The Relationship Between DPOAE Fine-Structure and Hearing Sensitivity Across Different Age Groups and Gender.

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Abstract

The present study aimed to study the relationship between amplitude of the distortion product oto-acoustic emission fine structure and hearing sensitivity across different age groups and gender. A total of 98 normal hearing individuals subdivided into three age groups participated in the study. The amplitude of DPOAE fine structure for 1/8 inter-octaves (1001 Hz-7996 Hz) was studied and was correlated with the behavioural puretone thresholds for respective 1/8 inter-octaves. The results revealed significant age and gender differences in the amplitude of DPOAE amplitude but a poor correlation between the amplitude of DPOAE fine structure and behavioural thresholds. Hence, the amplitude of the fine structure of the DPOAE cannot be used as a tool to predict the puretone threshold in normal hearing individuals.

Key words: *DPOAE fine structure, DPOAE amplitude, puretone threshold.*

Introduction

Distortion product oto-acoustic 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 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, Waldmann & Plinkert, 1996) and a periodicity of 3/32 octave (He & Schmiedt, 1993; Mauermann, Uppenkamp, Van Hengel & Kollmeier, 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. There are reports that suggest that DPOAE fine structure has more depth and wider spacing in newborns when compared with adults (Dhar & Abdala, 2007) However, several other reports suggest that DPOAE fine structure is independent of age (Wagner, Plinkert, Vonthein & Plontke, 2008) Also, some studies report that only at few frequencies the DPOAE fine structure is affected (He & Schmeidt, 1996).

The distortion product oto-acoustic emissions have been recorded in various age groups and there is always some debate about the age-related changes in oto-acoustic emissions. Some studies of distortion product oto-acoustic emissions in humans concluded that there was a statistically significant effect of age on the distortion product oto-acoustic emission amplitude (Bonfils, Bertrand & Uziel., 1988; Bonfils, 1989; Collet, Moulin, Gartner & Morgon, 1990; Lonsbury-Martin, Harris, Hawkins, Stagner & Martin, 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 oto-acoustic emissions were either significantly reduced in level or not measurable when thresholds were poorer than 30 dBHL (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.

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Also, there are studies which report a weak correlation between auditory thresholds and DPOAE level. Kimberley, Brown and Allen (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 in children and adults (Dhar & Abdala, 2007; Uchida et al., 2008; Wagner et al., 2008).

Hence, the present study was conducted with 3 objectives; first, 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), second to analyze the gender differences, if any, in fine-structure of the DPOAE and the third to correlate DPOAE fine structure with the behavioural thresholds.

Method

Participants

A total of 98 individuals in the age range of 8 yrs to 60 years participated in 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 selection criteria

Participants were selected based on normal hearing sensitivity in both the ears as defined by pure tone threshold of less than or equal to 15 dBHL in the octave frequency from 250 Hz to 8000 Hz for air conduction. Speech identification scores were greater than or equal to 90% in quiet. All the participants had normal middle ear functions as revealed by immittance measures and ENT evaluations. Also all the participants had presence of DPOAE as defined by signal to noise ratio of 6 dB or greater in the frequencies between 1000 Hz to 8000 Hz.

Instrumentation: A calibrated dual channel audiometer (Orbiter 922), with TDH-39 headphones and B-71 bone vibrator was utilized for air conduction and bone conduction pure tone testing respectively. The same audiometer was utilised for speech audiometry as well. A calibrated immittance meter was used for tympanometry and reflex measurements while ILO V6 was used for recording DPOAE and DPOAE fine-structure. 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, Lonsbury-Martin, Probst, Scheinin & Coats, 1987, Martin, Jassir, Stagner, Whitehead & Lonsbury-Martin (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 and 8000 Hz were established to obtain the 'auditory microstructure'.

Speech identification scores (SIS): SIS was measured in quiet using word list given by Vandana (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.

