Cochlear Functioning In Individuals With Sensorineural Hearing Loss With And Without Tinnitus

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Abstract

The aim of the study was to evaluate the cochlear functioning in sensorineural hearing impaired individuals with and without tinnitus. The study consists of two group of hearing impaired participants in the age range of 18 to 45 years. Group 1 consist of 15 participants of hearing impaired with tinnitus and Group 2 consists of 15 participants of hearing impaired without tinnitus. Each group were further divided into 3 sub-groups depending on degree of hearing loss in to minimal, mild and moderate (each subgroup consists of 5 participants). The cochlear function was assessed through SWPTC, TEN test and ECochG. Results revealed, reduced Q10 of PTC and reduced CM amplitude in individuals with tinnitus compare to individuals without tinnitus; whereas no significant difference was found between groups for tip frequency of PTC and TEN test. It was also found that the there was no significant difference within individuals with tinnitus across all parameters. However, PTCs obtained from individuals with tinnitus reduced from minimal to moderate hearing loss. Thus, it can be concluded from the study that, damage to OHC are more common in individuals with tinnitus than in those without tinnitus also that OHC are the probable site of generation for tinnitus. Also, it can be concluded that, as degree of hearing loss increases the frequency resolution of cochlea tend to become poorer.

Key words: *Q10 value, Tip frequency, CM amplitude and CM latency.*

Introduction

Tinnitus is the perception of sound in the absence of any external sound. The word tinnitus is derived from Latin word 'tinnire', which means 'to ring'. As defined by McFadden (1982), 'Tinnitus is the conscious expression of a sound that originates in an involuntary manner in the head of its owner, or may appear to him to do so'. There is an increased risk of tinnitus associated with hearing loss. Studies have shown a clear relation between tinnitus and hearing loss (Axelsson & Barrenas, 1992; Davis & Refaie, 2000), and most of individuals with tinnitus have certain degree of hearing loss (Davis & Refaie, 2000; Henry & Wilson, 2001). The other risk factors include head and neck injuries, noise exposure, ear diseases, cardiovascular diseases, medication, mental status, and lifestyle factors (Ahman & Seidman, 2004; Hoffman & Red, 2004). The exact pathophysiology underlying tinnitus is yet to be understood. No single theory, hypothesis or the model can explain pathophysiology of tinnitus, but it is the multiple mechanism which results in perception of tinnitus.

Animal studies have reported a strong link between the presence of tinnitus and damage to the auditory peripheral system (Bauer, Turner, Caspary, Myers, & Brozoski, 2008; Brozoski, Bauer, & Caspary, 2002; Heffner & Harrington, 2002; Kaltenbach, Zacharek, Zhang, & Frederick, 2004). However, the tinnitus perception was still reported even after the ablation of auditory nerve (Sasaki, Babitz & kauer, 1981). This indicates that tinnitus is majorly a central phenomenon, such as cortical reorganization (Eggermont & Komiya 2000; Rajan & Irvine, 1998) or hyperactivity present in the central auditory pathway (Sasaki, Kaner, & Babitz, 1980; Eggermont, 2007; Bauer et al., 2008). Therefore, damage in the inner ear is likely necessary, but not adequate, for tinnitus to occur (Cacace, 2003).

Sensorineural hearing impairment consists of outer hair cells, inner hair cells damage or both, with outer hair cell being more susceptible to damage (Hawkins, 1973; Jastreboff, 1990), but studies have also shown that inner hair cell damage with subsequent neural degeneration can co-occur with outer hair cells being functionally normal (Kujawa & Liberman, 2009). It is unclear that which of this cochlear damage might cause the central changes and results in tinnitus perception. Hearing loss is mainly assessed through the audiometry; still auditory threshold assessed through audiometry gives limited information about the status of the cochlea at the signal frequency. Studies have reported only moderate correlation between degree of hearing loss and OHC dysfunction (Davis, Qiu, & Hamernik, 2004). Also, damage to IHC can result in less responsive region in cochlea which results in off- frequency listening (Moore, Huss, Vickers, Glasberg, & Alcantara. 2000; Moore, 2004). Hence, detailed assessment of inner ear is necessary, which should include test other than audiometry which can assess inner hair cell and outer hair cell damage independently and help to draw a conclusion about tinnitus and hearing loss.

PTC (Psychophysical Tuning Curves) measures the frequency resolution of cochlea. For individuals with normal hearing, the tip of the PTC lies close to the signal frequency (Moore, 1978; Moore et al., 2000; Moore & Alcantara, 2001). Studies have reported that variations which present in psychophysical and physiologic tuning curves which shows a reduced sharpness of tuning which is measured from damaged OHCs (Ryan, Dallas, &

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McGee, 1979; Smith, Moody, Stebbins, & Norat, 1987). Moore (2004) employed PTC to explore dead region in cochlea (which is basically complete loss of IHC in certain place of cochlea), his results suggested that tip of the PTC's will shifted towards the edge frequency where effective masking takes place. The cochlear dead region can be also found using TEN (Threshold-Equalizing Noise) test, given by Moore et al. (2000). Other test to assess the functionality of cochlea includes Electrocochleography (ECochG). ECochG is a method for recording the electrical potentials of the cochlea.

In order to evaluate the involvement of cochlear pathology, that is extent of OHC and IHC damage which leads to tinnitus perception, the test battery should include tests which assess OHC and IHC functions independently. Thus, test battery of PTC, TEN and EcochG test will be helpful assessing functionality of OHC and IHC independently.

Need of the study.

Tinnitus consists of many ontological symptoms, which requires audiological assessment in detail. Many models suggest that tinnitus is central in origin (Bauer et al. 2008; Brozoski et al. 2002; Kaltenbach et al. 2004). At the same time, many studies report that it's the peripheral pathology which leads tinnitus of central origin. The discordant damage hypothesis suggests that tinnitus is generated with damaged or temporarily dysfunction of OHC but preserved IHC. (Bohne & Clark, 1982; Bohne et al., 1987; Liberman, 1987; Liberman & Kiang, 1978).

