OAE Profile in Individuals with Tinnitus having Normal Hearing Sensitivity

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Abstract

The present study was aimed to establish an OAE profile in individuals with tinnitus having normal hearing sensitivity. Ninety individuals with normal hearing sensitivity participated in the study, of whom forty five had tinnitus. SOAEs, TEOAEs, DPOAEs and contralateral suppression of TEOAEs were recorded in all the ninety individuals. Tinnitus present in the 45 individuals (clinical group) was characterized using the psycho- acoustic measures of tinnitus like pitch matching and loudness matching. Results showed that, in individuals with tinnitus, mean TEOAE and DPOAE amplitude was significantly poorer at all frequencies than the individuals without tinnitus. On the other hand, the frequency of occurrence of SOAEs was almost same in both the groups. The mean SOAE frequency and the amplitude also did not differ significantly between the groups. Results in the contralateral suppression of TEOAEs showed that only 29% of ears in the clinical group had presence of contralateral suppression of TEOAEs, while this percentage was about 76.6% in the control group. There was a small positive correlation between loudness of the tinnitus and the DPOAE having maximum amplitude. Thus the absolute amplitude of OAE may be clinical indicator of cochlear damage in individuals with tinnitus having normal hearing sensitivity.

Key words: *Tinnitus, OAEs, psychoacoustic measures.*

Almost everyone at one time or another has experience brief periods of mild ringing or other sounds in the ear. Perception of sound in the ears or head that lacks an external acoustic source is commonly called as tinnitus or ringing in the ears (Jastreboff, 1993). According to ASHA (2005), tinnitus ("TIN-a-tus" or "tin-EYE-tus") is the perception of sound in the head when no external sound is present.

The majority of tinnitus patients have hearing loss (Coles, 1981; Axelsson & Ringdabl, 1989; Davis, 1989), but it can also occur in patients with normal hearing (Sanchez, 2005). Ringing and head noises can occur in one ear or both ears, and can be perceived inside or outside the ear (Snow, 2004). Tinnitus evaluation is mainly done to determine the frequency (pitch) and Intensity (Loudness) of perceived tinnitus. The range of tinnitus pitch has been found to extend from 80 Hz to 16,000 Hz (Meikle, 1995). Most of the studies indicate that the loudness of the tinnitus is matched from 0 to 30 dB SL (Henry & Meikle, 2000).

Tinnitus may trigger or originate from within the para-auditory structures, and it may be a pointer to underlying pathological conditions (Han, Lee & Kim 2009). Some forms of tinnitus are mostly generated in the ear by abnormal activity of hair cells or abnormal functioning of most peripheral part of the auditory nerve (Cazals, Negrevergne & Aran, 1978). Morest and Yurgelun (1979) found that, noise and ototoxic drugs (e.g aspirin) are assumed primarily to affect the hair cells but the tinnitus may in fact be generated in the CNS as a result of deprivation of input or because of abnormal input from the ear.

Presence of OAEs may confirm the integrity of the cochlear mechanism since they will be absent when the hearing sensitivity as a whole is lowered by 25 or 30 dB HL (Glattke & Robinette, 2002; Lopes & Carlos, 2005). Despite the difficulty of localizing the site of tinnitus generation, a number of studies (Ceranic, Prasher & Luxon, 1995) have shown evidence that in tinnitus patients; OAEs are not normal or easily detectable at the tinnitus frequency region, even in subjects with normal hearing thresholds.

Ceranic, Prasher and Luxon, (1995) found that SOAE, correspond to tinnitus pitch in, at best, approximately 4 to 5% of cases with tinnitus. Penner (1990) noted that for SOAE induced tinnitus the tone matched frequency was in the 500 to 2,000 Hz range. Martin, Folmer, Shi and Edlefsen (2006) detected SOAEs in 22% of the patients with sensorineural hearing loss with varying degrees.

Almeida, Granjeiro, Sampaio and Furtado (2006) reported that TEOAEs were abnormal in 70.2% of subjects with normal hearing than subjects without tinnitus whereas DPOAEs were abnormal in 68.4% of subjects who had normal hearing with tinnitus. DPOAE levels in tinnitus patients having normal hearing have been reported to be lower or higher than those in normal-hearing individuals without tinnitus (Mitchel, Sindhusake, Doungkamol, Golding, & Philip, 1993). Kaul, Mishr, Walmsley, Loutfy, Logue, and Gold (2008), showed that tinnitus in normal hearing patients is often associated with varying degrees of cochlear dysfunction. In a study

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by Paglialonga, Del Bo, Ravazzania and Tognolaa (2010), they found that 13% of tinnitus subjects exhibited abnormal TEOAEs. They also found significantly reduced DPOAE amplitude (74%) in the frequency range of 1.5 to 8 kHz.

