Frequency Discrimination and Speech Identification Abilities in Individuals with and without Cochlear Dead Regions

Megha & S. N. Vinay*

Abstract

The aim of the study was to assess the frequency discrimination and speech identification abilities and also to assess the correlation between the frequency discrimination abilities and speech identification abilities in individuals without and with cochlear dead regions at 1 kHz, 2 kHz and 4 kHz edge frequencies. TEN (HL) test was administered to assess the presence of absence of dead regions. Frequency modulation difference limens (FMDLs) were obtained and consonant- vowels (CVs) both unfiltered and filtered till the edge frequency was presented to both the groups. FMDLs were better in individuals with dead region and better near the edge frequency. The scores for filtered CVs were better in individuals with dead region than for the unfiltered CVs. However, there was no correlation between the FMDLs and the speech identification scores in individuals with dead region. The enhanced frequency discrimination in individuals with dead region might be due to cortical re-organization and better performance in filtered speech conditions helps in further rehabilitation of these individuals.

Key words: TEN (HL), FMDL, Speech identification.

Introduction

Cochlear hearing loss has many causes and it is often seen that the damage is caused to the outer hair cells (OHCs) and inner hair cells (IHCs) in the cochlea (Moore, 2004a). A dead region (DR) can be defined as a region in the cochlea where the IHCs and/or neurons are functioning very poorly, if at all present (Moore, 2001). DRs are relatively common among young and adult people with severe-to profound sensorineural hearing impairment (Moore et al., 2003; Preminger, Carpenter & Ziegler, 2005; Alexander, Cox, Rivera, Johnson & Gardino, 2007; Vinay & Moore, 2007a; Aazh & Moore 2007).

Cochlear damages have been shown to induce changes in tonotopic maps in the central auditory system of animals. Neurons deprived from peripheral inputs start to respond to stimuli with frequencies close to the cut-off frequency or edge of the hearing loss, which then become over-represented at the neural level (Thai-Van et al., 2007). This neuronal arborization is mainly due to the effect of off-frequency listening, which a common phenomenon is observed in individuals with sensorineural hearing loss (Patterson & Moore, 1986).

* Lecturer in Audiology, All India Institute of Speech and Hearing, Mysore, India
email: vinaysn@lycos.com

Studies have examined whether discrimination abilities were enhanced near the hearing loss *fe* in patients with hearing loss of cochlear origin (Buss, Hall, Grose, & Hatch, 1998; Mc Dermott et al., 1998; Thai-Van, Micheyl, Norena, & Collet, 2002). The latter two studies revealed that the difference limens for frequency (DLFs) were found to be significantly enhanced at or near the *fe* in patients with steeply sloping, high-frequency hearing loss, estimated using the TEN (SPL) test.

Thai-Van, Micheyl, Moore, and Collet (2003) suggested that local improvement in difference limen frequency (DLFs) represents a side effect of neurophysiological mechanisms that have no major perceptual consequences on speech or music perception. However, studies of the intelligibility of low-pass filtered speech for individuals with DRs suggest that this may not be true. Under some filtering conditions individuals with DRs obtain better scores than individuals without DRs (Vestergaard, 2003; Vickers, Baer, Fullgrabe, Vinay & Moore, 2006).

Need for the study

The relationship between frequency discrimination abilities and speech identification abilities are not similar in individuals with DR and those without DR. This is proven by the various consequences of DR, like altered perception of loudness, pitch and speech which is different from that of an individual with sensorineural hearing loss without DR. Thus, these phenomenon need to be studied, as these have implications in fitting the amplification devices for individuals with DR.

Objective of the study

The objectives of the study are:

1. To assess the frequency discrimination abilities in individuals without and with cochlear dead regions at 1 kHz, 2 kHz and 4 kHz edge frequencies.
2. To assess the speech identification abilities in individuals without and with cochlear dead region at 1 kHz, 2 kHz and 4 kHz edge frequencies.
3. To assess the correlation between the frequency discrimination abilities and speech identification abilities in individuals without and with cochlear dead regions at 1 kHz, 2 kHz and 4 kHz edge frequencies.

