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Original Research Article

Psychophysical Tuning Curves and Extended High Frequency Audiometry Findings in Individuals with Normal Hearing Having Tinnitus

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ABSTRACT

Tinnitus is one of the most common problems confronted in routine audiology practices. The occurrence of tinnitus in the absence of audiometrically detectable hearing loss poses a challenge to the clinicians as the exact pathophysiology behind this phenomenon is not clearly established. A detailed audiological assessment is essential as the origin of tinnitus can be at any level within auditory system. This study aimed at characterization of the psychophysical tuning curves (PTCs) and Extended High Frequency Audiometry (E-HFA) in individuals with normal hearing having tinnitus. The PTCs and E-HFA were administered on 20 adults with a complaint of tinnitus having normal hearing sensitivity and the results were compared with that of individuals with normal hearing sensitivity without tinnitus. The results showed no difference in Q_{10} values between the two groups. The tip frequencies of PTCs of individuals with tinnitus were significantly different from that of individuals without tinnitus at 4000 Hz and 6000 Hz; indicating a cochlear lesion. The E-HFA thresholds were elevated in individuals with tinnitus; which is suggestive of damage corresponding to these frequencies. Overall findings indicated the presence of pathology at the level of basilar membrane, which remained hidden in conventional audiometry; more likely to be inner hair cell damage at frequency regions corresponding to 4000 Hz and above on the basilar membrane. The study signifies the inclusion of PTCs and E-HFA in individuals with tinnitus so as to track the underlying lesions which remain hidden in conventional audiometry.

Key words: Tinnitus, Normal hearing, Psychophysical Tuning Curves, Extended High Frequency Audiometry.

INTRODUCTION

Tinnitus is defined as the perception of sounds in the absence of any external stimulus. It is one among the most common problems confronted in routine audiology practices. It occurs in an estimated 10-15% population. [(1,2)] Regardless of years of research in the field of tinnitus and a rapid development in the understanding of auditory system, the phenomenon of origin of tinnitus is still a mystery. Various causes for the development of tinnitus are reported so far; hearing impairment being the major factor. Hearing impairment or any other pathology of auditory nerve leads to deprivation of signals to the central auditory structures, triggering a sequence of reactions in the central nervous system, leading to tinnitus. Not all incidences of tinnitus are directly associated with evident pathologies of auditory system. The fact that individuals with normal hearing sensitivity can have tinnitus clearly suggests that tinnitus is not always associated with hearing loss. [(3,4)] At the same time, normal hearing thresholds need not always be an indicator of absence of cochlear pathology. Individuals with normal conventional audiograms presented with reduced amplitude of the I peak and normal amplitude of V peak of auditory brainstem responses. [4] This suggested the presence of an abnormal physiology, wherein there was a decreased neural output from the cochlear structures; but a re-normalization of neural response magnitude happening at the brainstem level. Evidences of cochlear dead regions, outer hair cell lesions, and elevated thresholds in the extended high frequency regions compared to control group are reported in case of individuals with tinnitus and normal audiometric thresholds, [5,6] suggesting the presence of some degree of hearing impairment. Thus, the conventional audiometric data does not provide sufficient information regarding the hidden auditory lesion perhaps present in tinnitus population with normal hearing sensitivity.

Studies on tinnitus pitch matching have revealed that tinnitus pitch is typically in high frequency region. [7] It was also postulated that tinnitus presented a certain bandwidth called ‘tinnitus spectrum’ which correlated with the frequency range of hearing loss. [7] Literature reports the presence of high frequency and extended high frequency hearing loss in individuals having tinnitus with normal hearing sensitivity. [8,9] So, the inclusion of E-HFA in the assessment battery of tinnitus possibly provides information regarding the sub-clinical damage of hair cell coding for frequencies above the conventional audiometric frequencies.