A study done by Tan, Lecluyse, McFerran and Meddis (2013) assessed cochlear function in hearing impaired individual with tinnitus and without tinnitus using psychophysical measures and their result suggested better OHC functioning in individual with tinnitus. Another complimenting study done by Kiani,Yoganantha,Tan, Meddis and Schaette (2013) reported presences of dead region in hearing impaired individual with tinnitus which is proportional to hearing impaired individual without tinnitus using PTC. Both studies report better OHC functioning and IHC dysfunction.In contrast, study done by Mitchell and Creedon (1995) employed Psychophysical tuning curves and studied difference in PTC in individual with tinnitus and without tinnitus and their result showed significantly different between individual with and without tinnitus, and subjects often had some elevated tips and hypersensitive tails. The shapes of tuning curves were consistent with cochlear lesions which involve the damage to outer hair cells.

It is unclear that which part of the cochlea is involved in generation of tinnitus. Few studies reported that it's the OHC damage/ hyper functioning in the cochlea which causes the tinnitus, in contrast few studies reported that presence of the cochlear dead region which involves in generation of tinnitus.There are many studies in literature which reports that the peripheral pathology which results in tinnitus of central origin (Bauer et al. 2008; Brozoski et al. 2002; Heffner & Harrington, 2002; Kaltenbach et al. 2004). But, it is imprecise as in whether peripheral pathology includes OHC or IHC dysfunction. Thus the present study is taken up with purpose of identifying the specific role of OHC and IHC in tinnitus perception.

Aim of the study.

The present study aims to assess the OHC and IHC functioning in individual with and without tinnitus having various degrees of hearing loss.

Objectives of the study.

- To compare findings of PTC, ECochG and TEN test in individual with (Group 2) and without tinnitus (Group 1) across different degree of hearing loss.
- To compare findings of PTC, ECochG and TEN test in individual with tinnitus (Group 2) across different degrees of hearing loss.

Method

The present study tested the null hypothesis which states that 'there is no significant difference in the result of PTC, TEN test and ECochG test in individuals with sensorineural hearing loss, with tinnitus and without tinnitus'. To test the hypothesis SWPTC, TEN test and ECochG were used in individuals in the same target group. The results of these tests were further analysed to assess the functioning of IHCs and OHCs. The following method was used in the study to test the hypothesis.

3.1. Selection of participants.

The study involved two groups of individuals with hearing impairment in the age range of 18 to 45 years. Group 1 consist of 15 individuals having sensorineural hearing loss without tinnitus and Group 2 consists of 15 individuals having sensorineural hearing loss with tinnitus. Each group were further divided into 3 sub-groups depending on degree of hearing loss in to minimal, mild and moderate (5 participants in each sub-group)..

3.1.1. Inclusion criteria. The participants in Group 1 with Sensorineural hearing loss of either minimal, mild or moderate degree and having flat audiometric configuration and Individual with SIS of 70% and above were included in the study. In Group 2, apart from the criteria governing intake for participants selected in Group 1, all individuals in Group 2 were required to have a score of moderate and above in Tinnitus Handicap Inventory (THI), a questionnaire to assess the individual's reaction to tinnitus (Newman, Jacobson, & Spitzer 1996).

3.1.2. Exclusion criteria. Participants in Group 1 with any history or presence of middle ear disorders and presence of retrocochlear pathology were exclude from the study. In Group 2, individuals with any somatosensory or other conditions those are typically associated with tinnitus (vestibular schwannoma or Meniere's Diseases) or any history or presence of psychological problems was excluded from the study.

3.2. Instrumentation.

A calibrated dual channel audiometer along with TDH-39 was used to obtain air conduction threshold; whereas Radio ear B-71 was used to obtain bone conduction threshold. Grason-Stadler GSI Tympstar middle ear analyser was used for evaluation of middle ear status and to obtain acoustic reflex threshold. PTC is administered using SWPTC software (version 1.4.50.1) installed in personal computer and TEN test was administered through TEN(HL) CD (Moore, 2014). To record ECochG, Biologic navigator pro AEP (version 7.2.1) was used.

3.3. Test environment.

All tests were carried out in acoustical treated audiometric room where the ambient noise level were within the permissible limits as specified by ANSI S3.1 (1999).

3.4. Procedure.

3.4.1. Routine evaluation. Pure tone threshold was obtained using calibrated dual channel audiometer. Based on four frequency pure tone average the individuals were categorized into three sub-groups having minimal, mild and moderate hearing loss (Clark, 1981).

Speech audiometry, Tympanometry and Acoustic reflex was carried out. Based on the results of the above tests, those participants who satisfy the selection criteria were included for the study. All the individuals with continuous tinnitus were given a Tinnitus Handicap Inventory (THI), a questionnaire. Individuals with a score of moderate and above were selected for the study.

3.4.2. Software Psychophysical tuning curves (SWPTC). The software PTC (SWPTC, version 1.4.50.1) was installed in personal computer fitted with soundcard and output was delivered through TDH 39 head phone. Before starting testing, the software was calibrated to ensure correct amount of sound level being delivered by the system. The probe signal used was a pulsed and fixed in frequency. The same was presented at an intensity of 10 dB above the absolute threshold at 500 to 4000 Hz in mid octave step. The signal duration at each frequency was maintained at 0.2 second; with an interval of 0.2 second between the pulses. The noise used for masking was swept in forward sweeping manner with a rate of change of 2dB/s. The initial noise level for the test was set at 50 dB SPL and this level was kept constant across all the test frequencies. The participants were instructed to press and hold the space bar in keyboard as long as the tone is heard and to leave the key once the tone becomes inaudible. The participants were also instructed to ignore the noise and only concentrate on tone and then respond to only tone.

3.4.3. TEN Test. For the administration of TEN test the unmasked pure-tone thresholds were obtained through routine audiological examination and TEN masked threshold were obtained through TEN CD which contains special masking noise called TEN noise (Threshold Equalizing Noise). For conducting TEN test, right and left output from the computer was connected to the right and left input socket of audiometer respectively. The Track 1 contained calibrated tone which was used to calibrate output from audiometer. Later, the tracks from both the channel was mixed and presented to the same ear such that both TEN noise and warble tone are delivered to same ear. The test frequencies consist of 500, 750, 1000, 1500, 2000, 3000 and 4000 Hz. The TEN levels were specified as the level of a one ERBn (equivalent rectangular bandwidth) wideband centred at 1000 Hz (Glasberg & Moore, 1990; Moor, 2004). The level of the signal and the TEN was controlled by using attenuator in the audiometer. The TEN masking noise was always kept constant at 70 dBHL (Vinay & Moore, 2007). The signal level was varied in 2 dB steps to determine the threshold (Moore, Glasberg, & stone, 2004). A 'no response' was indicated if subject did not respond for maximum output level of the audiometer.