Attias, Bresloff and Furman (1996) demonstrated a clear relationship between tinnitus and efferent neural activity. In his study tinnitus patients responded with increased EOAE amplitude, particularly at low contra lateral noise intensities. While other studies in subjects with tinnitus showed a less effective TEOAE suppression with the contralateral stimulus than subjects with no tinnitus (Favero, Sanchez, Bento & Ferreira, 2006).

According to different reports, 85 to 96% of patients with tinnitus present some level of hearing loss and only 8 to 10 % present normal hearing sensitivity. So the patients with tinnitus and normal hearing constitute an important group. However this group is rarely studied. The generation of tinnitus is a topic much debated. There is less information available in the literature about the generation of tinnitus in individuals with normal hearing. This type of study might highlight possible site of generation of tinnitus in individuals with tinnitus with normal hearing sensitivity. Though there are several studies done in individuals with tinnitus, none of the studies have taken all the OAE tests (both spontaneous and evoked) and tried to find out whether there is a subgroup which might show abnormality in any one OAE test and might be normal in other OAE results. Hence the present study is taken up to find the relationship between OAEs and tinnitus in individuals with tinnitus having normal hearing sensitivity. There is also dearth of information regarding the relationship between the frequency (pitch) and intensity (loudness) of tinnitus with the OAE findings. In this study an attempt was also made to search for the relation between the two.

Thus main objective of the current study was to establish an OAE profile in individuals with tinnitus having normal hearing sensitivity and thus to subgroup the ears with tinnitus that might show abnormality only in one measure of OAE or different OAE measures. The present study also aimed to find out whether efferent auditory system has any role in the generation of tinnitus and to know the relationship between OAE findings and pitch and loudness of tinnitus.

Method

Subjects: A total of 90 (48 males and 42 females) subjects in the age range of 7 to 60 years participated in the study. They were categorized into two groups:

a) Clinical group and b) Control group. Clinical group included 45 individuals (24 males and 21 females) with tinnitus having normal hearing. While control group: This group had 45 age and gender matched individuals (24 males and 21 females) with normal hearing, without tinnitus.

All subjects in the clinical group had tinnitus either in one ear or both the ears. Number of the subjects who had bilateral or unilateral tinnitus is shown in Table 1.

Table 1. Number of subjects with unilateral or bilateral tinnitus participated in the clinical group

Subjects	Number of subjects who had tinnitus in one ears	Number of subjects who had tinnitus in both ears
Males	18	6
Females	15	6
Total	33	12

Subjects in both the group had pure tone thresholds within 15 dB HL in octave frequencies from 250 Hz to 8 kHz for air conduction. They had no history of exposure to noise or ototoxicity which might cause hearing loss. No observable neurological symptoms or any other general body weakness noticed or reported. None of them reported to have any history of ear pain, ear discharge and giddiness. Subjects in the clinical group had 'A' type tympanogram with presence or absence of acoustic reflexes. While in the control group subjects had 'A' type tympanogram with presence of acoustic reflexes.

A two channel GSI 61 Audiometer coupled to impedance matched TDH 39 earphones with MX-41/ AR ear cushions and a bone vibrator (Radio ear B-71) was used to obtain pure tone threshold at different frequencies for both air conduction and bone conduction, frequency of the tinnitus (pitch matching) and intensity of the tinnitus (loudness matching). Broad band noise was used in the contralateral ear to activate efferent auditory system and was fed through the insert receiver of the same audiometer. Each ear of the subject was tested for the type of tympanogram and presence or absence of acoustic reflexes using a calibrated Immittance meter (Grason - Stadler -TS). Capella OAE analyzer was used to measure SOAE (SOAE frequencies & amplitude), TEOAE (TEOAE amplitude, SNR & reproducibility), DPOAE (DP gram) and Contra lateral suppression of TEOAEs.

All Audiological evaluations and recording of OAEs were carried out in a sound treated room. The ambient noise was within the permissible limits as recommended by ANSI (S3.1, 1991).

Procedure

To obtain the data from both the clinical and control group, the whole study was carried out in two phases. Phase 1 included physiological assessment which was done in both clinical and control group participated. Phase 2 included psychoacoustic assessment of tinnitus which involved pschocoustic tinnitus evaluation (pitch matching and loudness matching) and was done only in the clinical group.

Phase 1: (Physiological assessment)

SOAE measurements: Stimulus parameters used to record SOAEs included a maximum frequency range up to 10,000 Hz. The number of acceptable repetitive samples was 500. The number of repetitive samples rejected on the basis of S/N level criterion was 10 % of the total number of sweeps. SOAE frequency and amplitude were noted from the spectrum. The amplitude and frequency of multiple SOAEs, if present were also noted. SOAEs were considered to be present if the signal to noise ratio exceeded 6 dB SPL.

TEOAE measurements: TEOAEs were recorded by presenting clicks with duration of 40 µs. Two sixty sweeps of clicks were presented at an intensity of approximately 75 dB Peak SPL. The response was acquired using standard nonlinear click trains. TEOAE amplitude at each frequency band (1 kHz, 1.5 kHz, 2 kHz, 3 kHz & 4 kHz) and global TEOAE amplitude were noted. This was also considered as baseline for measurement of contralateral suppression of TEOAEs. Responses were accepted only if the reproducibility was 80 % or greater and the overall amplitude over the noise floor was greater than or equal to 6 dB SPL (Glattke et al, 2002).

