996
1001	S				S	S	S									S				S
1086													S		S	S				S
1184					S	S									S	S				S
1294					S										S	S	S		S	S
1416				S	S										S	S	S		S	S
1538			S	S	S						S	S		S	S	S	S		S	S
1685			S	S	S				S	S	S	S		S	S	S	S	S	S	S
1831		S	S	S	S			S	S	S	S	S		S	S	S			S	S
2002			S	S	S			S	S	S	S	S			S	S			S	S
2185			S	S	S						S	S			S	S			S	S
2380			S	S	S						S	S		S	S	S				S
2600			S	S	S				S	S	S	S		S	S	S			S	S
2832			S	S	S						S	S		S	S	S			S	S
3088			S	S	S				S	S	S	S		S	S	S				S
3369			S	S	S				S		S	S			S	S			S	S
3662			S	S	S			S	S		S	S			S	S			S	S
4004			S	S	S				S		S	S			S	S			S	S
4358			S	S	S				S	S	S	S			S	S			S	S
4761		S	S	S	S				S		S	S		S	S	S				S
5188			S	S	S						S	S		S	S	S				S
5652			S	S	S										S	S				S
6165			S	S	S										S	S				S
6726					S										S	S				
7336					S															

Table-4.3.3

Bonferroni's pairwise comparison for the III age group.

Freq.	Males								Females							
	Right								Right				Left			
	4761	5188	6726	7996	1001	1685	7336	7996	6165	6726	7336	7996	1416	6726	7336	7996
1001								S			S	S			S	S

1086						S		S					S		S	S
1184								S		S	S	S		S	S	S
1294					S		S	S			S	S		S	S	S
1416				S	S		S	S			S	S		S	S	S
1538		S		S	S		S	S			S	S		S	S	S
1685		S		S	S		S	S			S	S		S	S	S
1831		S		S			S	S			S	S		S	S	S
2002				S			S	S			S	S		S	S	S
2185		S		S			S	S				S		S	S	S
2380			S	S				S				S		S	S	S
2600		S	S	S			S	S			S	S			S	S
2832	S	S	S	S			S	S			S	S			S	S
3088				S				S			S	S			S	S
3369		S		S			S	S				S			S	S
3662				S			S	S			S	S		S	S	S
4004				S			S	S			S	S			S	S
4358		S		S			S	S			S	S			S	S
4761				S				S			S	S			S	S
5188								S	S		S	S			S	S
5652								S				S				S
6165								S				S				

S-significant, p<0.05

In the present study the amplitude of the fine structure of the DPOAE varied between -3 dB to 10.34 dB for the first age group, -7.34 dB to 10.74 dB for the second age group, and -14.29dB to 6.37 dB for the third age groups. The amplitude obtained in the present study is more than recorded by Uchida et al. (2008) and Dhar and Abdala (2007). The difference in amplitude could be due to the different instrumentation used in the recording for all the three studies. The difference in amplitude could also be due to the fact that the amplitude of the DPOAE varies according the race (Dreisbach, Kramer, Cobos & Cowart, 2007).

Studies using otoacoustic emissions (OAEs) have shown differences across racial groups. Whitehead et al (1993) found that spontaneous otoacoustic emissions (SOAEs) were more prevalent in African Americans, followed by Asians, and then by Caucasians. Furthermore, African Americans exhibited multiple SOAEs (96% of ears) compared to Caucasians (58% of ears). Whitehead et al also found that Asians displayed SOAEs at higher frequencies than either African Americans or Caucasians. Chan and McPherson (2001) did not find significant differences between Caucasians and Asians in the prevalence of SOAEs, or the signal-to-noise ratios (SNRs), used as an indirect measure of amplitude, of transient evoked otoacoustic emissions (TEOAEs). However, they did find that Asians demonstrated significantly more responses in the high frequencies compared to Caucasians for both SOAEs and TEOAEs. Shahnaz (2006) found greater overall SNRs of TEOAEs for Asians compared to Caucasians. Thus, the differences obtained in the present study could be due to the different instrumentation used or due to different population.

In the present study a decrement in amplitude of the fine structure of the DPOAE was noted as the age increased. There was decrement in the amplitude of the DPOAE fine structure for the group III and even for group II there was a decrement in amplitude at higher frequencies. Several other reports also suggest that as the age increases there is significant decrease in the amplitude of DPOAEs. Oeken, Lenk and Bootz (2000) studied normal hearing individuals in the age range of 14 to 82 years and found significant decrease in the DPOAE amplitude with aging. Brenda, Lonsbury-Martin, Cutler and Martin (1991) studied normal hearing individuals in the age range of 31-60 years. They found that when compared to young individuals, the aged individuals had deterioration in the high frequency region. Lonsbury-Martin and Martin (1990) also found that older subjects had reductions in the amplitudes of the high-frequency DPOAEs and the concomitant increases in detection thresholds to aging effects. Also, in young subjects DPOAE amplitudes tended to decrease and detection thresholds increase, with age, for the two highest test frequencies at 6 and 8 kHz.