Method

The present study was conducted with an aim of studying frequency discrimination and speech identification abilities in individuals with and without dead regions. The study also aimed at correlating the frequency discrimination and speech identification abilities in individuals with and without dead regions.

Participant selection criteria

A total of 52 participants (82 ears) between the age group of 20 and 68 years with mean age of 43.6 years (SD =13.72) were taken for the study and they were divided into two groups based on the Threshold Equalization Noise (TEN) test results.

Group 1: Consisted of 38 ears with sensori-neural hearing loss without cochlear dead regions.
Group 2: Consisted of 44 ears with sensori-neural hearing loss with cochlear dead regions.

All the participants had acquired post-lingual sloping sensori-neural hearing loss. Degree of hearing loss varied from minimal to moderate till the start of the slope / edge frequency in both Group 1 and Group 2 respectively. Participants with sharply sloping hearing loss i.e., 15-20 dB threshold increase per octave (Carhart, 1945) were taken in both the groups, with the slope starting from 1 kHz and above. For each ear with a dead region, a matching ear without a dead region was selected, either within the same participant or in a different participant. Participants in Group 2 with *fe* at 1 kHz, 2 kHz and 4 kHz were matched for the start of slope at corresponding frequency at 1 kHz, 2 kHz and 4 kHz. These frequencies, 1 kHz, 2 kHz and 4 kHz in Group 1 were named 'A', 'B' and 'C' respectively as the term edge frequency is inappropriate for individuals without dead regions. All the participants with speech identification scores greater than 60% were considered for the study.

Participants with no history or present complaints of middle ear disorders, neurological symptoms were selected for the study. All the participants were native speakers of Kannada with good language abilities.

Instrumentation/Material

Following instruments and materials were used for the study:

- Calibrated two channel diagnostic audiometer Orbiter 922 with TDH 39 headphones with MX 14AR cushion for performing the pure tone audiometry, speech audiometry, the TEN test and frequency discrimination test for both Group 1 and Group 2.
- Calibrated GSI Tympstar middle ear analyzer version 2.0 to rule out middle ear pathology.
- TEN (HL) test Compact Disc (CD), developed by Moore et al. (2004) to detect the presence or absence of cochlear dead region.
- Speech material was constructed based on the frequency composition of the Consonant-vowels (CVs). They were divided into low frequency, mid frequency and high frequency based on their frequency composition as per the classification given by Ramaswami (1999). A total of 30 CVs were used, 10 in each category.
- PRATT software version 4.5.16 to record and low pass filter the speech stimuli and Adobe Audition 1.0 to normalize the stimuli.

- Hewlett Packard (HP) laptop with 1.3 GHz Centrino Core 2 Duo processor connected to audiometer through auxiliary input for running the TEN (HL) test and presenting the unfiltered and low pass filtered speech stimuli.

All testing was done in a sound treated double room. The ambient noise levels were within permissible limits as recommended by ANSI (1999).

Procedure

Pure-tone thresholds were obtained at octave intervals from 0.25 kHz to 8 kHz and 0.25 kHz to 4 kHz for air conduction and bone conduction audiometry respectively, using modified Hughson-Westlake procedure developed by Carhart and Jerger (1959). Speech audiometry was done to obtain the speech recognition thresholds and speech identification scores. Immittance using the low frequency probe tone, 226 Hz, and acoustic reflex threshold measurements, both ipsilateral and contralateral thresholds were carried out to rule out the conductive component. The procedure was carried out in three phases.