Contralateral suppression of TEOAEs: TEOAE amplitude, reproducibility and SNR were recorded in the presence of continuous broad band noise. Contralateral broad band noise was presented at an intensity level of 50 dB HL through the insert receiver. Difference between the baseline TEOAE amplitude and TEOAE amplitude measured in the presence of contra lateral noise at different frequency bands were considered as the amount of contra lateral suppression. If this value was positive, it was considered as the presence of suppression and if it was negative or equal to zero, it was considered as absence of suppression. In this study difference of 0.5 dB SPL was considered as the presence of contralateral suppression.

DPOAE measurements: DPOAEs were measured using two primary tones with frequencies of f1 and f2. F1 frequencies include 500 Hz, 1000Hz, 2000 Hz, 4000 Hz and 8000 Hz. A ratio of 1.2 between f1 and f2 was used to elicit DPOAEs. The intensity level of primaries f1 and f2 were 65dB SPL (L1) and 55 dB SPL (L2) respectively. A total number of 1000 sweeps were used. The amplitude at various DP frequencies and signal to noise ratio was noted. DPs were considered to be present if the signal to noise ratio exceeded 6 dB SPL (Gorga, 1997).

Phase 2: Psychoacoustical assessment of tinnitus

Prior to psychoacoustic assessment of tinnitus, a Tinnitus Questionnaire developed by Gore (2006) was administered. This questionnaire consisted of 13 questions. Psychophysical assessment of tinnitus was done in the following 2 steps.

Step I- Pitch matching: The appropriate pitch of the tinnitus for each client was determined using method of limits procedure. In clients with unilateral tinnitus, the signal was presented through headphones, to the ear, opposite to the side where tinnitus was present. In case of clients with bilateral tinnitus, the signal was presented in the ear opposite to the ear with predominant tinnitus or to the right ear if tinnitus was perceived equally loud in both the ears. The subjects were then instructed to indicate which of these types of signals (pure tone, NBN or BBN) resembled most closely to the pitch of their tinnitus. The frequency of the signal that was matched with the tinnitus was considered as pitch of the tinnitus. This frequency was then considered as reference frequency for the loudness match.

Step II- Loudness matching: The reference signal was presented to the ear opposite to the side having tinnitus or the ear with predominant tinnitus or to the right ear incase the tinnitus perceived by the subject in both ears was equally loud. The intensity of the reference signal was increased in 5 dB steps, till the subject first heard it. This level was considered to be the threshold for the particular signal. The signal level was then further increased in 5 dB steps, till the subject indicated that it was equal in loudness to their tinnitus. The difference between the threshold level and the level at which the reference sound was equally loud to the tinnitus was taken as the loudness of the client's tinnitus and expressed in dB SL (re: threshold). Tinnitus of 0-15 dB SL loudness was considered as mild. Tinnitus of 16 to 30 dB SL was considered as moderate. Tinnitus of 31 to 45 dB SL was considered as severe degree.

The amplitude of OAEs from both control group and clinical group and psychoacoustic measurements of tinnitus obtained from the clinical group were analyzed using SPSS version 16.

Results

TEOAE measures: Paired t-test was carried out to see the significant difference for TEOAE amplitude between the ears for both the groups separately. It was found that there was no significant difference between the two ears for TEOAE amplitude at

different frequencies for both the groups. Since the paired t-test did not show any significant difference between the right and left ears, data obtained from the right ear and left ear of 45 individuals in the control group were combined. The combined (right and left ear) mean and SD of TEOAE amplitude was calculated for the 90 ears at different frequencies. The mean TEOAE amplitude obtained at the low frequencies was higher than the high frequencies as shown in figure 1. The lowest mean amplitude was obtained at 4 kHz.

There were 57 tinnitus ears in the clinical group. Out of the 57 tinnitus ears, there were 27 ears (47.3%) with present TEOAEs and 30 (52.6%) ears with absent TEOAEs in the clinical group. Mann Whitney test was carried out to see the difference in amplitude of TEOAE obtained between the subjects with unilateral tinnitus (33 ears) and subjects with bilateral tinnitus (24 ears). The result showed that the TEOAE amplitude of both the groups at different frequencies did not vary significantly.

Since the paired-t test did not show any significant difference in TEOAE absolute amplitude between the right and left ears and also Man-Whitney test did not show any significant difference between the unilateral and bilateral tinnitus ears, data obtained from 57 ears (irrespective of right or left ear) with tinnitus were combined. The mean and SD obtained for TEOAE absolute amplitude from the 57 ears in the clinical group at different frequencies were calculated. For the calculation of mean and standard deviation of absolute TEOAE amplitude, data obtained from 57 ears were considered irrespective of whether they had TEOAE amplitude below 6 dB SPL or above 6 dB SPL. The mean amplitude of TEOAE for the individuals with tinnitus having normal hearing sensitivity is higher at low frequencies than at high frequencies (Figure 1). This finding is similar to that obtained in the control group.