There are studies which also reports that middle age and elderly have decreased amplitude compared to children. O-Uchi et al. (1994) compared DPOAE amplitude across three age groups namely children (till 30 years), middle aged (30-50 years) and elderly (51 and above) and found that middle aged and elderly had decreased amplitude compared to the children. **Kon, Inagaki and Kaga (2000) studied** 275 normal subjects aged from 1 month to 39 years and found that at high frequencies the DP levels did not change much across the age range, however, those at low and middle frequency there was significant decrease with age. Karzon, Philip, Peterein and Gates (1994) studied 71 elderly individuals in the age range of 56-93 years and 8 young individuals in the age range of 19-26 years. They found that the DPOAE amplitude did not decrease significantly with age if the hearing thresholds were within the normal limits. Wagner, Plinkert, Vonthein and Plontke (2008) studied

DPOAE fine structure for 102 participants in the age range of 17-81 years. The authors found no significant age effect on DPOAE fine structure.

The reduction in the amplitude of the fine structure could be due to subtle changes in the properties of the outer hair cells with the increase in age. The amplitude reduction of the DPOAE fine structure could represent evidence of latent functional decline of OHCs which may start in the middle age only. A reduction in the generation of OAEs with aging could reflect progressive OHC damage associated with the aging process. It is known that OHCs are particularly vulnerable to ototoxic insult; damage to them occurs before damage occurs to the other sensory cells of the ear, the inner hair cells (Gorga, Neely, Dorn & Hoover, 2003). Thus, OAEs measurements in normal-hearing elderly as defined by puretone threshold may have the potential to provide early indications of presbycusis.

Comparison of amplitude of fine structure for the males and the females

An independent t-test was done to see the overall significant difference across the two genders for all the frequencies. To see the significant difference between the males and females the data of all the three age groups were combined and were compared for the gender differences. Independent t-test revealed significant differences for the two genders for frequencies, 2002 Hz [$t(96) = 2.170$, $p<0.05$], 2185 Hz [$t(96) = 2.245$, $p<0.05$], 2600 Hz [$t(96) = 2.401$, $p<0.05$], 2832 Hz [$t(96) = 2.513$, $p<0.05$], 3088 Hz [$t(96) = 3.061$, $p<0.01$], 3369 Hz [$t(96) = 2.204$, $p<0.05$], 4761 Hz [$t(96) = 2.263$, $p<0.05$], 5188 Hz [$t(96) = 2.347$, $p<0.05$] and 6726 Hz [$t(96) = 2.839$, $p<0.01$]. For rest of the frequencies there was no significant difference between the males and the females for the amplitude of the fine structure of the DPOAE.

Several studies report higher emissions in females compare to their counterparts. Gaskill and Brown (1990) found that DPOAEs were significantly better in females compared to male especially in the frequency range of 1000-5000Hz. Lonsbury-Martin, Cutler and Martin (1991) reported significant interactions between frequency and gender in females with larger DPOAE amplitude for 2000-8000Hz frequency range. Cacace et al (1996) found 2.4 dB more sensitive auditory thresholds on an average for females compared to age matched males. Tadros et al (2005) found significant interactions between age and ear asymmetry. Dunckley and Dreisbach (2004) found significant interactions between gender and DPOAE group delay values at low frequencies and for DPOAE levels at high frequencies. McFadden, Martin, Stagner and Maloney (2008) also showed higher DPOAE levels for females. Magnus, Johanasson and Arlinger (2003) reported significant effect of gender. Females showed 2-3 dB higher levels of DPOAE.

The increased amplitude of DPOAEs found in females might be the result of increased emissions seen in females. Also, better auditory thresholds found in females compared to males (McFadden, 1993). Anatomical differences in the cochlear length can also result in increased amplitude in females. Females have smaller cochlea therefore the cochlear travelling time delays are less in females compared to males (Kimberley, Brown and Eggermont, 1993). Subject related factors can also influence like the presence of spontaneous otoacoustic emissions (SOAEs). SOAEs are more prevalent in females (Talmadge et al., 1993) and their proximity to distortion product enhances the DPOAEs.