It has been assumed that tinnitus is frequently accompanied by damage of inner hair cells (IHCs) even without any measurable hearing loss in the audiometric frequencies. [10,5] Severely damaged IHCs can lead to deafferentation and thus forming dead regions within cochlea. Dead region is a region within the cochlea wherein the IHCs and/or neurons function poorly so that a tone which produces peak vibration in that particular region is detected by off-frequency. [11] To trace the presence of such off-frequency listening, psychophysical tuning curves (PTCs) can be employed. PTCs offer the most precise method for assessing the frequency limits of dead regions. [12,13] The edge frequency of the PTC is the boundary of the healthy inner hair cells. The PTCs plot the level of a narrow-band masker required to mask a fixed sinusoidal signal, as a function of masker frequency. The PTC indicates best response of the auditory nerve fibers; and thus better thresholds at the characteristic frequency of the fibers and at frequencies immediately adjacent to it. [14] The common quantitative measures of PTC shape include Q_{10} and tip of the curve. The Q_{10} represents the sharpness of tuning of a filter. A PTC tip shifted downward in frequency, suggests a high-frequency dead region starting at the frequency of the shifted tip. A tip that is shifted upward in frequency, suggest a low frequency cochlear dead region, whose upper edge lies at the tip frequency of the PTC. [15] In spite of its diagnostic value, the conventional method of assessing PTCs is a time consuming procedure which limits its application in routine audiology practice. It requires at least two hours establishing the PTCs at four frequencies. The ‘fast PTC’ (fPTC) [15] offers a quick way to assess the quantitative measures of PTCs. Further, with the implementation of software in assessing fPTCs, the testing time has drastically reduced to three minutes for a single frequency under test. The software PTC (SWPTC) [16] assessment offers the best way to assess the cochlear hair cells on a routine basis at the clinic which utilizes fPTC principle.

Aims and Objectives

The study aimed at characterizing the findings of PTC and E-HFA in individuals with tinnitus having normal audiometric presentation.

Participants

Two groups of participants were involved in this study. Group 1 consisted of 20 individuals (10 males, 10 females) having tinnitus as their primary complaint with normal hearing sensitivity, in the age range from 20 to 48 years (mean age = 33.15 years, SD = 9.80 years). Group 2 comprised of 20 individuals (10 males, 10 females) with normal hearing in the age range from 18 to 22 years (mean age = 20.50 years, SD = 1.79 years).

All the participants in Group 1 and 2 had air- and bone- conduction hearing thresholds within 20 dB HL across the frequency range from 250 Hz to 8000 Hz. The test ears had speech identification scores greater than 90% and 'A' type tympanogram with normal acoustic reflexes. The participants had no history of any middle ear pathologies, usage of ototoxic drugs or considerable exposure to high levels of noise. The participants of Group I had complaint of continuous tinnitus lasting for a period of three months; with a score of greater than 38 (moderate tinnitus) as per Tinnitus Handicap Inventory (THI). [17] While, none of the participants in Group 2 complained of tinnitus.

MATERIALS AND METHODS

After obtaining written consent from the participants, a detailed case history was taken from the participants of Group 1. Following this, audiological evaluation was carried out to estimate the air-conduction thresholds between 250 Hz and 8000 Hz and bone-conduction thresholds from 250 Hz to 4000 Hz using a calibrated diagnostic audiometer. Sennheiser HDA-200 headphones were used to establish the E-HFA thresholds at 10000 Hz, 12500 Hz, 14000 Hz and 16000 Hz. The modified Hughson-Westlake procedure [18] was used to find out the behavioral thresholds. The Speech Identification Scores were obtained at 40 dB SL (re: Speech Recognition Threshold) with Phonemically Balanced Kannada Word Test. [19]

The tympanograms and acoustic reflex thresholds, both ipsilateral and contralateral, were obtained with 226 Hz probe tone to rule out normal middle ear functioning. The THI questionnaire was administered on participants in Group 1 to find out the nature of tinnitus.

The software PTC (SWPTC, version 1.4.50.1) [16] was used to obtain the psychophysical tuning curves using pure tones at 500 Hz, 1000 Hz, 2000 Hz, 4000 Hz and 6000 Hz. The signal duration at each frequency was maintained at 0.2 second; with an interval of 0.2 second between the pulses. The level of the signal was 10 dBSL (re: absolute thresholds in dB SPL at the test frequencies) which was selected based on the pure tone thresholds of the participants at the frequencies mentioned above. The noise used for masking was swept in forward sweeping manner with a rate of change of 2 dB/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. Further, an additional low pass noise of 200 Hz at 40dB SPL was delivered during the measurement to prevent this band from providing listening cues, since the individuals were having normal audiometric thresholds at this frequency. At 500 Hz, 1000 Hz, 2000 Hz, 4000 Hz and 6000 Hz, the Q_{10} values and the tip frequencies were measured, analyzed and compared between the two groups.