Multiple analysis of variance (MANOVA) was done to compare the amplitude of TEAOEs at different frequencies between the groups. Global TEOAE amplitude was also compared between the groups. The results showed that there was a significant difference in TEOAE amplitude at all the frequencies tested between the control and the clinical group (Table 2).

Table 2. F-value and significant level for TEOAE amplitude at different frequency and global amplitude between the groups

Frequency	F(df, error)	Significant level
1 kHz	23.11(1, 178)	0.000
1.5 kHz	33.857(1, 178)	0.000
2 kHz	20.856(1, 178)	0.000
3 kHz	24.851(1, 178)	0.000
4 kHz	15.063(1, 178)	0.000
Global	6.69(1, 178)	0.002

From the Figure 1 it is clear that the mean amplitude levels of TEOAEs for subjects with tinnitus having normal hearing were found to be much lesser than that obtained in individuals with normal hearing sensitivity without tinnitus.

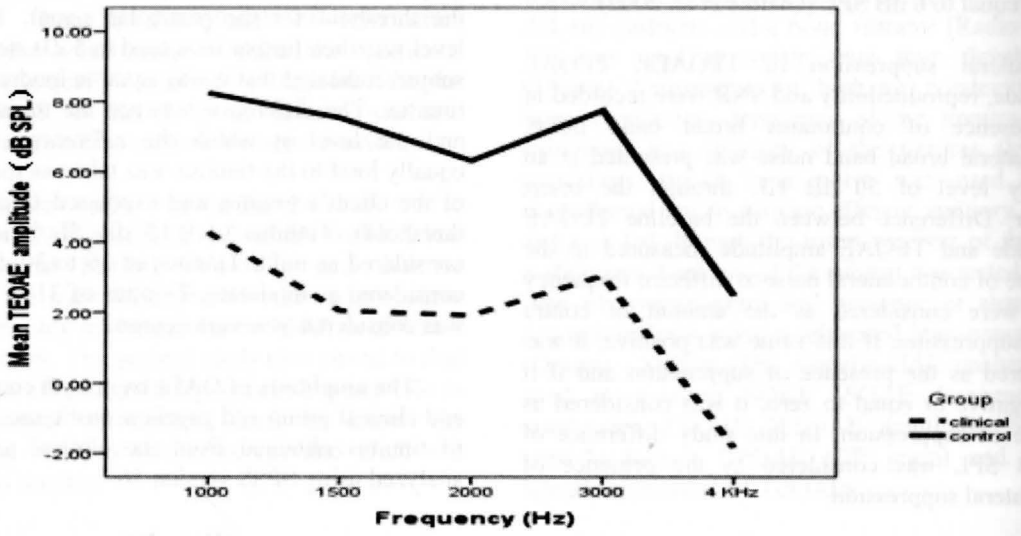

Figure 1. Mean TEOAE amplitude obtained at 1 kHz, 1.5 kHz, 2 kHz, 3 kHz and 4 kHz in both the groups.

Table 3. The number and percentage of ears that had absent TEAOE, below, normal and above normal amplitude at different frequencies in the clinical group

Frequency (kHz)		1	1.5	2	3	4	Global
Above Normal	No of ears	13	11	15	13	4	16
	Percent (%)	22.8	19.2	31.9	22.8	7.0	28.0
Normal	No of ears	3	2	2	1	0	4
	Percent (%)	5.26	3.50	3.50	1.7	0	7.0
Below normal	No of ears	7	4	2	3	6	7
	Percent (%)	12.2	7.0	3.50	5.26	10.5	12.2
Absent TEOAEs	No of ears	34	40	38	40	47	30
	Percent (%)	59.6	70.1	66.6	70.1	82.4	52.6

Attempt was made to see how many ears with tinnitus had TEOAE amplitude less than or more than the mean TEOAE amplitude obtained in the control group at different frequencies. The mean amplitude ±2 SD at each frequency obtained in the control group has been considered for the comparison. The details are given in the Table 3.

It can be observed from the above Table 3 that most of the ears with tinnitus had absent TEOAEs. The detailed observation in the table also reveal that only 7% of the ear had normal global TEOAE amplitude and 93% of the ears with tinnitus had abnormal TEOAE amplitude.

DPOAE measures: The paired t-test was carried out to see the significant difference between DPOAE amplitude obtained from right and left ear for both the groups. There was no significant difference between the two ears for DPOAE amplitude at different frequencies for both the groups.