3.4.4. Electrocochleography. ECochG was done using a single channel recording. Initially skin was prepared for electrode placement by using skin preparation gel and subject was made to relax on an inclining chair. Tip- trode electrode was used to record ECochG. The impedance of the each electrode was within 5 k? and between electrodes was 2 k?. The protocol used to record ECochG is given in table 1

Table 1: Stimulus and acquisition parameters for recording ECochG

Stimulus parameters	
Transducer type	ER-3A Insert headphone
Type of stimulus	Click
Intensity	80dBnHL
Stimulus polarity	Rarefaction
Stimulus rate	7.1/s
Acquisition parameters	
Analysis time	10ms
gain	10000
Filter setting	10-3000 Hz
No of sweep	1500
Electrode montage	Inverting (-) = Non test ear Mastoid (M_1/M_2) Non inverting (+) = Ear canal (A_1/A_2) Ground = Forehead (Fz)

3.5. Analysis of responses.

3.5.1 Analysis of SWPTC. The Q10 values were analysed; i.e. the ratio of central frequency to the band width measured 10 dB above the lowest point on the tuning cure. Tip frequency was measured to assess the function of IHC.

3.5.2. Analysis of TEN test. For identifying cochlear dead region through TEN test, the following two criteria were considered and the individuals who met both the criteria were considered as having cochlear dead region. Firstly, the masked threshold in the TEN should be 10 dB or more above the TEN level/ERBN, Secondly, the masked threshold in the TEN should be 10 dB or above the absolute threshold or unmasked threshold.

3.5.3. Analysis of waveform of EcochG. The latency and the amplitude of cochlear microphonics were measured by using rarefaction stimuli. The waveforms were analysed subjectively. The waveforms recording were given to the two qualified audiologists for the analysis of parameters. If there was agreement between both the audiologists, then only the waveform were taken for further analysis.

Results

The current study aimed to compare the cochlear functioning in individual having sensorineural hearing loss with and without tinnitus. This was achieved through following objectives.

4.1. PTC, ECochG and TEN test results in Group 1 and Group 2.

Under this section, which address the first objective of the study, includes results of PTC (Q10 and tip frequencies), TEN masked thresholds and cochlear microphonic (latencies and amplitude). Results were compared between individuals having sensorineural hearing loss without tinnitus (Group 1) and individuals with sensorineural hearing loss with tinnitus (Group 2) across minimal, mild and moderate degrees of hearing loss. The results are subcategorised based on degree of hearing loss.

4.1.1. Minimal hearing loss. The results of PTCs, TEN test and ECochG between Group 1 and Group 2 are discussed under the following headings.

4.1.1.1. Psychophysical tuning curves.

a) Q10 values. Descriptive statistics was carried out to find the median and range of Q10 values in individuals having minimal SNHL without tinnitus (Group 1) and with tinnitus (Group 2). It was found that most of the individuals in Group 1 had higher Q10 values compare to Group 2. Higher value indicates better frequency resolution capability of outer hair cells. Median and range values are given in Table 2 It can be seen from the Figure 1, that the median for Q10 of PTCs are higher (in most of the cases) for Group 1 than Group 2.

Table 2:Median and range for Q10 values of PTC for Group 1 and Group 2

	Median (dB)		Minimum (dB)		Maximum (dB)	
	Group 1	Group 2	Group 1	Group 2	Group 1	Group 2
500 Hz	4.00 (5)	3.00 (5)	3.00	2.00	6.00	4.00
1000 Hz	4.00 (5)	3.00 (5)	3.00	3.00	6.00	4.00
1500 Hz	4.00 (4)	4.00 (5)	4.00	3.00	4.00	4.00
2000 Hz	4.00 (5)	3.00 (5)	3.00	3.00	5.00	4.00
3000 Hz	3.00 (5)	4.00 (3)	3.00	2.00	6.00	5.00
4000 Hz	3.00 (3)	2.00 (3)	3.00	2.00	5.00	2.00

Note: N given in parenthesis

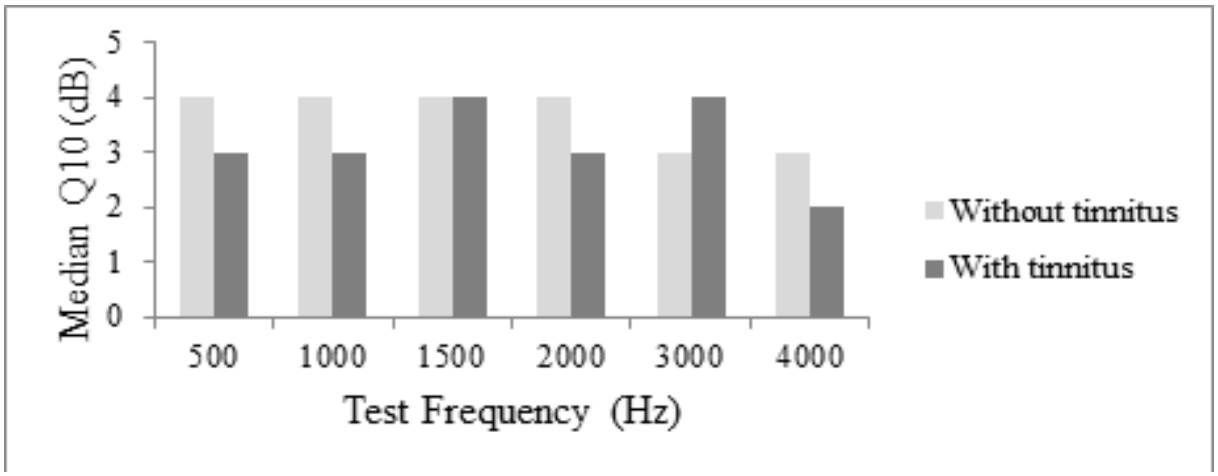

Figure 1: Median for Q10 values of PTC for Group 1 and Group 2.