Behavioural thresholds

Descriptive statistics was done to obtain the mean and standard deviation for the behavioural thresholds across the different age groups. The frequencies at which puretone thresholds were obtained were similar to the f2 of DPOAE fine structure. The details of the mean and standard deviation of the amplitude of DPOAE fine structure for the three different age groups across age, ear and gender are given in figure 4.3 a and b.

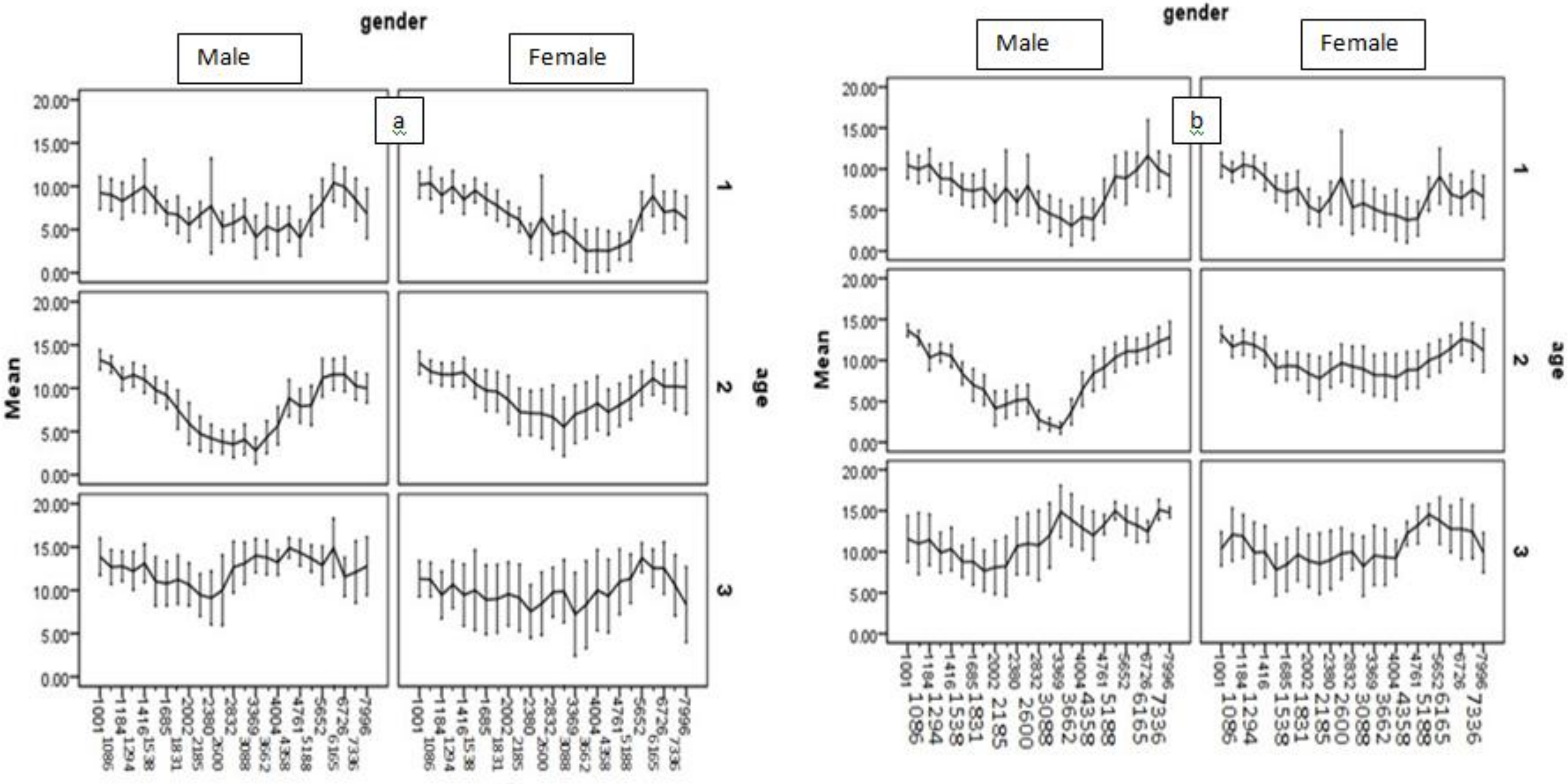

Figure- 4.3. Puretone Hearing threshold for the a) For the right ear b) For the left ear

Correlation between Puretone threshold and DPOAE fine structure.