Phase 1: Diagnosis of presence / absence of cochlear dead regions and to determine the edge frequency (fe)

TEN (HL) test was administered to diagnose cochlear dead regions in participants with sensorineural hearing loss and also to determine the edge frequency. The TEN (HL) level is specified as the level of a one-ERB_N wide band centered at 1 kHz, where ERB_N stands for Equivalent Rectangular Bandwidth of the auditory filter determined by using young normal hearing individuals at moderate sound levels (Glasberg & Moore, 1990; Moore, 2003). The TEN (HL) test was carried out as described by Moore et al. (2004), using a procedure similar to manual audiometry, except that masked thresholds were measured using a 2-dB step size. The TEN (HL) test was administered using a CD player run through a HP laptop, connected to an audiometer with TDH 39 earphones. Test frequencies were 0.5, 0.75, 1, 1.5, 2, 3, and 4 kHz. A TEN level of 70 dB HL/ERB_N was used for most individuals and a lower level of 50 dB HL/ERB_N was used for individuals with minimal and mild hearing loss, especially if they complained of loudness of the TEN.

A "no response (NR)" was recorded when the subject did not indicate hearing the signal at the maximum output level of the audiometer. The presence or absence of a dead region at a specific frequency was based on the criteria suggested by Moore et al. (2004).

- If the masked threshold in the TEN was 10 dB or more, above the TEN level/ERB_N, and the TEN elevated the absolute threshold by 10 dB or more, then a dead region was interpreted to be present.
- If the masked threshold in the TEN was less than 10 dB above the TEN level/ERB_N, and the TEN elevated the absolute threshold by 10 dB or more, then a dead region was interpreted to be absent.

- In cases where the TEN (HL) level could not be made high enough to elevate the absolute threshold by 10 dB or more i.e., the individuals with inconclusive results were not taken for the study as the edge frequency could not be determined in these individuals.

Phase 2: Establishing Frequency Modulation Difference Limen (FMDL)

Following the TEN test, frequency discrimination test for modulated signal was administered for both Group1 and Group 2 by obtaining the frequency modulation difference limens (FMDLs).

FMDLs were obtained using the two alternative forced choices. Two tones were presented successively, one modulated (0.2 %, 0.5%, 1.0%, 2.5%, 5.0%, 7.5%, 10.0%, 12.5% and 15.0 %) and other unmodulated tone. The level of presentation was 40 dB SL. The stimulus duration was 500ms. The participants were instructed to indicate whether the first tone or the second tone was modulated. The amount of modulation required for detection of the modulation was determined. Catch trials were presented at random to rule out the false responses.

FMDLs were obtained for individuals with dead regions and for individuals without dead regions at two frequencies. One frequency was selected at farther to the edge frequency/ corresponding slope, F_F, which can be defined as the nearest octave/ mid-octave frequency that is farther from the edge in DR / corresponding slope in individuals without DR. Another frequency was selected nearer to the edge frequency/ corresponding slope for without dead region individuals, F_N, which was *fe*- $1/8^{th}$ octave, due to the fact that the enhancement is usually seen at this frequency and a farther frequency was taken to cross check this phenomenon. Table 1 depicts the edge / corresponding start of slope frequency and the corresponding frequencies at which the FMDLs were obtained.

Table 1: Different frequencies at which frequency modulation difference limens were obtained for each edge frequency/ corresponding frequency at start of the slope

Edge Frequency / Corresponding slope (kHz)	Frequencies tested	
	F_F (kHz)	F_N (kHz)
1	0.5	0.8
2	1	1.8
4	3	3.8

Phase 3: Speech identification testing

Speech identification test was performed following the frequency discrimination testing. A combination of Consonant-Vowel (CV) stimuli were selected such that the CVs were concentrated in the low frequency, mid frequency and high frequency regions based on the classification given by Ramaswami (1999). Each CV was recorded by a male speaker in

PRATT software, version 4.5.16. All the CVs were normalized to avoid the amplitude variations of the recorded speech stimuli using the Adobe Audition 1.0 software. A total of 30 CVs were taken and were divided into three lists based on their frequency composition. Table 3 shows the different list of CVs taken based on frequency composition of the same.