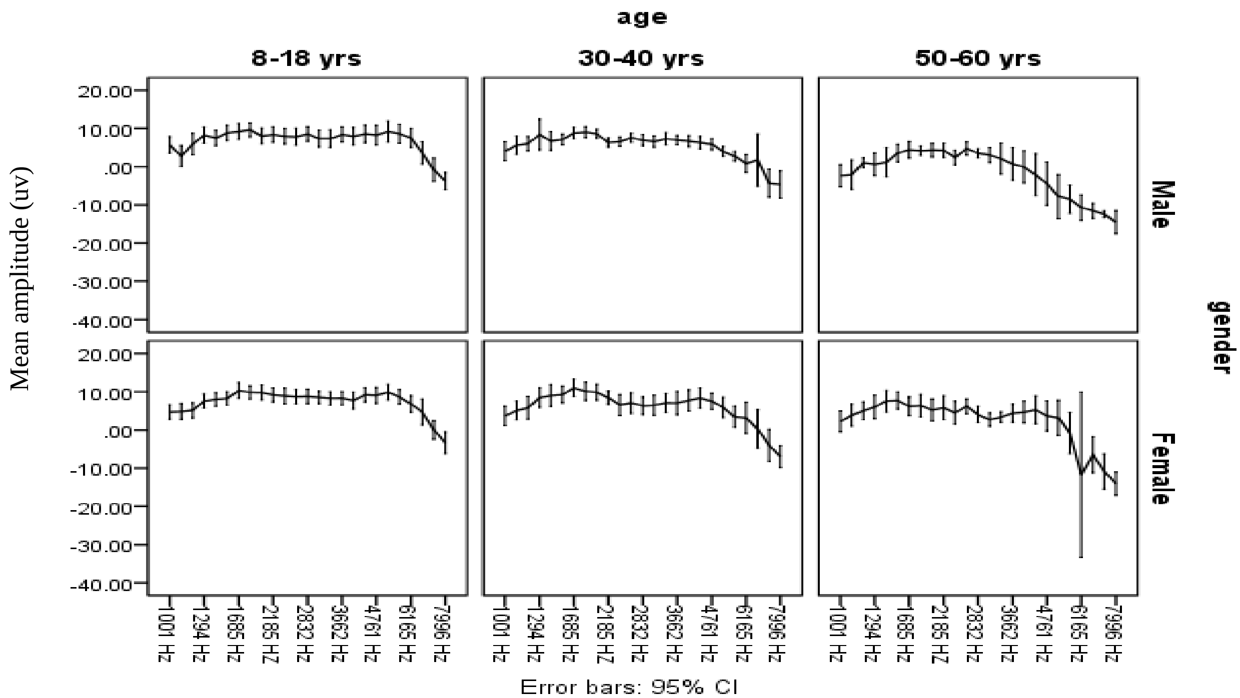

Figure 1: Amplitude of DPOAE fine structure for the three age groups across males and females for the right and left ear.

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 dBHL and 55 dBHL, respectively.

Results and Discussion

Descriptive statistics was done to find out the mean and standard deviation of amplitude of DPOAE fine structure. The details of the mean and standard deviation of amplitude of DPOAE fine structure are given in Figure 1a (right ear) 1b (left ear).

It can be seen from Figure 1 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 from Figure 1 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 that in the 2nd age group there was a reduction in the amplitude of DPOAE fine structures above 5188 Hz frequencies for the right ear.

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 [$F(1, 91)=0.39$, $p>0.05$], ear and age [$F(2, 91)=0.35$, $p>0.05$], 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 [$F(2, 91)=0.98$, $p>0.05$]. 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 pair-wise differences for the different frequencies of the DPOAE fine structure and Boneferroni revealed a significant difference for only few frequencies.

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 pair-wise analysis was done to see the group wise differences and it revealed significant differences at only few frequencies for the three age groups.

