INTENSITY DISCRIMINATION IN INDIVIDUALS WITH AND WITHOUT COCHLEAR DEAD REGIONS

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Abstract

Objective: The objective of the present study was to analyze intensity discrimination between individuals with and without cochlear dead regions using SISI test. Method: Thirty ears diagnosed as having sensorineural hearing loss were considered for the present study, out of which 15 were individuals without cochlear dead regions and 15 with cochlear dead regions. The age criterion ranged from 20 to 75 years (mean age=55.16 years) and the degree of hearing loss ranged from mild to moderately-severe. The TEN test was administered to detect the presence or absence of cochlear dead regions. Short Increment Sensitivity Index (SISI) was administered to find out the ability of each individual to detect small intensity changes (1 dB increment) at equal sensation levels (SLs). Results: The analysis of the data collected revealed statistically significant difference in SISI scores between the individuals with and without cochlear dead regions, i.e., SISI scores were better in individuals having cochlear dead regions when compared to those without cochlear dead regions. The results also showed significant difference in SISI scores across frequencies in the group with cochlear dead regions and increase in SISI scores with increase in frequency. Conclusion: Cochlear dead region is associated with a better ability for intensity discrimination and this effect may reflect cortical re-organization and over representation induced by the cochlear dead regions.

Key words: *Cochlear dead region; Cortical re-organization; SISI; Loudness perception*

Introduction

The human ear is a complex organ performing a vital role in our daily life. Both in terms of its absolute sensitivity and in terms of the range of intensities to which it can respond, the human ear plays a major function. Loudness corresponds to the subjective impression of the magnitude of a sound. Loudness if defined formally is that attribute of auditory sensation in terms of which sounds can be ordered on a scale extending from quiet to loud (ANSI, 1994). The smallest perceivable difference in decibel (dB) between two intensities is called Difference Limen for Intensity (DLI) or just noticeable difference (jnd). There are various methods such as modulation detection, increment detection and intensity discrimination of gated or pulsed stimuli through which the smallest detectable change for intensity can be measured.

Intensity discrimination has been studied widely in individuals with cochlear hearing loss. Glasberg and Moore (1989) reported that at equal sensation levels (SLs), subjects with cochlear damage have smaller values of DLI than normals, whereas at equal SPLs, they have DLI values that are similar to normal or still worst than in normal. The authors attribute this to the larger spread of excitation that is utilized by cochlear impaired ears at relatively higher SPL. Schroder, Viemeister and Nelson (1994) also reported that at same SLs, the Weber fraction (ratio of difference limen for intensity to its starting intensity) was smaller in individuals with cochlear impairment than in normal hearing listeners.

Loudness perception of the human ear can be affected by changes in the cochlear mechanism (Moore, 2007) and one such change can be complete loss of Inner Hair Cells or functional neurons at some regions in the cochlea which is referred to as Cochlear Dead Regions (CDR). In a CDR, little or no information is transmitted to the brain about basilar membrane vibration. However, a tone producing peak vibration in that region may be detected by off-frequency listening (Kluk & Moore, 2006). The extent of a cochlear dead region is indicated in terms of its edge frequency (fe). This fe corresponds to the characteristic frequency (CF) of the inner hair cells and/or neurons, which are immediately adjacent to the cochlear dead regions (Moore, Huss, Vickers, Glasberg & Alcantara, 2000).

Research carried out in animals suggests that any injury in the basal region of the cochlea results in high-frequency cochlear dead region which in

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turn leads to cortical reorganization, such that frequencies just lower than the edge frequency of the cochlear dead region get over-represented. This is because the neurons that are cut down from the peripheral inputs start responding to the stimuli with frequencies close to the fe of the hearing loss.

Various studies have been carried out in the human ear as well and have evidenced cortical re-organisation and over representation in the auditory cortex of individuals with cochlear dead regions. This has been widely studied and depicted through frequency discrimination abilities in those with cochlear dead regions (Thai-Van, Michelyl, Norena & Collet, 2002; Thai-Van et al., 2007; Kluk and Moore 2006). Thai-Van et al., 2007, reported that changes in tonotopic maps in the central auditory system are induced due to the cochlear damages. Also, they observed a local improvement in the difference limens for frequency (DLFs) at or near the edge frequency. Moore and Vinay (2009) studied and compared frequency discrimination, intensity discrimination and consonant identification in two groups, i.e., with and without acquired high-frequency cochlear dead regions. For the first task with frequency-discrimination, the ears with cochlear dead regions demonstrated improved thresholds for frequencies just lower than the fe. Also, for those subjects with unilateral cochlear dead regions, the betterment in the thresholds was seen only for those ears with cochlear dead regions. For the next task with amplitude-modulation detection, the DLIs were smaller for the ears with cochlear dead regions than for the ears without. Lastly, with the consonant identification it was found that the scores were significantly better for the ears with than without cochlear dead regions. This finding was reflected even in the case of individuals with unilateral cochlear dead regions.