To compare results of Q10 values of PTC in minimal SNHL with and without tinnitus Mann Whitney U test was carried out. Results showed no significant difference in Q10 value between two groups ($p>0.05$), except at 4000 Hz ($p<0.05$). The p and Z value obtained in the Mann Whitney u test is given in Table 3.

Table 3: /Z/ value and level of significance obtained on Mann Whitney U test for Q10 comparison

Q10 (Hz)	500	1000	1500	2000	3000	4000
/Z/	1.643	1.417	1.352	1.315	0.461	2.121
Level of significance	p>0.05	p>0.05	p>0.05	p>0.05	p>0.05	p<0.05

b) Tip frequencies. Descriptive statistics was carried out to find the median and range for tip frequencies. It was found that median was similar between both groups across all frequencies. The median and range for tip frequencies of PTC for Group 1 and group 2 are shown in the table 4.

Table 4: Median and range for tip frequencies of PTC for Group 1 and Group 2

Frequencies (Hz)	Median (Hz)		Minimum (Hz)		Maximum (Hz)	
	Group 1	Group 2	Group 1	Group 2	Group 1	Group 2
500	513 (5)	549 (5)	498	496	556	598
1000	1094 (5)	1062 (5)	963	1015	1260	1164
1500	1513 (4)	1642 (5)	1487	1064	1605	1756
2000	2075 (5)	2088 (5)	1905	1942	2643	2134
3000	3172 (5)	3033 (3)	3091	3011	3528	3784
4000	3960 (3)	4147 (3)	3704	3981	4178	5358

Note: N given in parenthesis

To compare results of tip frequencies in individuals with minimal SNHL with and without tinnitus, Mann Whitney U test was carried out. Results showed no significant difference in tip frequency between two groups ($p>0.05$) in individuals having minimal SNHL without tinnitus (Group 1) and with tinnitus (Group 2). It was found that median was similar between both groups across all frequencies. The median and range for TEN masked threshold for Group 1 and group 2 are shown in the table 5.

4.1.1.2. TEN test. Descriptive statistics was carried out to find the median and range for TEN masked threshold

Table 5: The median and range for TEN masked thresholds for Group 1 and group 2

Frequencies (Hz)	Median (dB)		Minimum (dB)		Maximum (dB)	
	Group 1	Group 2	Group 1	Group 2	Group 1	Group 2
500	4.00 (5)	4.00 (5)	2.00	4.00	4.00	12.00
750	4.00 (5)	4.00 (5)	4.00	4.00	6.00	6.00
1000	6.00 (5)	6.00 (5)	4.00	4.00	6.00	8.00
1500	4.00 (5)	4.00 (5)	2.00	4.00	4.00	6.00
2000	4.00 (5)	6.00 (5)	2.00	4.00	6.00	8.00
3000	4.00 (5)	4.00 (5)	2.00	2.00	6.00	6.00
4000	4.00 (5)	8.00 (5)	4.00	6.00	8.00	10.00

Note: N given in parenthesis

To compare results of TEN test in individuals with minimal SNHL Mann Whitney U test was carried out. The TEN masked thresholds were subjected to Mann Whitney U test to see the difference between Group 1 and Group 2. Results showed no significant difference in TEN masked threshold between two groups (p>0.05).

4.1.1.3. EcochG. Descriptive statistics was carried out to find the median and range for latency and amplitude of cochlear microphonics in individuals having minimal SNHL without tinnitus (Group 1) and with tinnitus (Group 2). It was found that median was similar between both groups for latency of cochlear microphonics and amplitude was higher for Group 2 (SNHL without tinnitus). The median and range for latency and amplitude of cochlear microphonics for Group 1 and Group 2 are shown in the Table 6. The median for CM latency and amplitude are depicted in the Figure 2 and 3 respectively. It can be observed from the figure the median of CM amplitude is higher for the individuals without tinnitus (Group 1) than with tinnitus (Group 2).

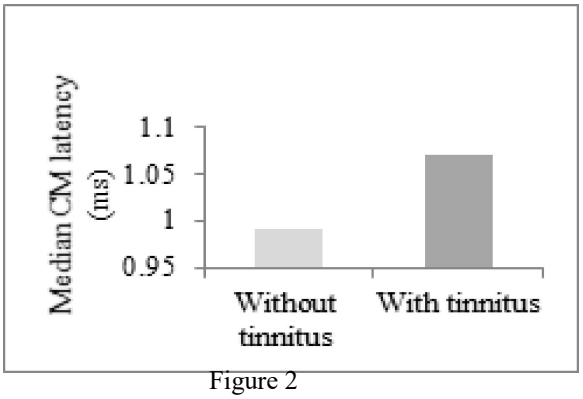

Figure 2

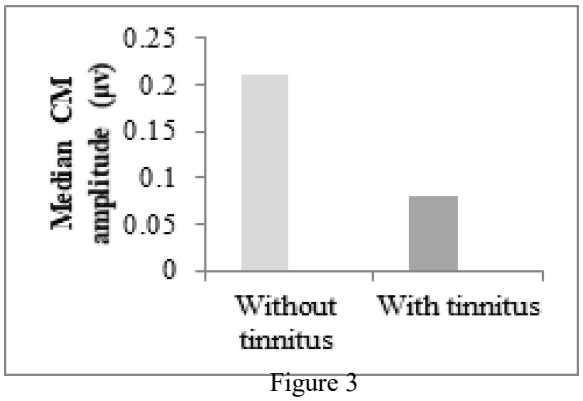

Figure 3

Figure 2 and Figure 3: Median for latency of cochlear microphonics for Group 1 and Group 2 ad median for amplitude of cochlear microphonics for Group 1 and Group 2 respectively.

