

# Psychoacoustic characteristics of tinnitus in individuals with auditory neuropathy spectrum disorder

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## Abstract

The study aimed at understanding the psychoacoustic characteristics of tinnitus in individuals with auditory neuropathy spectrum disorder (ANSD). It attempts to assess the pitch and intensity of loudness of tinnitus matched by individuals with ANSD. Fifty individuals who were diagnosed as having auditory neuropathy spectrum disorder were included in the study. Tinnitus evaluation was carried out where the individuals matched the frequency and intensity of loudness of the tinnitus. The results of the study shows that pitch matched by majority of patients with ANSD is predominantly low pitched (<1000 Hz). The frequency of tinnitus matched by the patients with ANSD also correlated with the degree of maximal hearing loss. The intensity of loudness of the tinnitus was around 10-15 dB higher than their threshold in majority of the patients considered in the study. There was a weak negative correlation for the matched frequency and intensity of loudness. The results of the study suggest that majority of individuals with low frequency hearing loss had low pitched tinnitus. Thus, there could be discordant damage between outer and inner hair cells, abnormal firing of auditory nerve in individuals with ANSD which can lead to tinnitus.

Thus, it can help to understand the physiology of tinnitus in individuals with ANSD.

## Introduction

Auditory neuropathy spectrum disorder (ANSD) is a condition in which a patient's outer hair cells are normal [represented by normal otoacoustic emission (OAE) response/Cochlear microphonics] and an absent/abnormal auditory brainstem response (ABR) with fluctuating hearing loss.<sup>1-5</sup> The cause of ANSD is presumed to be at the inner hair cells, junction of the spiral ganglion cells and/or the auditory nerve.<sup>6,7</sup> ANSD is diagnosed based on multiple behavioral and electrophysiological tests (such as ABR, OAE, acoustic reflexes, word recognition scores, speech perception in noise, etc.).<sup>8</sup> Among the variety of symptoms reported by individuals with auditory neuropathy spectrum disorder, tinnitus can be one of the common complaints. The overall incidence rate of ANSD as reported varies from 11% to 0.54% of the hearing-impaired population.<sup>5,9,10</sup> Chandan *et al.*<sup>11</sup> reported that tinnitus is prevalent in of 67% of patients with ANSD. Prabhu *et al.*<sup>12</sup> reported that 83.3% (25 out of 30) of the participants of the study reported of tinnitus. Kumar and Jayaram<sup>10</sup> also reported 50% of the auditory dys-synchrony population had bilateral tinnitus. Thus, literature review suggests that most of the individuals with auditory neuropathy spectrum disorder reported difficulty in understanding speech, and tinnitus was found to be one of the complaints.<sup>10-12</sup> Tinnitus is the perception of sound by the listener in the absence of an external sound source.<sup>13</sup> In general population, tinnitus has been reported in approximately 10 to 15% of adults. The prevalence rate increases with age and gender, as more men than women report tinnitus, and in 1 to 2%, tinnitus is severe enough to impair daily life significantly.<sup>14</sup> Tinnitus can be a symptom of a variety of auditory disorders, but exact causal mechanisms are not well understood. In more than 95% of cases, the perceived tinnitus is purely subjective in nature. In individuals with persistent tinnitus complaints, the acoustical characteristics of the tinnitus (*e.g.*, loudness or pitch) are not univocally related to the severity of tinnitus or treatment outcome.<sup>15</sup> Only a weak relationship can be established between perceived psychoacoustic characteristics of the tinnitus (*e.g.*, loudness or pitch) and the severity of complaints since there can be individual variations in perception of loudness and pitch of tinnitus. Thus, the psychoacoustic characteristics cannot be used to determine the severity of tinnitus but may be useful in understanding the pathophysiology and causal mechanism of underlying condition.

The review of literature shows that there is limited number of studies regarding the nature and characteristics of tinnitus in individuals with ANSD.<sup>11</sup> Chandan *et al.*<sup>11</sup> reported that tinnitus is mostly bilateral (89.5%) and seen more often in females (70.52%) in individuals with ANSD. The subjective pitch was low-pitched in individuals with low frequency hearing loss and the perceived pitch was high with flat configuration of loss. There are no studies which explores the psychoacoustic

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characteristics of tinnitus in individuals with ANSD. Thus, it is necessary to know the psychoacoustic characteristics of tinnitus in individuals with ANSD. The present study tries to find the psychoacoustic characteristics of tinnitus among individuals with ANSD. It attempts to assess the pitch and intensity of loudness matched by individuals with ANSD.