Since the paired t-test did not show any significant difference between the right and left ears, data obtained from the right ear and left ear of 45 individuals in the control group were combined to obtain mean DPOAE amplitude of 90 ears. It was found that, the mean amplitude of DPOAEs were high for the high frequencies (Figure 2). For 500 Hz, the mean DPOAE amplitude was below 6 dB SPL in many subjects with normal hearing sensitivity without tinnitus. This could be due to the high noise level that was observed at 500 Hz during recording. So in the present study, DPOAE obtained at 500 Hz was not considered for further analysis.

Mann Whitney test was carried out to see the difference in amplitude of DPOAE between the subjects with unilateral tinnitus and subjects with bilateral tinnitus. The result showed that the DPOAE amplitude of both the groups at different frequencies did not vary significantly. As the paired-t test did not show any significant difference between the right and left ears for DPOAE amplitude and the Man-Whitney test did not show any significant difference between the ears with unilateral and bilateral tinnitus, the data obtained from 57 ears (irrespective of right or left ear) with tinnitus were combined.

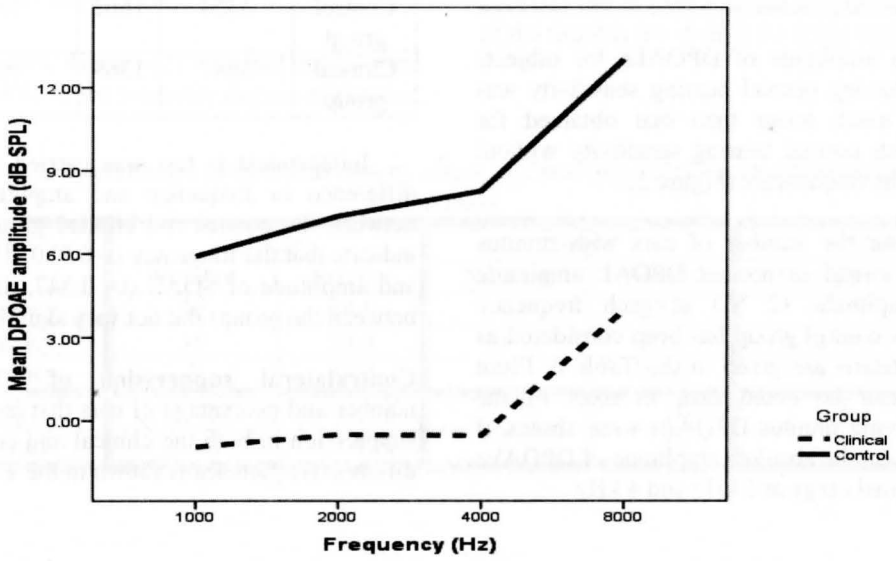

Figure 2. Mean absolute DPOAE amplitude obtained at different frequencies in both the groups.

The number and percentage of ears in the clinical group that had DPOAEs among the 57 ears with tinnitus having normal hearing sensitivity were calculated at different frequencies. The details are given in the Table 4. It can be noted from the table that, DPOAEs were present more at the high frequencies.

Table 4. Number and percentage of ears that had present DPOAEs at different frequencies in the clinical group

Frequency	1 kHz	2 kHz	4 kHz	8 kHz
No of ears	10	12	13	26
Percentage	17.5	21.0	22.8	45.6

For the calculation of mean and standard deviation of DPOAE amplitude, data obtained from 57 ears were considered irrespective of whether they were below 6 dB SPL or above 6 dB SPL. The mean and SD obtained for DPOAE amplitude for the 57 ears in the clinical group at different frequencies were calculated. The mean amplitude of DPOAEs was high for 8 kHz compared to other frequencies (Figure 2).

Multiple analysis of variance (MANOVA) was done to compare the absolute DPOAE at different frequencies between the control and clinical group. The results showed that there was a significant difference in DPOAE amplitude at all the frequencies tested between the control and the clinical group. The results of the analysis are given in Table 5.

Table 5. F-value and significant level for DPOAE amplitude at different frequency between the groups

Frequency	1 kHz	2 kHz	4 kHz	8 kHz
F(1, 178)	47.37	61.45	54.11	26.29
p	0.008	0.000	0.000	0.000

The mean amplitude of DPOAEs for subjects with tinnitus having normal hearing sensitivity was found to be much lesser than that obtained for individuals with normal hearing sensitivity without tinnitus at all the frequencies (Figure 2).

To find out the number of ears with tinnitus which has abnormal or normal DPOAE amplitude the mean amplitude ±2 SD at each frequency obtained in the control group has been considered as normal. The details are given in the Table 6. From the table it can be noted that, in most of the individuals having tinnitus DPOAEs were absent, if they were present the absolute amplitude of DPOAEs was above normal range at 2 kHz and 4 kHz.