Table 6: The median and range for latency and amplitude of cochlear microphonics for Group 1 and group 2

	Median		Minimum		Maximum	
	Group 1	Group 2	Group 1	Group 2	Group 1	Group 2
CM latency (ms)	0.99 (3)	1.07 (5)	0.89	0.99	1.07	1.28
CM amplitude (µv)	0.21(3)	0.08 (5)	0.19	0.01	0.41	0.18

Note: N given in parenthesis

Following descriptive statistics, the cochlear microphonics latency and amplitude was analysed using Mann Whitney U test to study for any difference between Group 1 and Group 2. Results showed no significant difference in cochlear microphonics latency between two group (p>0.05), whereas significant difference was found in CM amplitude between two group (p<0.05). The /Z/ and p value obtained on Mann Whitney U test for comparison of CM latency and amplitude is given in Table 7.

Table 7: /Z/ value and level of significance obtained on Mann Whitney U test for comparison of CM latency and amplitude

	Latency	Amplitude
/Z/	1.439	2.236
Level of significances	P>0.05	P<0.05

4.1.2. Mild hearing loss

The results of PTCs, TEN test and ECochG between Group 1 and Group 2 are discussed under the following headings.

4.1.2.1. Psychophysical tuning curves:

a) Q10 values: Descriptive statistics was carried out to find the median and range of all parameter in individuals having mild SNHL without tinnitus (Group 1) and with tinnitus (Group 2). Median and range values are given in Table 8. It can be seen from the figure, the median for the Q10 at 3000 Hz was higher in Group 1 than Group 2.

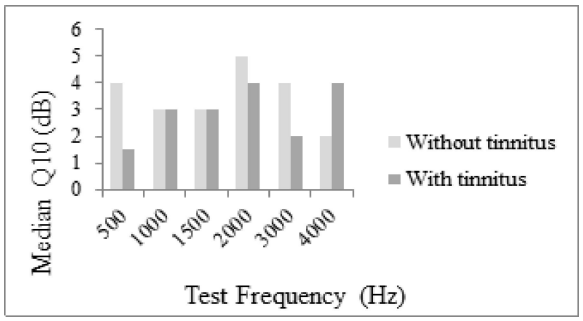

Figure 4: Median for Q10 values of PTC for Group 1 and Group 2.

To compare results of Q10 values of PTC in mild SNHL with and without tinnitus a Mann Whitney U test was carried out. Results showed no significant difference in Q10 value between two groups (p>0.05) except at Q10 value of 3000 Hz (p<0.05). Table 9 shows the /Z/ value and level of significance obtained on Mann Whitney U test for comparison of Q10 value.

Table 8: Median and range for Q10 values of PTC for Group 1 and Group 2

Frequencies (Hz)	Median (dB)		Minimum (dB)		Maximum (dB)	
	Group 1	Group 2	Group 1	Group 2	Group 1	Group 2
500	4.00 (5)	1.50 (4)	2.00	1.00	6.00	4.00
1000	3.00 (3)	3.00 (4)	3.00	2.00	4.00	4.00
1500	3.00 (4)	3.00 (3)	2.00	2.00	4.00	3.00
2000	5.00 (3)	4.00 (3)	4.00	2.00	5.00	4.00
3000	4.00 (3)	2.00 (3)	4.00	2.00	5.00	3.00
4000	2.00 (3)	4.00 (1)	1.00	4.00	2.00	4.00

Note: N given in parenthesis

Table 9: /Z/ value and level of significance obtained on Mann Whitney U test for Q10 comparison

Q10 (Hz)	500	1000	1500	2000	3000	4000
/Z/	1.634	0.592	0.592	1.650	2.023	1.414
Level of significances	p>0.05	p>0.05	p>0.05	p>0.05	p<0.05	p>0.05

b) Tip frequency: Descriptive statistics was carried out to find the median and range for tip frequencies. It was found that median was similar between both groups across all frequencies. The median and range for tip frequencies of PTC for Group 1 and group 2 are shown in the Table 10.

Table 10: Median and range for tip frequencies of PTC for Group 1 and Group 2

Frequencies(Hz)	Median (dB)		Minimum (dB)		Maximum (dB)	
	Group 1	Group 2	Group 1	Group 2	Group 1	Group 2
500	563 (5)	474 (4)	473	406	592	520
1000	1040 (3)	1109 (4)	1033	1041	1100	1118
1500	1518 (4)	1637 (3)	1484	1553	1578	1740
2000	2143 (3)	2168 (3)	2117	2117	2143	2189
3000	3194 (3)	2886 (3)	3046	2763	3316	3398
4000	3755 (3)	3188 (1)	3729	3188	4517	3188

Note: N given in parenthesis

Mann Whitney U test was carried out to compare results of tip frequencies of PTC in mild SNHL with and without tinnitus. Results showed no significant difference in tip frequency between two groups (p>0.05).

4.1.2.2. TEN test: Descriptive statistics was carried out to find the median and range for TEN masked threshold in individuals having mild SNHL without tinnitus (Group 1) and with tinnitus (Group 2). It was found that median was similar between both groups across all frequencies. The median and range for TEN masked threshold for Group 1 and group 2 are shown in the Table 11.

Table 11: The median and range for TEN masked thresholds for Group 1 and group 2

frequencies (Hz)	Median (dB)		Minimum (dB)		Maximum (dB)	
	Group 1	Group 2	Group 1	Group 2	Group 1	Group 2
500	6.00 (5)	4.00 (5)	4.00	4.00	8.00	10.00
750	4.00 (5)	4.00 (5)	4.00	2.00	6.00	8.00
1000	6.00 (5)	6.00 (5)	4.00	2.00	8.00	8.00
1500	4.00 (5)	6.00 (5)	4.00	2.00	6.00	8.00
2000	4.00 (5)	4.00 (5)	4.00	2.00	4.00	4.00
3000	6.00 (5)	4.00 (5)	4.00	4.00	8.00	8.00
4000	8.00 (5)	8.00 (5)	4.00	6.00	8.00	10.00

Note: N given in parenthesis

To compare the results of TEN test in individual with mild SNHL a Mann Whitney U test was carried. Results showed no significant difference in TEN masked threshold between two groups (p>0.05).

4.1.2.3. ECochG: Descriptive statistics was carried out to find the median and range for latency and amplitude of cochlear microphonics in individuals having mild SNHL. It was found that median was similar between both groups for latency and amplitude of cochlear microphonics. The median and range for latency and amplitude of cochlear microphonics for Group 1 and Group 2 are shown in the Table 12.