## Materials and Methods

The study consisted of 50 individuals (19 males and 31 females) who were diagnosed as having ANSD. The mean age for males and females were 21.6 and 19.8 respectively. The participants were selected from individuals diagnosed as having ANSD in the Department of Audiology, All India Institute of Speech and Hearing between October 2007 and June 2013. Among the 109 clients diagnosed as ANSD, 50 participants who reported of the symptom of tinnitus were selected for the study. ANSD was diagnosed based on the criteria recommended by Starr *et al.*<sup>16</sup> They are preserved cochlear amplification, reflected by the presence of transient evoked otoacoustic emissions and/or cochlear microphones; altered auditory nerve responses as indicated by absent or severely abnormal auditory brainstem responses; and normal otologic and tympanometric findings with absent acoustic reflexes. A detailed neurological examination was carried out on all participants to rule out any space occupying lesion by a neurologist with a detailed clinical neurologic examination that also included the result from radiologic investigations such as computed tomography/magnetic resonance imaging.

## Procedure

All subjects were tested with calibrated audiometers in sound treated rooms. Pure-tone testing was done using modified Hughson and Westlake procedure.<sup>17</sup> The participants of the study had an average pure-tone thresholds (average of 0.5, 1, 2 kHz) ranging from 20 dB HL to 50 dB HL with symmetrical sensorineural hearing loss. Figure 1 shows the average pure-tone thresholds of individuals with ANSD across the octave frequencies ranging from 0.25 to 8 kHz. Speech identification testing was done with monitored live voice presentation of phonemically balanced Monosyllables or phonemically balanced word list in Kannada<sup>18</sup> at 40 dB SL (*re*: speech recognition threshold). The participants did not report of any symptoms of intolerance to loud sounds and the uncomfortable level was not reduced in any of the participants of the study. Immittance evaluation (tympanometry and acoustic reflex threshold testing) for a 226-Hz probe tone was carried out with a calibrated middle ear analyzer (GSI 33 or Tymstar V 2.0). The transient evoked otoacoustic emissions was measured from calibrated OAE analyzer (ILO 292 or ILO V6 DP Echoport) and Auditory brainstem response testing was done using Biologic Navigator or IHS Smart EP (Version: 3140) evoked

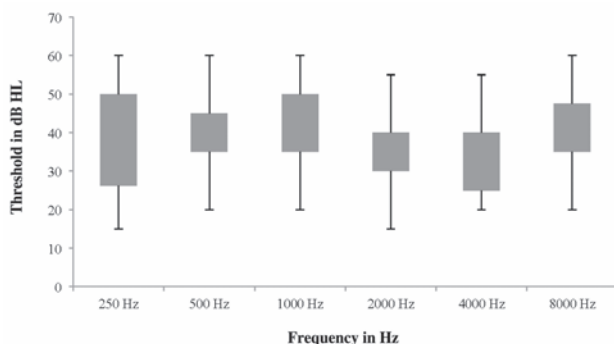


Figure 1. Audiogram of 50 individuals with auditory neuropathy spectrum disorder considered for the study. Tinnitus evaluation.

potential system. Identical protocol was used to test all the patients. The records confirmed that auditory brainstem testing was done twice to ensure reproducibility of waveforms. All the participants of the study reported tinnitus as one the complaint and as the routine test, the psychoacoustic characteristics of tinnitus (pitch and intensity of loudness) was obtained from all participants.

## Tinnitus pitch matching

For unilateral tinnitus, the ear with tinnitus was chosen as the test ear. For bilateral tinnitus with equal tinnitus loudness, right ear was chosen. For bilateral tinnitus with unequal tinnitus loudness, the ear with the loudest tinnitus was chosen. For pitch matching, frequencies were tested between 125 and 8000 Hz. Pitch matching was done using bracketing procedure starting from 1000 Hz. The participant was instructed to indicate whether the pitch was higher or lower than the tinnitus pitch. If the patient said *lower*, the tone was presented half an octave lower. The procedure was stopped when the tinnitus pitch was bracketed. The frequency at which the pitch was matched by the individuals, loudness of tinnitus was estimated. Octave confusion test was done to confirm the tinnitus frequency.

## Tinnitus loudness matching

The same procedure as described in pitch matching was employed to decide the test ear. The test tone was below the subject's threshold and only an ascending series of intensity levels was employed to minimize residual inhibition. The sound level is increased in small steps (1 dB) until the subject reports that the external tone is just equal to the loudness of the tinnitus.