RESULTS

The data collected from 40 ears with normal hearing (20ears with tinnitus and 20 without tinnitus) were analyzed using the statistical package for social sciences (SPSS, version 21). Shapiro-Wilk's test was administered to check for normality of data. The normal distribution of data was seen only for Q_{10} ($p<0.05$) and hence parametric test was administered for the same to look for any significant differences between the two groups. Non-parametric test was administered for the data on PTC tip frequency and E-HFA as data did not follow a normal distribution ($p>0.05$). This variability was accounted for the heterogeneity in the participants of the study.

Comparison of Q_{10} values of PTCs between Group1 and Group 2

Descriptive statistics to find out the mean and standard deviation (SD) was carried out for Group 1 and Group 2.The mean and SD of Q_{10} values were obtained for Groups 1 and 2 and are given in Table 1.

Table 1: The mean and SD of Q_{10} values for Group 1 and 2

	Frequency				
Stimulus Frequency	**500 Hz**	**1000 Hz**	**2000 Hz**	**4000 Hz**	**6000 Hz**
Group 1	2.92 (0.421)	3.275 (0.701)	3.44 (0.919)	3.99 (1.019)	4.39 (1.406)
Group 2	2.71 (0.444)	3.07 (0.670)	3.755 (0.638)	4.01 (0.993)	4.725 (1.087)

Note: SD given in parenthesis

Further, Multivariate analysis of variance (MANOVA) was carried out to investigate the difference in Q_{10}between Group 1 and Group 2. The F and p value for 500 Hz stimulus is $F(1, 33)=1.344, p> 0.05$; for 1000 Hz is $F(1, 33)=0.690, p> 0.05$; for 2000 Hz is $F(1, 33)=1.586, p>0.05$; for 4000 Hz is $F(1, 33)=0.052, p>0.05$ and for 6000 Hz is $F(1, 33)=0.677, p>0.05$. Thus, there was no significant difference in the Q_{10} values between the groups.

Comparison of tip frequencies of PTCs between Group1 and Group 2

Descriptive statistics to find out mean and SD was done for Group 1 and Group 2 to investigate the difference in tip frequencies of PTCs at 500 Hz, 1000 Hz, 2000 Hz, 4000 Hz and 6000 Hz. The mean and SD of tip frequencies obtained in Group 1 and 2 are given in Table 2. Further, the tip frequencies obtained at different signal frequencies for participants in Groups 1 and 2 are given in Figure 1.

Table 2: The mean and SD of tip frequencies obtained in Group 1 and 2

	Frequency				
Stimulus Frequency	**500 Hz**	**1000 Hz**	**2000 Hz**	**4000 Hz**	**6000 Hz**
Group 1	547.45 (40.92)	1063.00 (80.31)	2095.90 (86.55)	4383.65 (265.22)	6345.52 (380.24)
Group 2	532.30 (50.33)	1048.55 (40.98)	2088.20 (65.46)	4189.60 (118.16)	6103.60 (139.19)

Note: SD given in parenthesis

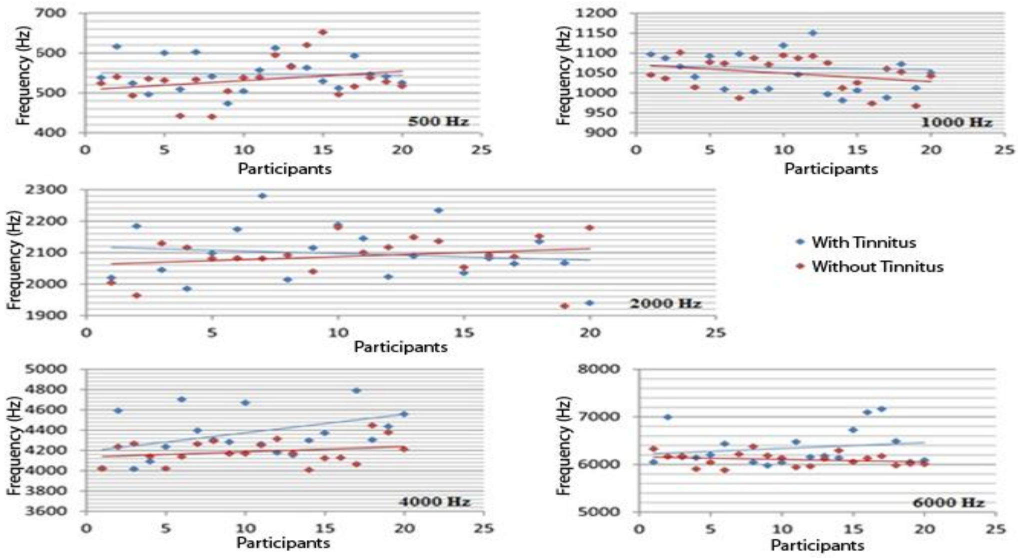

Figure 1: Tip Frequencies of PTCs in individuals with and without tinnitus (a representation of data obtained from all the participants in the study)