Table 12: The median and range for latency and amplitude of cochlear microphonics for Group 1 and group 2

	Median		Minimum		Maximum	
CM	Group 1	Group 2	Group 1	Group 2	Group 1	Group 2
Latency (ms)	1.03 (5)	1.07 (5)	0.86	0.66	1.16	1.16
Amplitude (μv)	0.21 (5)	0.22 (5)	0.12	0.16	0.38	0.27

Note: N given in parenthesis

To compare results of ECochG results in mild with and without tinnitus a Mann Whitney U test was carried out. The cochlear microphonics latency and amplitude were analysed using Mann Whitney U to look for any difference between Group 1 and Group 2. Results showed no significant difference in cochlear microphonics latency and amplitude between two groups ($p>0.05$).

4.1.3. Moderate hearing loss.

The results of PTCs, TEN test and ECochG between Group 1 and Group 2 are discussed under the following headings.

4.1.3.1. Psychophysical tuning curves.

a) Q10 values. Descriptive statistics was carried out to find the median and range of Q10 values in individuals having moderate SNHL without tinnitus (Group 1) and with tinnitus (Group 2). The Q10 values could not obtained in most of the frequencies in individuals having SNHL without tinnitus (Group 1). Median and range values are given in Table 13.

Table 13: Median and range for Q10 values of PTC for Group 1 and Group 2

Frequencies (Hz)	Median (dB)		Minimum (dB)		Maximum (dB)	
	Group 1	Group 2	Group 1	Group 2	Group 1	Group 2
500	- (0)	4.00 (1)	-	4.00	-	4.00
1000	- (0)	3.50 (2)	-	3.00	-	4.00
1500	- (0)	3.00 (3)	-	3.00	-	3.00
2000	- (0)	3.50 (2)	-	3.00	-	4.00
3000	2.00 (1)	3.50 (4)	2.00	2.00	2.00	6.00
4000	1.00 (1)	2.00 (3)	1.00	2.00	1.00	3.00

Note: N given in parenthesis

To compare results Q10 values of PTC in moderate SNHL with and without tinnitus, a Mann Whitney U test was carried out. In many of the individuals with moderate hearing, Q10 value could not be obtained for the frequency 500 Hz, 1000 Hz, 1500 Hz and 2000 Hz, therefore Mann Whitney U test could not be performed for these parameters. The Q10 value for the frequency 3000 Hz and 4000 Hz were analysed to see the difference between Group 1 and Group 2. Results showed no significant difference in Q10 value between two groups ($p>0.05$).

b) Tip frequencies. Descriptive statistics was carried out to find the median and range for tip frequencies. The tip frequency could not obtained in most of the frequencies in individuals having SNHL without tinnitus (Group 1). Median and range values are given in table 14.

Table 14: Median and range for tip frequencies of PTC for Group 1 and Group 2

Frequencies	Median (dB)		Minimum (dB)		Maximum (dB)	
(Hz)	Group 1	Group 2	Group 1	Group 2	Group 1	Group 2
500	- (0)	499 (1)	-	499	-	499
1000	- (0)	1006 (2)	-	953	-	1059
1500	- (0)	1516 (3)	-	1428	-	1903
2000	- (0)	1964 (2)	-	1886	-	2041
3000	3066 (1)	3142 (4)	3066	2936	3066	3592
4000	3364 (1)	3563 (3)	3364	3306	3364	4720

Note: N given in parenthesis

To compare results of tip frequencies of PTC in moderate SNHL with and without tinnitus, a Mann Whitney U test was carried out. In many of the individuals with moderate hearing, tip frequency could not be obtained for the frequency 500 Hz, 1000 Hz, 1500 Hz and 2000 Hz, therefore Mann Whitney U test could not be performed for few parameters. In those frequencies where comparisons were possible, results showed no significant difference in tip frequencies between two groups ($p>0.05$).

4.1.3.2. TEN test. Descriptive statistics was carried out to find the median and range for TEN masked threshold in individuals having moderate SNHL without tinnitus (Group 1) and with tinnitus (Group 2). It was found that median was similar between both groups across all frequencies. The median and range for TEN masked threshold for Group 1 and group 2 are shown in the table 15. It can be seen from the figure 5, median of TEN masked threshold was greater Group 1 compare to Group 2.

Table 15: The median and range for TEN masked thresholds for Group 1 and group 2

Frequencies (Hz)	Median (dB)		Minimum (dB)		Maximum (dB)	
	Group 1	Group 2	Group 1	Group 2	Group 1	Group 2
500	4.00 (5)	8.00 (5)	4.00	6.00	10.00	10.00
750	6.00 (5)	6.00 (5)	4.00	4.00	6.00	8.00
1000	6.00 (5)	6.00 (5)	2.00	4.00	8.00	6.00
1500	8.00 (5)	4.00 (5)	6.00	2.00	8.00	10.00
2000	8.00 (5)	4.00 (5)	6.00	4.00	10.00	6.00
3000	8.00 (5)	6.00 (5)	6.00	4.00	12.00	10.00
4000	12.00 (5)	8.00 (5)	8.00	6.00	12.00	12.00

Note: N given in parenthesis

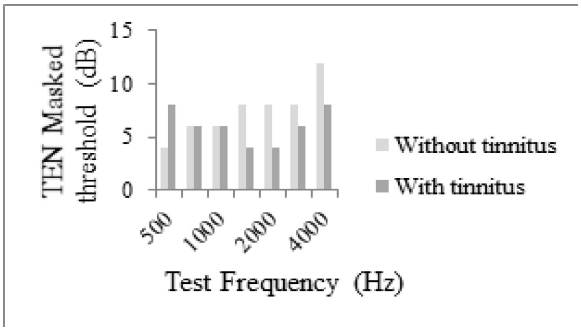

Figure 5: The median for TEN masked thresholds for Group 1 and group 2.

To compare the results of TEN test in individuals with moderate SNHL, Mann Whitney U test was carried out. Results showed no significant difference in TEN masked threshold between two groups ($p>0.05$), except for Ten 2000 Hz ($p<0.05$). The /Z/ and p values obtained on Mann Whitney U test for comparison TEN masked threshold is given in Table 16.