Pearson's correlation analysis was done to find out the correlation between the amplitude of the DPOAE fine structure and the pure tone threshold of the subjects in each age group. The correlation of the Puretone threshold and the amplitude of the fine structure of the DPOAE are given in table 4.4 below. In the table, frequencies that had significant positive correlation are shown. While those frequencies that were not significant has not been represented in the table. It can be seen from table 4.4 that there was a significant correlation between the puretone threshold and the amplitude of the DPOAE fine structure only at few frequencies. Most of the frequencies there was no correlation between the puretone threshold and the amplitude of the DPOAE fine structure for all the three age groups.

Table-4.4.

Results of Pearson's correlation analysis of amplitude of DPOAE fine structure and Puretone threshold

Freq	Age group I				Age group II				Age group III			
	Males		Females		Males		Females		Males		Females	
	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left
1001				r = 0.716**	r = 0.700**	r = 0.665**						
1086			r = 0.443*									
1184												
1294		r = 0.421*		r = 0.600**								
1416			r = 0.603**			r = 0.579*		r = 0.535*	r = 0.668*			
1538			r = 0.400*	r = 0.399*								
1685		r = 0.548**		r = 0.539**		r = 0.739**						
1831		r = 0.484*	r = 0.454*	r = 0.641**				r = 0.712**				r = 0.742*
2002	r = 0.458*	r = 0.575**		r = 0.540**							r = 0.758*	
2185		r = 0.487*							r = 0.758*			
2380		r = 0.419*							r = 0.787*			
2600					r = 0.751**							
2832												
3088							r = 0.639*					r = 0.732*
3369					r = 0.539*					r = 0.688*		
3662								r = 0.737**				
4004	r = 0.829**			r = 0.451*				r = 0.653**			r = 0.738*	
4358	r = 0.707**							r = 0.569*				
4761								r = 0.714**				
5188	r = 0.872**		r = 0.405*	r = 0.638**						r = 0.731*		
5652				r = 0.426*								
6165						r = 0.554*						
6726	r = 0.915**											
7336	r = 0.726**											
7996												

*=P<0.05, **= P<0.01

Few studies have reported a positive correlation between the DPOAE fine structure and puretone thresholds. He and Schmiedt (1996) studied DPOAE fine structure and found a positive correlation between DPOAE fine structure and hearing thresholds. The present study however supports the study by Heitmann, Waldmann & Plinkert (2004). Heitmann et al. (2004) have reported a weak correlation between the hearing thresholds and DPOAE fine-structure. They reported that the behavioural thresholds cannot be accurately predicted using the fine-structure.

The weak correlation between the puretone threshold and the amplitude of DPOAE fine structure for the third age group (50-60 years) could be due to the fact that aging may cause different process to degenerate differently. The loss in puretone threshold could be due to the loss of endocochlear potentials and loss of the inner hair cells. The findings of the present study can be interpreted as a differential change with age in the pure-tone hearing threshold level than in the DPOAE fine structure compatible with an age related fall in endocochlear potentials (Uchida et al., 2008). In the present study the amplitude of the fine structure of the DPOAE reduced to a greater extent compared to the puretone threshold, indicating that the loss of endocochlear potentials and loss of outer hair cells could be entirely two different phenomena. For the two younger age groups also there was no correlation between the puretone threshold and amplitude of fine structure of the DPOAE. This could also be due to the fact that the hearing threshold and OAE inherently reflect two different processes. This may be one of the reasons why there is no correlation between the puretone threshold and the amplitude of the fine structure of the DPOAE.

To summarise the results, the amplitude of DPOAE fine structure was almost similar for the 8-18 years and 30-40 years of age groups. There was a reduction in amplitude of DPOAE fine structure for the third age group (i.e. 50-60 years) for all the frequencies compared to the first two age groups for the right ear. Even for the 2nd age group there was a reduction in the amplitude of the DPOAE fine structures above 5188 Hz frequencies for both the ears. Pearson correlation showed a significant correlation of the amplitude of DPOAE fine structure and Puretone threshold only at few frequencies. Most of the frequencies there was no correlation between the Puretone thresholds and the amplitude of the DPOAE fine structure.

Chapter-5

SUMMARY AND CONCLUSION

Distortion product otoacoustic emissions (DPOAE) are elicited by the simultaneous presentation of two pure-tones closely spaced in frequency. DPOAE is a quick procedure and gives a quick and reliable measure of the outer hair cells functioning. DPOAEs are also recorded with micro precision which is known as fine structure. When the stimulus frequencies f1 and f2 are varied in small steps, distinct peaks and valleys in DPOAE level versus frequency functions can be observed. This structure which is obtained is called as DPOAE fine structure. Several studies have used the DPOAE fine structure to correlate the hearing threshold in normal hearing individuals as well as the clinical population.