## Results

The results of the study showed that majority of patients with ANSD had bilateral tinnitus. 86% (43 out of 50) of the patients reported of bilateral tinnitus and 14% (7 out of 50) had unilateral tinnitus. In addition, tinnitus was continuous and permanent in 72% (36 out of 50) of individuals and it was transient and fluctuating in 28% (14 out of 50) of the participants of the study. The result also shows that 76 % (38 out of 50) of individuals considered for the study had low pitched tinnitus (<1000 Hz) and 24% (12 out of 50) had high pitched tinnitus (>1000 Hz). Out of the 38 individuals, 20 individuals (40%) matched tinnitus at 250 Hz or 500 Hz and the remaining 18 individuals (36%) matched at 750 Hz or 1000 Hz. Six individuals (6%) matched the tinnitus between 1000 Hz to 2000 Hz and remaining six (6%) individuals matched the tinnitus at >2000 Hz. The above mentioned results are depicted in Figure 2. The overall mean tinnitus frequency was 1050 Hz

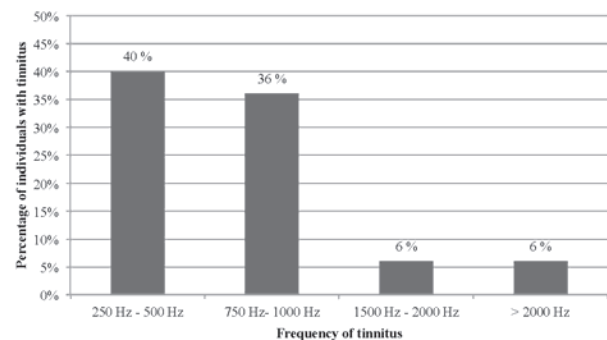


Figure 2. Pitch matching by 50 individuals with auditory neuropathy spectrum disorder with tinnitus.

with SD of 971 Hz. Out of the 50 individuals with ANSD, 38 had low frequency hearing loss (difference between threshold at 250 Hz and 1000 Hz more than 20 dB) and the tinnitus matched was also low pitched (<1000 Hz). The 12 individuals who matched their tinnitus to high frequency (>1000 Hz) had flat (difference between the thresholds is less than or equal to 10 dB) audiometric configuration.

The results of the study also show that the mean intensity of loudness of the tinnitus matched was 11.46 dB SL (SD of 4.67). The intensity of loudness of the tinnitus was less than 10 dB SL in 32% (16 out of 50) of patients, it was 10-15 dB SL in 58% (29 out of 50) and >15 dB SL in 10% (5 out of 50). The maximum intensity of loudness matched did not exceed 25 dB SL. The above mentioned results are depicted in Figure 3. Among the 38 individuals with ANSD with low frequency hearing loss, the mean intensity of loudness of tinnitus matched was 12.47 dB SL [standard deviation (SD)=4.60] and 12 individuals with flat loss, the matched tinnitus intensity of loudness was 8.25 dB SL (SD=3.36). It was attempted to analyze the correlation between the matched intensity of loudness and frequency of tinnitus using Karl Pearson's correlation coefficient. The result shows that there is a weak negative correlation ( $r = -0.358$ ) between the matched intensity of loudness and frequency. It shows that the intensity of loudness matched was higher for low frequencies relative to high frequencies. The results are shown graphically using a scatter plot in Figure 4.

## Discussion

An important outcome of this study is that most of the components of the tinnitus spectrum were matched in frequency ranges over which hearing thresholds were elevated in the individuals tested. This observation is consistent with the results of other studies reported in the literature which indicate that the pitch of tinnitus generally falls in the hearing loss range.<sup>19</sup> There are several theories that have been proposed to explain the above mentioned mechanism of tinnitus. One of the possible interpretation of this observation, proposed initially by Tonndorf<sup>20</sup> and Jastreboff,<sup>15</sup> is that tinnitus results from *discordant damage* between the inner and outer hair cells of the cochlea. Like the 'edge effect' hypothesis,<sup>21</sup> these interpretations predict that the pitch of tinnitus corresponds to the frequencies located relatively close to the frequency cut off. One of the site of lesion reported in individuals with ANSD are inner hair cells (IHC)<sup>3,6,7</sup> and also subtle damage at the level

of outer hair cells (OHC) with abnormal spontaneous otoacoustic emissions.<sup>22</sup> Narne *et al.*<sup>23</sup> did time frequency analysis of transient evoked otoacoustic emissions in individuals with ANSD and also reported subtle abnormality at the level of outer hair cells. Thus, the discordant damage between OHC and IHC in individuals with ANSD could be one of the possible reasons for matching the tinnitus at the frequency of maximal hearing loss.