Ability to detect small intensity changes can be studied using Short Increment Sensitivity Index (SISI) test (Jerger, Shedd & Harford, 1959). Typically, cochlear hearing loss leads to enhancement in the ability to detect small changes in the intensity level. Buus, Florentine and Redden (1982) reported that subjects with cochlear impairments showed higher SISI scores, and smaller difference limens (DLs) for detecting intensity modulations when compared to normal listeners at equal SLs. Difference Limen for intensity has not been studied much in individuals with cochlear dead regions. Thus, in the present study SISI test has been used to study the intensity discrimination in individuals with cochlear dead regions and also the SISI scores obtained were compared between individuals with and without cochlear dead regions.

Aims of the study

To study and compare the intensity discrimination ability in individuals having cochlear losses with and without dead regions using the SISI test.

Method

Participants: Thirty ears diagnosed as having cochlear hearing loss served as participants. The participants were divided into 2 groups, with 15 ears having CDRs and 15 ears without CDRs. All the listeners with hearing impairment underwent a battery of audiological tests to rule out conductive component (Tympanometry) and retrocochlear pathology (Reflex decay). The degree of hearing loss for the inclusion criteria for the present study ranged from mild to moderately-severe sensori-neural hearing impairment. The audiometric thresholds were matched between the two groups considered in terms of degree of hearing loss and the mean thresholds for the two groups are given in Table 1. The age range of participants ranged from 20-75 years with the mean age being 55.16 years.

Table 1: Mean Audiometric thresholds and standard deviation for individuals without and with cochlear dead regions.

	Without CDRs		**With CDRs**	
	Mean	**S.D**	**Mean**	**S.D**
250 Hz	33.33	5.56	29.33	5.97
500 Hz	37.00	5.92	34.66	6.21
750 Hz	43.00	8.62	42.33	8.88
1000 Hz	47.33	9.04	47.00	8.88
1500 Hz	51.33	6.93	57.00	6.81
2000 Hz	59.33	5.30	61.66	5.21
3000 Hz	64.00	5.73	67.33	6.12
4000 Hz	67.33	6.78	70.00	7.04

Test environment: All the evaluations were carried out in a sound-treated suite. The noise levels were maintained within permissible limits, as per ANSI S3.1- 1999.

Instrumentation: A calibrated two channel diagnostic audiometer, ORBITER-922, version-2 coupled with headphones (TDH-39) and bone vibrator (B-71) were used to estimate the pure-tone thresholds and speech identification abilities. A calibrated middle ear analyzer, GSI Tympstar version-2 was used to carryout immittance evaluation. A Philips 729K CD player was used to present the stimulus to carry out TEN test.

Procedure

Pure Tone Audiometry: Madsen Orbiter 922 clinical audiometer was utilized to obtain the audiometric thresholds. Frequencies from 250 Hz to 8000 Hz were tested for air conduction thresholds using TDH-39 headphones. Bone conduction thresholds were measured for frequencies from 250 Hz to 4000 Hz using a Radio Ear B-71 bone vibrator. Modified Hughson-Westlake (Carhart & Jerger, 1959) was used to measure the audiometric thresholds.

Immittance evaluation: Tympanometry and reflexometry were carried out to confirm normal middle ear functioning. Acoustic reflexes were obtained at 500, 1000, 2000 and 4000 Hz.

The Threshold Equalizing Noise (TEN) test: Once the diagnosis of sensori-neural hearing loss was made, each subject was subjected to TEN (HL) test (Moore, Glasberg & Stone, 2004) for the identification of cochlear dead regions. For the administration of this test, the TEN (HL) CD was played utilizing a Philips 729K CD player and the stimuli were presented through the Madsen Orbiter-922 clinical audiometer with TDH-39 earphones. Test was carried out at 500, 750, 1000, 1500, 2000, 3000 and 4000 Hz. The attenuators controlled the level of the signal and the TEN level in the audiometer. As recommended by Moore et al. (2004), the level of the signal was varied in 2 dB steps to obtain the masked thresholds. The criteria as suggested by Moore et al. (2004) were incorporated to determine the presence or absence of a cochlear dead region at a particular frequency. If the masked threshold in the TEN was 10 dB or more above the TEN level/ Equivalent Rectangular Bandwidth Noise (ERBN), and the TEN elevated the absolute threshold by 10 dB or more, then a cochlear dead region was assumed to be present.