Mann Whitney-U test was performed to investigate the difference between the tip frequencies of PTCs between the two groups. Z and p values obtained in Mann Whitney U test is given in Table 3.

Table 3: Z and p values obtained on Mann Whitney-U test for comparison of tip frequency

	Z values and level of significance(p)				
	500 Hz	**1000 Hz**	**2000 Hz**	**4000 Hz**	**6000 Hz**
Group 1 vs. Group2	1.177, $p>0.05$	0.081, $p>0.05$	0.068, $p>0.05$	2.610, $p<0.05$	2.037, $p<0.05$

Comparison of E-HFA thresholds of Group1 and Group 2

The mean and SD from the descriptive statistics done for Group 1 and Group 2 to investigate the behavioral thresholds at 10000 Hz, 12500 Hz, 14000 Hz and 16000 Hz is given in Table 4.

Table 4: The mean and SD of E-HFA thresholds obtained in Group 1 and Group 2

	Frequency			
	10000 Hz	**12500 Hz**	**14000 Hz**	**16000 Hz**
Group 1	9.750 (10.82)	23.500 (18.43)	33.250 (19.82)	30.250 (19.50)
Group 2	0.250 (6.97)	5.750 (12.70)	7.000 (16.65)	17.750 (13.12)

Note: SD given in parenthesis

Mann Whitney-U test was performed to examine the difference between the groups in E-HFA thresholds.

The Z and p values obtained on Mann Whitney-U test are given in Table 5.

E-HFA thresholds obtained at different frequencies for the participants in Group 1 and Group 2 are given in Figure 2.

Table 5: Z and p values obtained on Mann-Whitney U test for E-HFA thresholds.

	Z values and level of significance			
	10000 Hz	**12500 Hz**	**14000 Hz**	**16000 Hz**
Group 1 vs. Group2	3.316, P<0.05	3.447, P<0.05	3.760, P<0.05	2.411, P<0.05

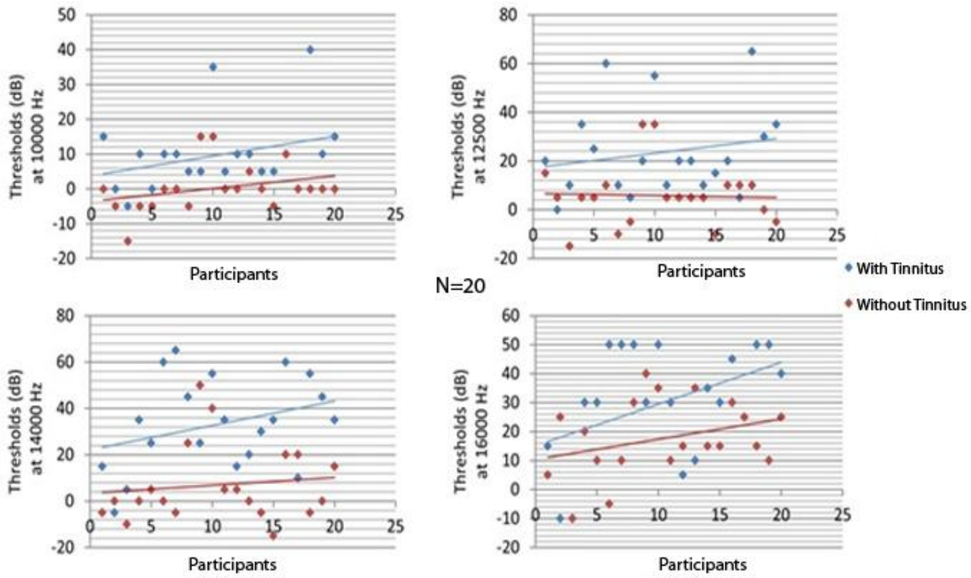

Figure 2: E-HFA thresholds of individuals with and without tinnitus (a representation of data obtained from all the participants in the study)