Table 2: Speech Stimuli classified according to frequency composition

Low frequency stimuli	Mid frequency stimuli	High frequency stimuli
/bo/, /b^{h}o/, /hu/, /hu/, /mo/, /mu/, /po/, /pu/, /p^{h}u/, /p^{h}o/	/ka/, /k^{h}a/, /ga/, /g^{h}a/, /ţa/, /ţ^{h}a/, /da/, /d^{h}a/, /na/, /ha/	/ti/, /te/, /de/, /di/, /si/, /se/, /shi/, /ci/, /je/, /ňe/

The CVs constructed were presented without any filtering known as the unfiltered condition. Thus, there were three unfiltered lists, namely, unfiltered low frequency (ULF) , unfiltered mid frequency (UMF) and unfiltered high frequency (UHF). The CVs were low pass filtered (LPF) at different cut-off frequencies to produce the filtered low frequency (FLF), filtered mid frequency (FMF) and filtered high frequency (FHF) speech stimulus. The low pass filtering was done using the PRATT software version 4.5.16. The cut-off frequency of the low pass filtered speech was the edge frequency or the frequency at start of the slope for the three different frequencies (1 kHz, 2 kHz, and 4 kHz). Table 3 depicts the different speech lists presented to participants of both Group 1 and Group 2.

The stimuli were randomized and the order of presentation of lists were also randomized and presented at 40 dB SL for most of the subjects or at the Most comfortable level (MCL) for higher degree of hearing loss, by connecting the CD player of the HP laptop to the audiometer. Written responses were obtained from all the participants.

Analysis of the obtained data was done using the Statistical Package for the Social Sciences (SPSS) version 16 software.

Table 3: Speech lists and filtering conditions presented to Participants of Group 1 and Group 2 with respect to start of slope /Edge frequencies

Edge frequency/ Start of slope (kHz)	Speech filtering condition	Low pass filtering cut off for filtered speech (kHz)
1	ULF, UMF, FLF, FMF	1
2	UMF, UHF, FMF, FHF	2
4	UMF, UHF, FMF, FHF	4

Results and Discussion

The mean scores and standard deviation (SD) for FMDL scores of F_F for individuals with and without DR across the edge frequencies/ corresponding frequencies at the start of slope are shown in Table 4.

Table 4: The mean and standard deviation (SD) for FMDL scores of F_F and F_N for individuals with and without dead regions across the edge frequencies/ corresponding frequencies at the start of slope

Groups	Frequency (kHz)	N	F_F		F_N	
			Mean (%)	SD	Mean (%)	SD
Group 1	1	12	3.20	1.95	2.87	1.96
	2	13	2.23	1.09	2.23	1.09
	4	13	1.38	0.79	1.26	0.72
Group 2	1	16	1.84	0.76	1.13	0.85
	2	14	1.53	0.74	1.17	0.74
	4	14	1.42	0.85	0.89	0.52

**Note*. 1 kHz, 2 kHz and 4 kHz frequencies in Group 1 refers to 'A', 'B' and 'C' respectively.

Two-way ANOVA was administered to find the effect of frequencies at the start of slope / edge frequencies on the frequency discrimination abilities of F_F and F_N in Group 1 and Group 2.

Results of Two-way ANOVA revealed that there was statistically significant difference in FMDL scores of F_F between Group 1 and Group 2, [$F (1, 76) = 7.78$, $p<0.05$], and also across the corresponding frequencies at the start of slope /edge frequencies [$F (2, 76) = 7.28$, $p<0.05$] and also for F_N between Group 1 and Group 2, [$F (1, 76) = 18.07$, $p<0.01$], and also between the edge frequencies / corresponding frequencies at the start of slope [$F (2, 76) = 6.33$, $p<0.05$]. However, there was no interaction observed between the Group 1 and Group 2 and the corresponding frequencies at the start of slope / edge frequency for both F_F and F_N [$F (2, 76) = 2.86$, $p>0.05$; $F (2, 76) = 2.15$, $p>0.05$].