Table 6. The number and percentage of ears that had absent DPAOE, below, normal and above normal amplitude at different frequencies in the clinical group

Frequency (kHz)		1	2	4	8
Above Normal	No of ears	8	10	12	13
	Percent (%)	14.0	17.5	21.0	22.8
Normal	No of ears	1	0	0	3
	Percent (%)	1.75	0	0	5.26
Below normal	No of ears	1	2	1	10
	Percent (%)	1.75	3.50	1.75	17.5
Absent DPOAEs	No of ears	47	45	44	31
	Percent (%)	82.4	78.9	77.1	54.3

SOAE measures: Out of the 45 individuals (90 ears) in the control group, 34 (37.7%) ears had presence of SOAEs. While in the clinical group, out of 57 ears with tinnitus, 24 (42.1%) ears had presence of SOAEs. The number of ears that had multiple SOAEs in the control group was about 16 (17.7%), while in the clinical group 12 (21.0%) ears. The Mean and Standard deviation of the SOAE frequency and amplitude for both the groups were calculated and shown in the Table 7.

Table 7. Mean and SD of SOAE frequency and amplitude

	SOAE frequency		SOAE amplitude	
	Mean (Hz)	SD	Mean (dB SPL)	SD
Control group	3354	1662	10.45	4.7
Clinical group	3047	1369	10.80	5.1

Independent t- test was carried out to see the difference in frequency and amplitude of SOAE between the control and clinical group. The results indicate that the frequency ($t=0.980$, $df= 97$, $p> 0.05$) and amplitude of SOAE ($t= 0.347$, $df= 97$, $p>0.05$) between the groups did not vary significantly.

Contralateral suppression of TEOAEs: The number and percentage of ears that had contralateral suppression in both the clinical and control group at different frequencies is shown in the Table 8.

Table 8. Number and percentage of ears that had presence of contralateral suppression of TEOAEs in both clinical and control group

	Control Group (N= 90)		Clinical Group (N= 57)	
	Number of ears	Percentage	Number of ears	Percentage
1 kHz	55	61.1	13	22.8
1.5 kHz	60	66.6	12	21.0
2 kHz	54	60.0	10	17.5
3 kHz	57	63.3	12	21.0
4 kHz	26	28.8	7	12.2
Global	69	76.6	19	29.1

For the calculation of the mean and SD data obtained only from the ears that had presence of contralateral suppression were taken. The results showed that the mean suppression amplitude of the clinical group was lesser than that of the control group for all the frequencies analyzed.

Non parametric Man- Whitney test was administered to compare the contralateral suppression of TEOAEs at 1 kHz, 1.5 kHz, 2 kHz, 3 kHz, and 4 kHz between the groups. The results showed that there was no significant difference seen at 1 kHz ($z= 0.469$, $p>0.05$), 2 kHz ($z=2.479$, $p> 0.05$), 3 kHz ($z=0.945$, $p>0.05$) and 4 kHz ($z=0.345$, $p>0.05$) between the control and the clinical group. But there was a significant difference between the control and clinical group in terms of TEOAE suppression amplitude at 1.5 kHz ($z= 2.479$, $p<0.05$).

Psychoacoustic measures of tinnitus: In the clinical group, there were 31 ears (54.3%) with low frequency tinnitus (frequency below 1000 Hz), 20 ears (35.0%) with mid frequency tinnitus (frequency between 1000 Hz to 3000 Hz), and 6 (10.5%) ears with high frequency tinnitus (frequency greater than 3000 Hz). None of them had tinnitus frequency below 125 Hz and above 12,000 Hz.

Out of 57 ears, 41 ears (71.9%) had mild degree and 16 ears (28%) in the moderate degree of tinnitus. None of the ears exhibited severe degree of tinnitus. The tinnitus pitch frequency and loudness of tinnitus was correlated with various OAE measures (SOAE, TEOAE & DPOAE).

Relation between the OAE measures and psychoacoustic measures of tinnitus

SOAEs and psychoacoustic measures of tinnitus: The number of ears with low frequency, mid frequency and high frequency tinnitus were calculated for the number of ears with absent, single SOAEs and multiple SOAEs. The details of the number of ears that fall into each group are given in the Table 9. It can be noted from the Table 9 that ears with mid frequency tinnitus had SOAE in 50% of the ears (single and multiple SOAEs), which is more than the other two groups. Almost 53% of the cases had moderate level tinnitus.

Karl Pearson correlation coefficient was done to see whether there was any relationship between the SOAE frequency and tinnitus pitch matched frequency and with the loudness. Pearson's rank correlation results indicate that there was no significant correlation between SOAE frequency and tinnitus frequency ($r=0.257$, $P> 0.05$). No correlation between the SOAE absolute amplitude and loudness of the tinnitus ($r= -0.362$, $P> 0.05$) was noticed.