DISCUSSION

The study aimed at characterizing the findings of PTC and E-HFA in individuals with tinnitus having normal audiometric presentation. The PTCs bear a close resemblance to the tuning curves for single auditory nerve fibers and these behavioral functions are mainly determined by processes happening at the level of auditory periphery. [20] The Q_{10} value is a representation of the sharpness of tuning (selectivity) of the auditory filter. The results of SWPTC revealed that there was no statistically significant difference between the Q_{10} values of tinnitus and non-tinnitus group; across all test frequencies. This is an indication of unaltered frequency resolution of the auditory filters in both the groups. Another observation was the increment of Q_{10} values with test frequency; and the trend was noted in both the groups. This was more pronounced at higher characteristic frequencies (4000 Hz and 6000 Hz) relative to lower ones. This could be attributed to the increased density of medial olivocochlear bundle fiber innervations at higher frequencies. Due to these inherent structural asymmetries, the modulatory gain provided by medial olivocochlear fibers to the cochlea is relatively higher towards the basal portion of the basilar membrane. [21]

The tip frequency of a PTC gives information regarding the status of inner hair cells of the cochlea. In the present study, tip frequency values at 4000 Hz and 6000 Hz were significantly different between the two groups. The shift of tip towards high frequency side was more at these two frequencies in individuals with tinnitus; suggestive of abnormal physiology taking place at the level of inner hair cells. The shifted tip frequency of PTCs is the most significant difference between inner and outer hair cell damage. [22] Since the tip frequencies at 4000 Hz and 6000 Hz is shifted towards higher frequencies in the present study, the individuals with tinnitus possibly have lesion of inner hair cells towards area corresponding to the mentioned characteristic frequencies in the basilar membrane. This finding conforms to that reported by Florentine and Houtsma (1983), [22] the present study revealed a shift of tip frequency with unaltered tuning which suggests damage or loss of inner hair cells in the regions coding for 4000 Hz and above.

All the participants in the study had hearing thresholds within normal limits across frequencies from 250 to 8000 Hz. Statistically significant difference was observed in the E-HFA thresholds between the two groups and it was more pronounced at 14000 Hz; suggesting the possibility of peripheral lesion in areas corresponding to this frequency in the auditory system. This goes in accordance with the earlier finding of increased abnormalities in high frequency audiogram in individuals with tinnitus. [8] Individuals with tinnitus and normal conventional audiograms are reported to have frequent cochlear dead regions, [23] outer hair cell damage and worse hearing thresholds in the extended high frequency area. [24] The extended high frequency audiometry helps in diagnosing cochlear damage in the early stages and it can be used in the routine audiologic assessment in case of individuals with a risk of hearing loss. [25] Acute idiopathic sensorineural hearing impairment at high frequencies (above 8000 Hz) was reported in five patients suffering from acute tinnitus without hearing loss by Sakata (2010). [26] In light of these findings, the impaired high frequency thresholds of individuals with tinnitus in this study can be attributed to peripheral hearing impairment, resulting from lesions at the cochlear level. Our findings also confirm that the E-HFA is more sensitive for detecting hearing damage in comparison to the conventional audiometry. [27-29] The threshold variations above 8000 Hz provide valuable information regarding the cochlear status. So, even if the pure tone audiometric test reports show normal hearing sensitivity in the conventional audiometric frequencies, i.e., below 8,000 Hz, individuals with tinnitus should be evaluated for higher frequencies. Otherwise, the normal hearing thresholds obtained through conventional audiometry may be misleading.

CONCLUSION

The study aimed at characterizing the findings of PTC and E-HFA in individuals with tinnitus having normal audiometric presentation. The findings of Psychophysical Tuning Curves signify a peripheral damage at the level of basilar membrane, confined in the region of inner hair cells, particularly at the regions corresponding to 4000 Hz and above in individuals with tinnitus having normal audiometric presentation. Further, the extended high frequency audiometry findings also discovered elevated thresholds at higher frequency regions in the cochlea; these damages however were not revealed in the routine audiological evaluations. Overall findings indicate that there is pathology at the level of basilar membrane, which remained hidden in conventional audiometry; more likely is the damage to the inner hair cells at frequency regions corresponding to 4000 Hz and above. This study emphasizes the use of psychophysical tuning curves and extended high frequency audiometry in the test battery for diagnosing an individual with tinnitus having normal hearing, to understand the patho- physiology in the auditory structures.

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