Duncan's post hoc analysis was administered to study if there was a statistically significant difference in FMDL scores of both F_F and F_N between the various edge frequencies / corresponding frequencies at the start of slope. Figure 1 depicts the FMDL scores for Group 1 and Group 2 at 1 kHz and 4 kHz for F_F.

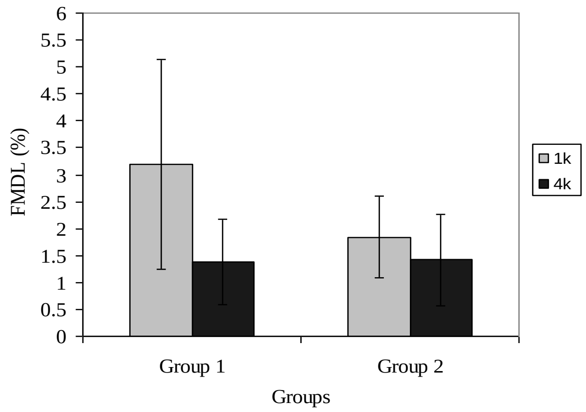

Figure 1: The FMDL scores at F_F for Group 1 and Group 2 at 1 kHz and 4 kHz

It can be seen from Figure 1 that overall mean FMDL scores for Group 2 were lower (Mean = 1.61) than Group 1 (Mean = 2.25), which shows that individuals with DR had better FMDLs than individuals without cochlear dead region.

Figure 2 depicts the FMDL scores for Group 1 and Group 2 at 1 kHz and 4 kHz for $F_{N.}$

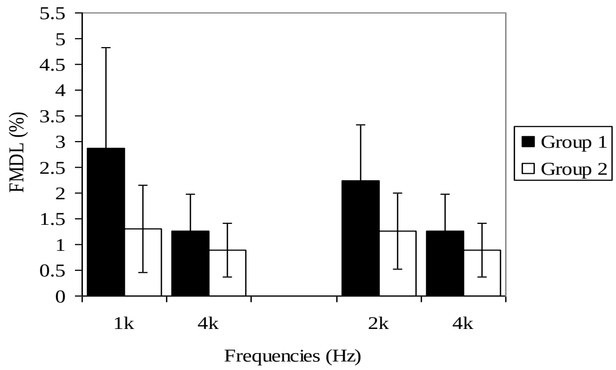

Figure 2: The FMDL scores at F_N for Group 1 and Group 2 at 1 kHz and 4 kHz and 2 kHz and 4 kHz

It can be seen from Figure 2 that the overall mean FMDL scores for Group 2 were lower (mean = 1.13) than Group 1 (mean = 2.10), for F_N, which showed that individuals with DR had better FMDLs than individuals without cochlear dead region. Across the edge frequency / corresponding frequencies at the start of slope, lower the edge frequency / corresponding frequencies at the start of slope, that is, 1 kHz edge frequency / corresponding frequency ‘A’ individuals showed relatively worse FMDLs than 2 kHz and 4 kHz for both Group 1 and Group 2, which was similar to FMDL scores of F_F.

Within groups comparison of frequency discrimination abilities in individuals with and without cochlear dead regions.

Paired sample t-tests were administered to study the comparison of FMDL scores of F_F and F_N within Group 1 and the same was carried out within Group 2 at different frequencies at the start of slope / edge frequencies. Table 5 depicts the results of paired sample t-test results across edge frequencies / corresponding frequencies at the start of slope for FMDL scores of F_F and F_N for Group 1 and Group 2.

Table 5: t value and significance across corresponding frequencies / edge frequencies at the start of slope for FMDL scores of F_F and F_N within Group 1 and within Group 2

Groups	Frequency (kHz)	N	F_F		F_N		't' value	Significance (2-tailed)
			Mean (%)	SD	Mean (%)	SD		
Group 1	1	12	3.20	1.95	2.87	1.96	1.43	0.18
	2	13	2.23	1.09	2.23	1.09	------**	------**
	4	13	1.38	0.79	1.26	0.72	0.89	0.38
Group 2	1	16	1.84	0.76	1.13	0.85	2.57	0.02*
	2	14	1.53	0.74	1.17	0.74	1.43	0.17
	4	14	1.42	0.85	0.89	0.52	2.89	0.01*

Note.***** indicates significant difference at 0.05 level; **could not be compared as the mean values were equal.