SISI test: Short Increment Sensitivity Index (SISI) test (Jerger, Shedd, & Harford, 1959) was administered in each subject to find out the individual's ability to detect 1 dB increments. A continuous tone was presented at 20 dB above the absolute threshold (20 dB SL). The presentation level for SISI administration ranged from 45 to 90 dB HL. The level was increased by 1 dB every five seconds, with a rise or fall time of 50 ms, and steady state duration of 200 ms. Larger 5 dB and 2 dB increments were used to familiarize the patient with the task. Catch trials were presented to control false positives and to eliminate rhythmic responding. The subject was asked to indicate whenever a small jump in loudness was heard and 20 test increments were presented. The number of increments to which a patient responded multiplied by 5 gave the SISI scores in percentage.

Results

The data collected for the present study from 30 ears, were subjected to statistical analyses using SPSS version 15.0. Statistical analyses were done to compare the data for intensity discrimination across the two groups i.e. participants with cochlear losses without dead regions and participants with cochlear dead regions. Analyses revealed that the mean percentage SISI scores were more for the individuals with cochlear dead regions than in the individuals without cochlear dead regions. The mean and standard deviation for the intensity discrimination for both the groups are given in Table 2.

Table 2: Mean and standard deviation of SISI scores for individuals with and without cochlear dead regions.

Frequency (Hz)	Individuals with cochlear dead regions (%)		Individuals without cochlear dead regions (%)	
	Mean	Standard deviation	Mean	Standard deviation
250	38.67	34.19	12.67	17.41
500	36.67	34.36	9.67	14.81
750	34.62	36.65	8.57	14.6
1000	37.69	38.97	8.93	17.77
1500	45	38.27	10	22.18
2000	53.13	32.61	11.43	23.81
3000	81.43	36.71	20	11.43
4000	90	15.49	22.92	36.58

As depicted in Figure 1, it can be seen that the SISI scores in percentage was more for individuals with cochlear dead regions when compared to the individuals without cochlear dead regions at all the frequencies. Also, it can be noticed that there was an increase in SISI scores with increase in frequency.

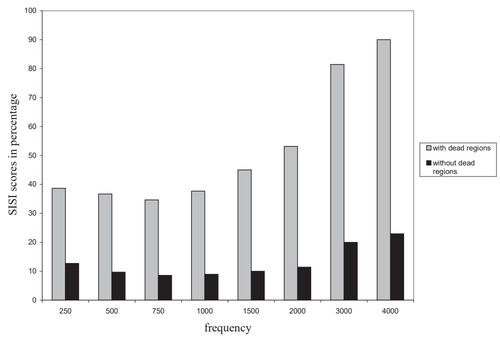

Figure 1: Percentage of SISI scores (intensity discrimination) across different frequencies with and without cochlear dead regions.

Repeated measure ANOVA was done to compare the percent SISI scores among the two groups. The analysis revealed a significant difference at 250 Hz [F (1, 28) = 6.88, p < 0.05]; 500 Hz [F (1, 28) = 7.80, p < 0.01]; 750 Hz [F (1, 28) = 6.05, p < 0.05]; 1000 Hz [F (1, 28) = 6.24, p < 0.05]; 1500 Hz [F (1, 28) = 8.24, p < 0.01]; 2000 Hz [F (1, 28) = 11.94, p < 0.01]; 3000 Hz [F (1, 28) = 12.72, p < 0.01] and 4000 Hz [F (1, 28) = 18.08, p < 0.01]. The results also showed significant difference in SISI scores across frequencies in the group with cochlear dead regions (p < 0.05) but the SISI scores across frequencies in the group without cochlear dead regions did not approach statistical significance (p > 0.05).

Discussion

The Threshold Equalizing Noise (TEN) test was used in the present study to detect cochlear dead regions, to group them into individuals with and without cochlear dead regions. TEN test was preferred over the psychophysical tuning curves (PTCs) as recent studies report higher sensitivity of TEN to detect cochlear dead regions when compared to PTCs (Vinay & Moore 2007).