In the present study, the amplitude of the fine structure of the DPOAE varied between -3 dB and 10.34 dB for the first age group, -7.34 dB to 10.74 dB for the second age group, and -14.29 dB 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 oto-acoustic emissions (OAEs) have shown differences across racial groups. Whitehead, Kamal, Lonsbury-Martin and Martinl (1993) found that spontaneous oto-acoustic emissions (SOAEs) were more prevalent in African Americans, followed by Asians, and then Caucasians. Furthermore, African Americans exhibited multiple SOAEs (96% of ears) compared to Caucasians (58% of ears). Whitehead et al (1993) 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. 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. 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 report 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 to 93 years and 8 young individuals in the age range of 19 to 26 years. They found that the DPOAE amplitude did not decrease significantly with age if the hearing thresholds were within the normal limits. Wagner et al., (2008) studied DPOAE fine structure for 102 participants in the age range of 17 to 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 representevidence 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 compared to their counterparts. Gaskill and Brown (1990) found that DPOAEs were significantly better in females compared to males especially in the frequency range of 1000 to 5000 Hz. Lonsbury-Martin et al., (1991) reported significant interactions between frequency and gender in females with larger DPOAE amplitude for 2000 to 8000 Hz frequency range.

Cacace, McClelland, Weiner and McFarland (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 (2009) also showed higher DPOAE levels for females. 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 & Eggermont, 1993). Subject related factors can also influence like the presence of spontaneous oto-acoustic emissions (SOAEs). SOAEs are more prevalent in females (Talmadge, Tubis, Long & Piskorski, 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 puretone hearing thresholds structure for the three different age groups across age, ear and gender are given in Figure 2a (right ear) 2b (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 1 below.

In the Table 1, 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 1 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.

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. that aging may cause different process to degenerate differently. The loss in puretone threshold could be due to the loss of endo-

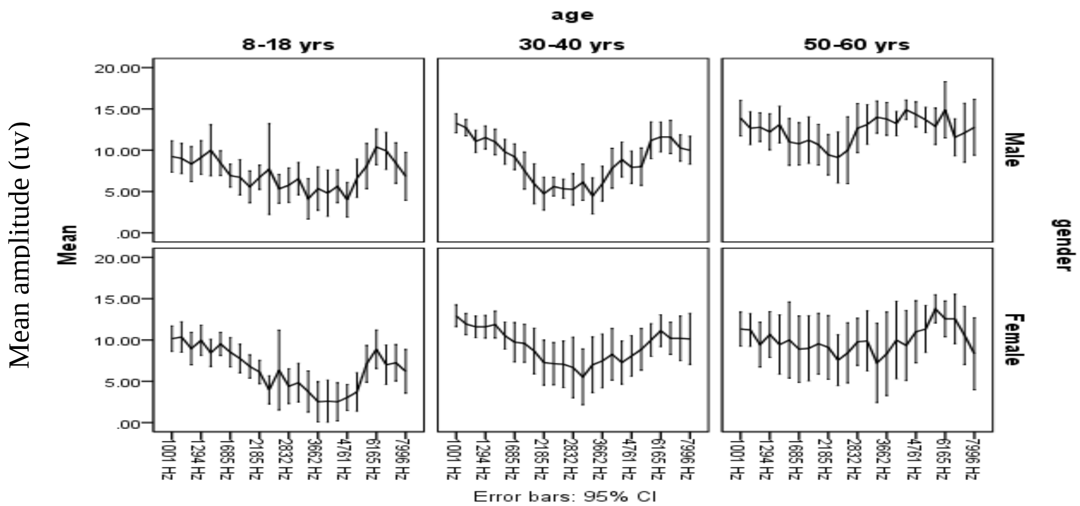

Figure 2a: Puretone threshold for the three age groups across male and females for the right ear.