Other models of tinnitus like the neural synchrony model suggest that tinnitus could possibly be generated by spontaneous synchronous neural activity that develops because of hyperactive neurons in the hearing loss region.<sup>24</sup> The outputs originating from these neurons is perceived in terms of their original sound as represented in the cochlea and gives the tinnitus percept, that would correspond to somewhere within the region of hearing loss. In individuals with ANSD, the common audiometric configuration found is the greater loss at low frequencies and a peak at around 2000 Hz.<sup>10</sup> This could be because low frequency information is usually coded by phase locked responses in Type I auditory nerve fibers<sup>25</sup> and individuals with ANSD cannot use phase locking cues to the same extent as normal-hearing listeners due to dys-synchronous discharges of auditory nerve fibers.<sup>26</sup> There are other models of tinnitus which also predicts that changes in the processing of neuronal activity occur predominantly in the frequency range of reduced sensory input, which finally results in ongoing increased neuronal activity and/or synchrony in the respective central auditory pathways.<sup>27</sup> Thus, according to these theories and explanations the frequency of tinnitus perception should correspond to the frequency of hearing loss.

The result of the study also shows that the intensity of loudness of tinnitus perceived was less than 25 dB SL in all the participants of the study. There was also a negative correlation indicating that the low frequency tinnitus was relatively louder than high frequency. The tinnitus could be perceived slightly louder at low frequency because of the central auditory system plasticity induced by peripheral damage.<sup>28</sup> The auditory neurons which were formerly excited by certain frequencies, and which are now deprived of peripheral inputs due to hearing loss at these frequencies, start to become responsive to neighboring frequencies. In addition, although neighboring neurons start responding they retain their 'perceptual qualities' that is there is no change in the perception of pitch.<sup>29</sup> The low frequencies are affected more and the high frequencies are relatively less affected in individuals with ANSD.<sup>26,30</sup> Thus, the high frequencies which are relatively less affected would probably take the role of firing for low frequency stimuli.

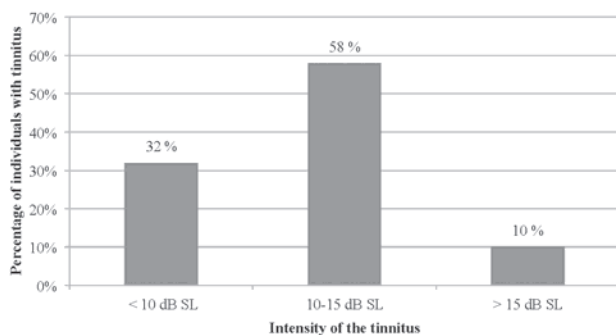


Figure 3. Intensity of loudness matching by 50 individuals with auditory neuropathy spectrum disorder with tinnitus.

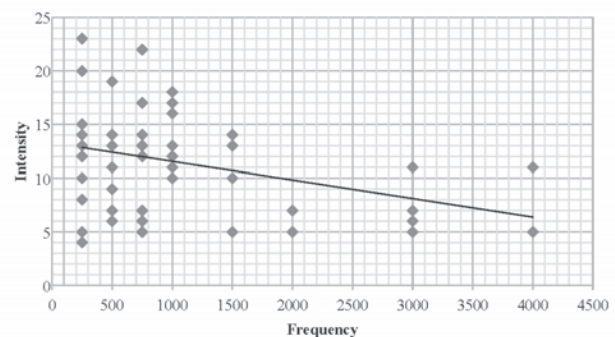


Figure 4. Scatter plot of tinnitus matching of intensity of loudness and pitch matching of individuals considered for the study.

## Conclusions

The present study tried to quantify and determine the psychoacoustic characteristics of tinnitus in individuals with ANSD. The result of the study shows that pitch matched by majority of patients with ANSD is low pitched (<1000 Hz). The frequency of tinnitus matched by the patients with ANSD correlated with the degree of maximal hearing loss. Majority of the patients with low pitched tinnitus had low frequency hearing loss. The intensity of loudness of the tinnitus was around 10-15 dB higher than their threshold at that frequency in majority of the patients considered in the study. The relationship between frequency of hearing loss and the tinnitus spectrum in individuals with ANSD deserves further investigation in future studies to understand the pathophysiology of tinnitus in individuals with ANSD.

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