Based on the results obtained by the statistical analyses, there was a significant difference in SISI scores between individuals with and without cochlear dead regions at equal SLs. The possible reason for the increase in SISI scores in individuals with cochlear dead regions may be due to enhanced intensity discrimination abilities in parallel with the enhanced frequency discrimination on the task for DLF (Kluk & Moore, 2006; Thai-Van et al., 2007).

Studies have reported that there is enhancement in the frequency discrimination in participants with cochlear dead region. This enhanced frequency discrimination was reported at the frequencies near the fe of the cochlear dead region (Thai-Van et al., 2002; Thai-Van et al., 2007; Kluk & Moore 2006). Modified neural representation of the primary auditory cortex has been demonstrated in those with cochlear damages (Robertson & Irvine, 1989). When the auditory threshold due to a peripheral damage at a particular frequency become abnormally elevated, the neurons with initial characteristic frequencies falling in such a place will develop lower threshold to frequencies whose cochlear place was at the fe. This is because, auditory cortical neurons to which direct cochlear input are cut down due to a cochlear dead region starts responding to cochlear regions for which significant input is still present (Thai-van et al. 2002).

Thai-van et al. (2002) reports locally improved thresholds near the edge frequency of the cochlear dead region and attributes it to cortical reorganization. Cortical re-organization and over-representation may be the reason for enhanced loudness perception in the present study. However, at higher presentation levels the responses may have been from adjacent frequency regions.

Better abilities in intensity discrimination abilities were also obtained in a study conducted by Moore and Vinay (2009). Amplitude-modulation detection was the task used where in statistically significant enhanced (better) threshold was obtained for the ears with cochlear dead regions than for the ears without. Also, for those individuals with unilateral cochlear dead regions, thresholds were enhanced for the ears with cochlear dead regions than for the ears without. They reported that this improved amplitude modulation detection thresholds could be associated with loudness recruitment. However, they believed that loudness recruitment was unlikely to have influenced the difference in the results obtained between the two groups as the ears were matched in terms of audiometric thresholds for low-frequencies, with the amount of loudness recruitment caused by cochlear hearing loss being closely related to the amount of hearing loss (Miskolczy-Fodor, 1960; Moore, Vickers, Plack & Oxenham (1999); Moore, et al., 2004). Thus, the most likely explanation they reported for obtaining better amplitude modulation detection for ears with than without cochlear dead regions was that the enhanced loudness perception was an outcome of cortical re-organization for the ears with cochlear dead regions. The authors thus concluded that the cortical over-representation of the low-frequency region of the cochlea that happens as a consequence of high-frequency cochlear dead region might result in a more rapid than normal growth of loudness as the intensity increases, and this in turn might lead to enhanced ability in terms of loudness perception.

The Increase in SISI scores with increase in frequency in the present study was unlikely, as these frequencies fell within the cochlear dead region. This can possibly be attributed to the larger excitation pattern seen at the higher frequencies as the presentation level was high at higher frequencies. This large excitation pattern would initiate the firing of the surviving neurons by off-frequency listening and because the surviving neurons have larger representation in the cortex, it may aid in better detection of small changes in intensity, which is reflected in SISI scores at high frequencies. The same was not seen in the lower frequencies, which can be attributed to relatively smaller excitation because of a lower presentation level**.** Unlike the DLFs, where there is local improvement near edge frequency, improved amplitude detection thresholds across the frequencies were also seen in the study conducted by Moore and Vinay, 2009 and the effect was not confined to a narrow frequency range just below the edge frequency.

Conclusions

The present study was carried out to analyze intensity discrimination in participants with cochlear losses with and without dead regions using the SISI test. Individuals with cochlear dead regions obtained good SISI scores at all frequencies which is typical of cochlear hearing loss. Individuals with cochlear dead regions obtained better SISI scores when compared to individuals without cochlear dead regions. Hence, individuals with cochlear dead regions exhibited better intensity discrimination ability at equal SLs.

The enhanced intensity discrimination can be attributed to cortical reorganization and over-representation in the auditory cortex for intensity in individuals with cochlear dead regions. However, increase in SISI scores at higher frequencies could be because of the larger excitation pattern as the presentation level was high at these frequencies.

Future considerations

Further studies need to be carried out on a larger population, with slope matched controls. Studies on intensity discrimination in cochlear dead regions have to be carried out incorporating other tests or methods to measure smallest detectable changes like modulation detection, discrimination of gated or pulsed stimuli. Comparison across edge frequencies is suggested.

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