In humans, when the distortion products are measured in small frequency increments, it exhibits a fine structure characterised by a series of amplitude peaks and valleys across frequency with peak to valley amplitude ratios as great as 20 dB (Gaskill & Brown, 1990; He and Schemiedt, 1993). The peak to peak frequency interval is about 3-32 octave (He and Schemiedt, 1993) and is numerically comparable with similar rippling patterns that have been observed in stimulus frequency emissions and the fine structure of the behavioural threshold (Zwicker and Schloth, 1984; Zwicker, 1990).

Present study was done with an aim of establishing the norms for the DPOAE fine structure in the Indian population across the different age groups and also to correlate the puretone threshold with the amplitude of the DPOAE fine structure.

To arrive at the aim, total of 98 subjects in the age range of 8-60 years were selected for the study. Subjects were selected based on normal hearing sensitivity in both the ears as defined by pure tone threshold of less than or equal to 15 dB HL, a normal middle ear function as defined by a normal tympanometry and presence of ipsilateral and contralateral acoustic reflexes. The participants were further sub grouped into three subgroups:

Group I: 50 young individuals (8 to 18 years) – (25 males and 25 females)

Group II: 30 middle aged individuals (30 to 40 years) – (15 males and 15 females)

Group III: 18 elderly individuals (50 to 60 years) – (9 males and 9 females)

Behavioural puretone thresholds and DPOAE fine structure across the frequency range of 1001 Hz- 7996 Hz was noted. The various frequencies in the range of 1001 Hz – 7996 Hz, which were tested for puretone thresholds as well as the DPOAE fine structure were 1001 Hz, 1086 Hz, 1184 Hz, 1294 Hz, 1416 Hz, 1538 Hz, 1685 Hz, 1831 Hz, 2002 Hz, 2185 Hz, 2380 Hz, 2600 Hz, 2832 Hz, 3088 Hz, 3369 Hz, 3662 Hz, 4004 Hz, 4358 Hz, 4761 Hz, 5188 Hz, 5652 Hz, 6165 Hz, 6726 Hz, 7336 Hz and 7996 Hz.

Following parameters were analysed:

- Absolute Amplitude of the DPOAE fine structure was measured.
- Auditory microstructure using behavioural puretone testing was established.
- The DPOAE fine structure amplitude across the three age groups was analyzed.
- The DPOAE fine structure amplitude across gender was analyzed.
- The auditory microstructure and the amplitude of the DPOAE fine structure were correlated**.**

To analyse the above following statistical analysis was done analyses were carried out:

- Descriptive statistics to find out the mean and the standard deviation of amplitude of DPOAE fine structure
- Mixed ANOVA to see the interactions among the frequency, age, gender and ear.
- Bonferroni's post hoc for pairwise comparison across the frequencies.
- Duncan's post hoc analysis to see the significant differences across different age groups.
- Repeated measures of ANOVA was done for whichever variable showed interaction in the Mixed ANOVA test
- Pearson's Correlation to find out the correlation among the DPOAE fine structure amplitude and Puretone threshold.

Results of the study were as follows-

1) The amplitude of the DPOAE fine structure was more for the group I and group II compared to the age group III.
2) Reduction in the DPOAE amplitudes was seen for high frequencies for the age group II also.
3) There was a significant difference in the amplitude of the DPOAE fine structure between males and females at few frequencies.
4) The correlation between the amplitude of the DPOAE fine structure and behavioural thresholds was found to be poor.

The reduction in the amplitude of the DPOAE fine structure could be due to the change in the properties of the outer hair cells functioning irrespective of the puretone loss seen in the individuals with normal hearing. The poor correlation between the amplitude of the fine structure of DPOAE and puretone could be due to the fact that OAE level and hearing threshold inherently reflect two different processes The poor correlation between the amplitude of the DPOAE fine structure and the puretone threshold seen in the present study for III age group could be due to the fact that the hearing thresholds although it was within normal hearing sensitivity for the third group but it was elevated compared to the other two age groups..

Conclusions

The data presented above can be used as a norm for the amplitude of the DPOAE fine structure. From the present study it can be concluded that the amplitude of the fine structure of the DPOAE cannot be used as a tool to predict the puretone threshold in normal hearing individuals.

Future Implications:

- Larger sample can be taken up for middle aged and elderly group.
- Along with amplitude of the DPOAE fine structure, DPgram and DPOAE input-output function also can be studied.
- The signal to noise ratio can be studied to see whether there is any correlation between the signal to noise ratio and the pure tone threshold.

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