Table 9. Number and percentage of ears with absent, single and multiple SOAEs with different tinnitus pitch and loudness

SOAEs	Absent		Single		Multiple	
	Number	Percent	Number	Percent	Number	Percent
Low frequency	20	64.5	7	22.5	4	12.9
Mid frequency	10	50.0	6	30.0	4	20.0
High frequency	5	83.3	1	16.6	0	0
Mild	27	67.5	8	20.0	5	12.5
Moderate	8	47.0	6	35.2	3	17.6

Table 10. Number of ears with absent, reduced, normal and robust TEOAEs within different tinnitus pitch and loudness

TEOAE	Absent		Reduced		Normal		Robust	
	No	Percent	No	Percent	No	Percent	No	Percent
Low frequency	15	48.3	5	16.1	4	12.9	7	22.5
Mid frequency	10	50.0	5	25.0	2	10.0	3	15.0
High frequency	5	83.3	0	0	1	16.6	0	0
Mild	24	60.0	4	25.0	3	7.5	3	7.5
Moderate	6	35.2	6	35.2	4	23.5	7	41.1

Table 11. Number of ears with absent, reduced, normal and robust DPOAEs within tinnitus pitch and loudness groups

DPOAE	Absent		Reduced		Normal		Robust	
	No	Percent	No	Percent	No	Percent	No	Percent
Low frequency	24	77.4	2	6.4	3	9.6	2	6.4
Mid frequency	9	45.0	3	15.0	3	15.0	5	25.0
High frequency	5	83.3	0	0	0	0	1	16.6
Mild	25	62.5	3	7.5	3	7.5	9	22.5
Moderate	16	94.1	0	29.4	0	17.6	1	23.5

TEOAEs and psychoacoustic measures: It can be noted from the table that most of the individuals with low (48.3%), mid (50%) and high frequency tinnitus (83.3%) exhibited absent TEOAEs. Also most of the individuals with mild tinnitus had absent TEOAEs. No such trend was seen in moderate degree of tinnitus.

The Karl Pearson correlation coefficient result showed that there was no correlation between the tinnitus pitch frequency and TEOAE frequency having maximum amplitude ($r = 0.131$, $p>0.05$) and loudness of the tinnitus and TEOAE global amplitude ($r = 0.009$, $p>0.05$).

DPOAEs and psychoacoustic measures: It can be noted from the table that most of the individuals with different tinnitus frequency and loudness had absent DPOAEs. There were 9 ears with normal DPOAEs in both having different frequency tinnitus frequency and having different loudness of tinnitus. Among the ears that had normal DPOAEs, majority of the ears had mid frequency tinnitus (15%) and moderate degree of tinnitus (18%).

Karl Pearson's rank correlation results indicate that there was a small significant positive correlation between tinnitus loudness and DPOAE having maximum amplitude ($r=0.042$, $P< 0.05$), but there was no correlation noted between DPOAE frequency having maximum amplitude and tinnitus pitch frequency ($r=0.204$, $P> 0.05$).

Subgrouping the tinnitus ears based on OAE measures: The frequency of occurrence of SOAEs (single or multiple) was equal in both control and clinical group.. The statistical analysis also did not show any significant difference in frequency and amplitude of SOAE between the groups. Also no significant correlation was obtained between frequency of tinnitus (pitch) and SOAE frequency and also amplitude of SOAE and loudness of the tinnitus within the clinical group. Thus, to find out the subgroup of ears with tinnitus which had abnormality in one OAE measure alone or several OAE measures, SOAEs was not considered.

Table 12. Number of ears that had abnormality in single or several OAE measures

Sl. No	Abnormal	Number of ears
1.	TEOAE alone	0
2.	Contralateral suppression	0
3.	DPOAE alone	7
4.	TEOAE & Contralateral suppression	4
5.	DPOAE & Contralateral suppression	15
6.	TEOAE & DPOAE	0
7.	TEOAE, DPOAE & Contralateral suppression	25
8.	None	6

It is evident from the Table 12 that only six ears with tinnitus did not show any abnormality in any one of the OAE measures. However, most of the ears with tinnitus showed abnormality in multiple OAE measures.

Discussion

SOAE measures: SOAEs were found to be present in approximately 42 % in individuals with tinnitus having normal hearing, while in the control group,

the prevalence was about 38 %. The results of the present study were similar to the findings of Martin, Folmer, Shi and Edlefsen (2006). He found that SOAEs could be detected from about 30.5 % of the ears with tinnitus. Ceranic et al (1998) reported that the prevalence of subjects with SOAE was not notably different between the controls and subjects with tinnitus. The SOAE mean frequency and amplitude of the individuals with tinnitus with normal hearing did not vary significantly from that of the control group in their study. There was no information in literature where they have compared the SOAE mean frequency and amplitude between both the groups.

TEOAE measures: Clinical group had significantly lesser amplitude than control group in terms of TEOAEs at all frequencies analyzed, clinical group having lesser amplitude. The results were consistent with the findings of Paglialonga et al, (2010). The reduced absolute amplitude of TEOAEs in subjects with tinnitus may be related to peripheral a hearing disorder that is not evident on conventional audiometry (Fernandes & Santos, 2009). This result suggests reduction of outer hair cells activity in patients with tinnitus having normal hearing.