4.1.3.3. EcochG. Descriptive statistics was carried out to find the median and range for latency and amplitude of cochlear microphonics in individuals having moderate SNHL without tinnitus (Group 1) and with tinnitus (Group 2). It was found that median was similar between both groups for latency and amplitude of cochlear microphonics. The median and range for latency and amplitude of cochlear microphonics for Group 1 and Group 2 are shown in the Table 17.

To compare results of ECochG results in moderate SNHL with and without tinnitus, Mann Whitney U test was carried out. The latency and amplitude of cochlear microphonics were analysed by using Mann Whitney U to study the difference between Group 1 and Group 2. Results showed no significant difference in cochlear microphonics latency and amplitude ($p>0.05$).

4.2. PTC, ECochG and TEN test results in individual with tinnitus.

To study the difference in PTC, ECochG and TEN test results across different degrees of hearing loss (objective 2 of the study), Kruskal Wallis test was performed and result revealed no significant difference found across different degree of hearing loss in SNHL individuals with tinnitus for comparison of Q10 values of PTCs, tip frequency of PTC, TEN masked threshold and CM latency and amplitude. The level of significance was greater than 0.05 for all the parameters.

Summary of results: The results of the first objective revealed significant difference in Q10 values of PTC at

Table 16: /Z/ value and level of significance obtained on Mann Whitney U test for comparison of TEN masked threshold.

Frequencies (Hz)	500	750	1000	1500	2000	3000	4000
/Z/	1.078	0.346	0.438	1.611	2.479	1.708	1.017
Level of significances	p>0.05	p>0.05	p>0.05	p>0.05	p<0.05	p>0.05	p>0.05

Table 17: The median and range for latency and amplitude of cochlear microphonics for Group 1 and group 2

	Median		Minimum		Maximum	
	Group 1	Group 2	Group 1	Group 2	Group 1	Group 2
CM latency(ms)	1.11 (1)	0.99 (4)	1.11	0.81	1.11	1.16
CM amplitude(μv)	0.29 (1)	0.15 (4)	0.29	0.06	0.29	0.31

Note: N given in parenthesis

4000Hz and 3000Hz in minimal and mid hearing loss respectively and Q10 values did not show any difference in moderate hearing loss between individuals with and without tinnitus. Results of tip frequency of PTC showed no significant difference across degrees of hearing loss between individuals with and without tinnitus. TEN test also showed no difference in TEN masked threshold in individuals with and without tinnitus across degrees of hearing loss except at 2000 Hz in moderate hearing loss.

The results of ECochG showed a significant difference in CM amplitude only in minimal hearing loss and CM latency showed no difference across degrees of hearing loss in individuals with and without tinnitus.

The results of second objective revealed no significant difference in PTC, TEN test and ECochG across degrees of hearing loss in individuals with tinnitus. Whereas, when the data were combined across degrees of hearing loss and comparison was made between the group, results showed significance difference in Q10 value at 500 Hz and 2000 Hz and CM amplitude irrespective of degrees of hearing loss.

Discussion

The purpose of the present study is to compare the cochlear function in individual without and with tinnitus. The outcomes of the experiment were discussed in following headings.

5.1. PTC, ECochG and TEN test in individual having sensorineural hearing loss without and with tinnitus across different degree of hearing loss.

5.1.1. PTC result across different degrees of hearing loss.

a) Q10. On comparison of Q10 values in individuals with and without tinnitus across degrees of hearing loss, it was found that there was no significant difference between the group except at 4000 Hz in minimal and at 3000 Hz in individuals having mild degree of SNHL. But, it was seen that Q10 was lower for individuals with tinnitus compare to individual without tinnitus, which indicates poorer frequency resolution in OHC of individuals with tinnitus compared to those without tinnitus.

Literature shows, more of OHC dysfunction in individuals with tinnitus and IHC being intact. A study done by Shiomi, Tsuji, Naito, Fujiki and Yamamoto (1997) found significant decreases in DPOAE amplitude over a limited frequency range in DP- gram in individuals with tinnitus compared to individuals without tinnitus with normal hearing, also moderate correlation were found between DPOAE amplitudes and hearing levels. Reduction in DPOAE amplitude directly indicated OHC dysfunction in these individuals. Mitchell and Creedon (1995) also found irregularity in PTC curve in individuals with tinnitus and these irregularities included hypersensitive tail and elevated tips in individuals with tinnitus compare to individuals without tinnitus indicating OHC dysfunction in individuals with tinnitus without IHC or nerve damage.

A study done by Zhou et al. (2011) reported that, subjects with tinnitus had elevated thresholds, reduced DPOAE, and increased slope of the DPOAE input-output function in high frequency region ranging from 4000 Hz to 10000 Hz. Also, elevation in the perceptual threshold correlated with the tinnitus rating and this was indicated reduced amplitude in DPOAE in those frequency regions, which suggest impaired cochlear functioning in individual with tinnitus. In the present study, it has been seen that individuals with tinnitus had lower Q10 values, which directly reflects the broadening of the auditory filter. To draw support for these findings; Dauman and Cazals (1989) indicated that frequency selectivity in individuals was abnormally affected. They could clearly identify broadening of frequency selectivity in individual with tinnitus having bilateral hearing loss and also they reported broadening was more in the ear with the tinnitus than the ear without tinnitus, which strongly suggests tinnitus originates in the cochlea and outer hair cell are site of generation for tinnitus.

There are contradicting studies which reports IHCs being affected in individuals with tinnitus rather than OHCs. A recent study done by Tan et al. (2013) reported the presence of off frequency listening (phenomenon which results when there is intact OHCs and non-function IHC) and better frequency selectivity in individuals with tinnitus compare to individuals without tinnitus. They also report changes observed between these individuals were relatively minor and the involvement of OHCs dysfunction cannot rule out completely.

In the present study, most of the individuals with moderate hearing loss, PTCs obtained were relatively flat and lacked in tip. Therefore Q10 and tip frequency could not be obtained in these individuals. In the present study, Q10 values for only 3000 Hz and 4000 Hz could be compared between the group (due to small N) and no significant result was found between the groups. But Q10 was present in most of the individual with tinnitus (15) when compare to individuals without tinnitus (2) in moderate hearing loss. The reason can attribute to the absolute threshold of individuals. Most of the individuals with tinnitus had threshold within 50 dB (mean threshold of 47.48 dB) where as individuals without tinnitus had threshold more than 50 dB (mean threshold of 51.74 dB).