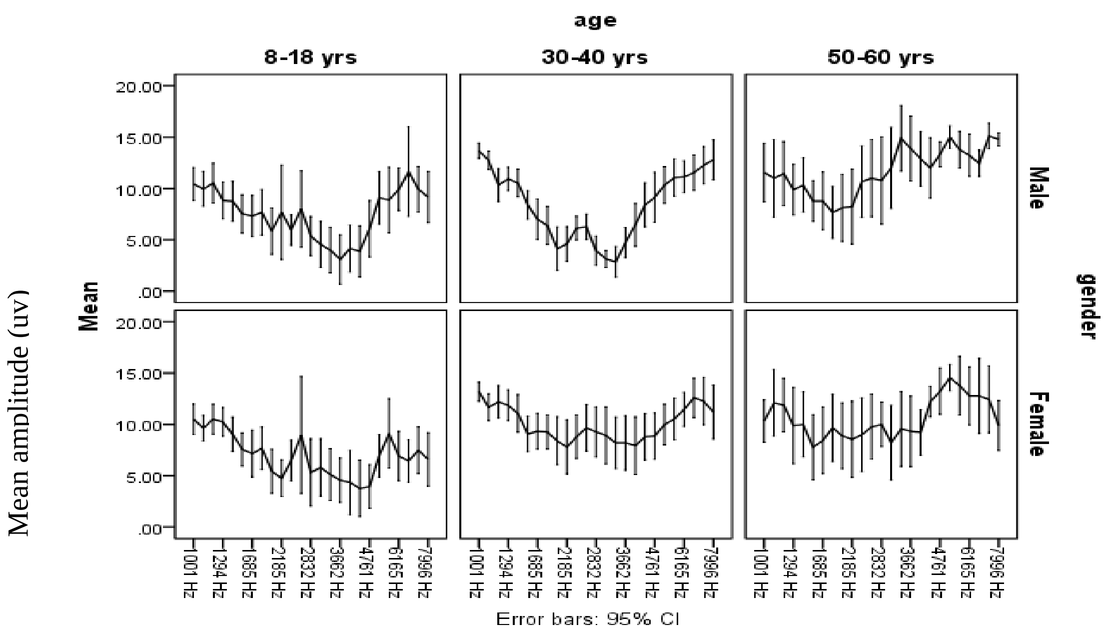

Figure 2b: Puretone threshold for the three age groups across male and females for the left ear.

cochlear 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.

Table 1: Pearson's correlation of DPOAE fine structure amplitude and puretone thresholds

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				0.71^{**}	0.70^{**}	0.66^{**}						
1086			0.44^{*}									
1294		0.42^{*}		0.60^{**}								
1416			0.60^{**}			0.57^{*}		0.53^{*}	0.66^{*}			
1538			0.40^{*}	0.39^{*}								
1685		0.54^{**}		0.53^{**}		0.73^{**}						
1831		0.48^{*}	0.45^{*}	0.64^{**}				0.71^{**}				0.74^{*}
2002	0.45^{*}	0.57^{**}		0.54^{**}							0.75^{*}	
2185		0.48^{*}							0.75^{*}			
2380		0.41^{*}							0.78^{*}			
2600					0.75^{**}							
3088							0.63^{*}					0.73^{*}
3369					0.53^{*}					0.68^{*}		
3662								0.73^{**}				
4004	0.82^{**}			0.45^{*}				0.65^{**}			0.73^{*}	
4358	0.70^{**}							0.56^{*}				
4761								0.71^{**}				
5188	0.87^{**}		0.40^{*}	0.63^{**}						0.73^{*}		
5652				0.42^{*}								
6165						0.55^{*}						
6726	0.91^{**}											
7336	0.72^{**}											

*$p<0.05$;** $p<0.01$

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.

Summary and Conclusions

Results indicate that the amplitude of the DPOAE fine structure was more for the group I and group II compared to the age Group III. Reduction in the DPOAE amplitudes was seen for high frequencies for the age Group II also. There was a significant difference in the amplitude of the DPOAE fine structure between males and females at few frequencies. 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 third age group could be due to the fact that the hearing thresholds although was within normal limits for the third group, was elevated compared to the other two age groups.

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