In the clinical group, there were 28% ears that had TEOAE amplitude above normal mean. The possible reason for the increased amplitude in these subjects could be due the reduction in central efferent suppression of cochlear mechanics. This might have led to an increase in cochlear amplifier gain which further resulted in higher TEOAE amplitude in these individuals.

DPOAE measures: The overall DPOAEs could be observed in only 20% of the individuals with tinnitus having normal hearing sensitivity in at least one of the frequencies analyzed. While in 80% of the ears the DPOAEs were found to be absent. In 93% of the individuals DPOAEs were found to be abnormal i.e. DPOAEs were either absent, reduced, or robust. This supports the findings of Almeida et al. (2006). They reported that DPOAEs were abnormal in 68.4% of subjects who had normal hearing with tinnitus.

There was a significant difference in DPOAE amplitude at all the frequencies tested between the clinical and control groups, DPOAE amplitude being lesser in control group. Mitchell et al., (1993) also reported that DP levels in tinnitus patients with normal audiograms were lower than those in individuals with normal hearing without tinnitus. The result of this study was also consistent with the results of Paglialonga et al (2010). According to Sanchez, Mak, Pedalini, Levy and Bento (2005), the occurrence of tinnitus in patients without hearing loss should be explained by diffuse damage to up to 30% of the outer hair cells in the whole cochlear spiral, with no hearing threshold impairment. The presence of damaged outer hair cells and intact inner hair cells can characterize the tinnitus with frequencies close to the site of cochlear lesion. So it can be concluded that the low DPOAE-amplitudes are a sign of damaged outer hair cells of the patients that might have resulted in tinnitus.

Contralateral suppression of TEOAEs: In the present study, there was high variability observed between the TEOAE amplitude with and without the presence of contralateral broad band noise, varying from their non reduction to their increase. Similar findings were also reported by Ryan and Kemp (1996). They found a large range of suppression variability when there was a contralateral acoustic stimulation.

The percentage of ears that had presence of contralateral suppression of TEOAEs is less for individuals with tinnitus compared to the normal hearing control group. The result of the study is consistent with the findings of Paglialonga et al (2010) who reported slightly decreased TEOAE suppression in tinnitus subjects compared to non-tinnitus ears.

The mean suppression amplitude of the clinical group at all the frequencies is reduced compared to the control group. The possible reason could be that the effect of any lesion or dysfunction of medial olivocochlear system leads to the absence or reduction of contralateral acoustic suppression, which may further lead to a decrease in suppression amplitude.

Relationship between the OAE measures and psychoacoustic measures of tinnitus: Low frequency tinnitus was seen commonly in subjects studied in the present study. Also most of the individuals had mild degree of tinnitus. There was a small positive correlation between loudness of the tinnitus and the DPOAE having maximum amplitude, while no correlation was obtained for any of the psychoacoustic parameters and the OAE measures. There was no information available where they compared the evoked OAE (TEOAE and DPOAE) measures and psychoacoustic measures of tinnitus. Penner and Burns (1987) found that when SOAEs occur in the ear of a tinnitus patient, they rarely correspond to the judged frequency of the tinnitus.

Subgrouping the tinnitus ears based on OAE measures: The results also showed that most of the ears with tinnitus showed abnormality in multiple OAE measures. There is no much information available in the literature which stated that most of the ears with tinnitus showed abnormality in all the OAE measures they have studied. However, studies

done using TEOAEs showed that 70.2% of individuals with tinnitus had abnormal TEOAEs (Almeida et al, 2006) and 74% of individuals with tinnitus had abnormal DPOAEs (Paglialonga, et al, 2010). Study on contralateral suppression also showed high percentage of ears that had absent or reduced suppression (Rita & Azevedo, 2005). This suggests that most of the ears with tinnitus are likely to show abnormality in most of the OAE measures as observed in the current study.

The results of the present study suggest that reduced outer hair cell activity, as noticed by reduced OAE amplitude, may manifest as tinnitus even before there is a shift on hearing threshold. The data also suggest peripheral auditory malfunction in individuals with tinnitus having normal hearing sensitivity.

Conclusions

It could be concluded from the study that OAEs are an effective objective tool to measure the cochlear dysfunction in individuals with tinnitus having normal hearing sensitivity. Abnormal OAEs are invariable findings in individuals with tinnitus having normal hearing sensitivity. So it can be concluded from the present study that OAEs showed evidence of cochlear dysfunction, which was associated with the perception of tinnitus at least in individuals with tinnitus having normal hearing sensitivity.

The present study helps to see whether OAE can be used as objective test for tinnitus in subjects with normal hearing sensitivity. The study helps to understand the role of outer hair cells and efferent auditory system in the generation of tinnitus using OAEs. The study also checks whether OAEs could reflect cochlear lesion in early stage prior to the onset of hearing loss in individuals with tinnitus. The information gained from OAEs can also be used in counseling the patient and convincing them that indeed their problem is real and in counseling them about the origin of tinnitus. Also the data obtained from the group of individuals with tinnitus having normal hearing adds information to the literature.

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