Many other studies in literature also reports of difficulty measuring Q10 value in moderate degree of hearing loss. A study done by Tan et al. (2013) reported that Q10 value were difficult to obtain since PTCs obtained were flat or inverted in some instance, as the threshold increases. Further, Smith et al (1987) reported that, with

increases in threshold of up to 30-40 dBHL, there was a selective elevation and broadening of the tip region in the PTC response. Once the threshold is 50 dBHL or greater the tip response was completely absent. This suggests that, threshold of greater than 40-50 dBHL is a results in of complete removal of OHC functioning. Nelson (1991) also found abnormally broader PTCs in individuals with coclear hearing loss, indicating cochlear hearing loss of greater than 40 dBHL influence the sharp tuning capabilities usually associated with outer hair cell function.

b) Tip frequency. The result of tip frequency between individual with and without tinnitus showed no significant difference across all degrees of hearing loss. Since shift in the tip frequency indicates the presence of dead region; in the present study there no such shift in the test frequencies found, which indicates the presence of the intact IHC in these individual. Also, the results of tip frequencies of PTC showed no change between the groups; again might be indicating IHCs are least susceptible to damage compare to OHCs (Hawkins, 1973; Jastreboff, 1990; Thabet, 2009).

The overall finding of the PTC indicated presence of OHC damage and intact IHCs in both the group, but the extent of damage was more in individuals with tinnitus compared to without tinnitus. Individuals with tinnitus showed less shaper tuning curve when compared to individuals without tinnitus (who showed sharper tuning curve) which was estimated through Q10. Also, it was found that there was no shift in the tip frequency which indicates presences of functional IHCs in both individuals.

5.1.2. TEN test.

The results of TEN obtained from the present study indicated no change in TEN masked threshold in individuals with tinnitus and without tinnitus in minimal and mild hearing loss. Similar result were obtained in a study done by Thabet (2009), wherein he reported that in individuals with tinnitus had abnormal TEOAEs; and only 15% of the individuals with tinnitus had dead region which was estimated through TEN test. This might be attributed to increased resistance of IHCs to damage compared to OHCs vulnerability.

The results of the TEN test indicated increased masked threshold in individuals without tinnitus compare to with tinnitus in moderate hearing loss. It was found that result was significant at only 2000 Hz, but TEN masked thresholds were within 10 dB of the TEN level at 2000 Hz again indicating presence of no dead region. Most of the studies in literature have shown presence of dead region when the absolute threshold was greater than 70 dBHL. (Aazh & Moore, 2007; Vinay & Moore, 2007b). Since in the present study has included only individuals with absolute threshold less than 55 dBHL, presence of dead region was not seen.

To summarise the results of TEN test, there was no dead region found in both the groups across degrees of hearing loss which could be attributed to the fact that the peripheral hearing sensitivity was not beyond 55 dBHL to have a definite IHC damage.

5.1.3. ECochG.

The result of the EChcoG showed the higher amplitude for cochlear microphonics in individuals without tinnitus than with tinnitus in minimal hearing loss, whereas no significant results were found in mild and moderate hearing loss. The latency of CM showed no significant difference between both the groups across degrees of hearing loss. The presence of cochlear microphonic is a good indicator of OHC functioning (Yoshie & Yamaura, 1969; Elberling & Salomon, 1973; Eggermont, 1976). In the present study it was seen that cochlear microphonic amplitudes are lesser in individuals with tinnitus, again indicating poorer functioning of OHC in individuals with tinnitus.

In the present study, most of the individuals (4) with tinnitus had CM present than individuals without tinnitus (1) again, could be attributed to absolute threshold of individuals. Most of the individuals with tinnitus had threshold less than 50 dBHL compare to individuals without tinnitus whose thresholds were greater than 50 dBHL. There are few studies done on effect of hearing loss on cochlear microphonics. One of such study done by Davis et al. (1989) reported about 25% of the OHC loss along the cochlear partition will result in reduction of CM potential by 25%.

All the findings in the present study indicate poorer functioning of OHCs in individuals with tinnitus than without tinnitus. The finding of all results can be summarised in terms of functioning of OHCs. In the present study it was found that lower Q10 values and lower amplitude of CM in individuals with tinnitus which directly indicate poorer functioning of OHC in individuals with tinnitus and results of tip frequency and TEN test showed normal functioning of IHCs. Thus, we can infer from the overall findings that OHC dysfunction is profound in individuals with tinnitus than damage seen at IHCs; this suggests that OHCs may be the site for generation for tinnitus.

4.2. PTC, ECochG and TEN test results in individual with tinnitus.

The result of PTC revealed no significant difference in all parameter across degree of hearing loss in individuals with tinnitus. Although it showed no difference across degrees of hearing loss, it was found that the number individuals in which PTCs obtained varied across different degrees of hearing loss. The total number of PTCs obtained in minimal, mild and moderate hearing loss was 26, 18 and 15 respectively (including all the test frequencies/parameters). As the loss increased from

minimal to moderate, the sharpness of tip of PTCs were reduced and PTC was more flat. Tip frequency and TEN results did not show any difference across degrees of hearing loss within individuals with tinnitus, indicating absence of dead region irrespective of degrees of hearing loss. The results of EcochG showed no difference in CM amplitude and latency across degrees of hearing loss. However, it was shown that in individuals with minimal hearing loss the CM amplitude was relatively less, which indicants poorer functioning of OHCs at the initials stages of hearing loss. It was also seen that CM was present only 4 individuals with moderate hearing loss, which can be attributed to greater extent of OHC dysfunction in individuals with moderate loss.

To summarise the results of second objective; the function of OHCs reduces as the loss progresses from minimal to moderate hearing loss.

Thus, it can be concluded from the present study that OHCs are more affected in individuals with tinnitus than in individuals without tinnitus. Also, normal functioning of IHCs in individuals with tinnitus were seen, which suggests that OHCs are the probable site of generator for tinnitus.

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