Results of paired sample t-test indicated that there was no statistically significant difference between FMDL scores of F_F and F_N within Group 1 across the frequencies 'A', 'B' and 'C'. However, there was statistically significant difference between FMDL scores of F_F and F_N within Group 2 at 1 kHz and 4 kHz edge frequencies, but no statistically significant difference between FMDL scores F_F and F_N at 2 kHz edge frequency. From the mean FMDL scores of F_F and F_N for Group 1 and Group 2, it was seen that the FMDL scores of F_F and F_N were almost similar in Group 1 whereas, in Group 2 the mean FMDL score of $F_{N\ was}$ very much lower than the mean F_F values. This indicates that FMDLs were better/ enhanced near the edge frequency for individuals with cochlear dead region.

The results obtained in the present study were in support with the study by Kluk and Moore (2006), who studied difference limen for frequency (DLF) in individuals diagnosed to have cochlear dead regions at the higher frequencies. Results indicated that only a very small amount of local DLF enhancement at *fe*, which reflected the fact that the frequency at which DLF_{min} (that is the enhancement of DLF) occurred sometimes above and sometimes below *fe*. For most of the individuals, the DLF_{min} occurred at *fe* – 1/8th octave frequency (Thai-Van et al. 2003; 2007). The DLFs for frequencies below and at *fe* showed good consistency across individuals. Thus in the present study, the FMDL at F_N frequency, which was one- eighth octave below *fe* for Group 2 showed better scores than F_F frequency, which was very much farther from the edge frequency. These findings were again consistent with the results of Thai-Van et al. (2003) who reported enhanced DLFs at or near *fcut-off*.

The interpretation of the DLF improvement in a narrow range around *fe* draws upon the neuro-physiological finding in animals (Irvine et al., 2001) which says that neighboring hearing-loss cut-off with a narrow frequency range is over-represented on the primary auditory cortex's tonotopic map and thus more neurons are available for encoding frequencies falling in that range, and discrimination performance is correspondingly better.

Comparison of speech identification scores in different filtering conditions across the edge frequencies/ corresponding frequencies at the start of slope

Paired sample t-test was performed to study the pair wise comparison of speech identification scores of ULF and FLF and UMF and FMF for both Group 1 and Group 2 for frequency 'A'/ edge frequency 1 kHz .

Table 6 shows the results of paired sample t-test for speech identification scores for speech identification scores of ULF and FLF and UMF and FMF for both the groups for edge frequency 1 kHz / frequency 'A'.

Results of paired t-tests revealed that for Group 1, there was statistically significant difference between the speech identification scores of ULF and FLF [t (11) = 3.02, p<0.05] but there was no statistical significant difference between the speech identification scores of UMF and FMF. In Group 2, there was statistically significant difference between the speech identification scores ULF and FLF [t (15) = 3.36, p<0.001] and also between the speech identification scores of UMF and FMF [t (15) = 4.71, p<0.001].

Table 6: t value and significance for frequency 'A'/ edge frequency 1 kHz for different filtering conditions for speech for both groups 1 and 2

	Group 1		Group 2	
Speech condition (Comparison Pair)	t value	Significance	t value	Significance
ULF- FLF	3.02	0.01*	3.36	0.00**
UMF- FMF	2.02	0.67	4.71	0.00**
ULF- UMF	0.71	0.49	0.58	0.56
FLF- FMF	0.89	0.38	1.93	0.07

Note. * indicates significance at 0.05; ** indicates at significance at 0.001 level.

Paired sample t-test was performed to assess the pair wise comparison of speech scores of UMF and FMF and UHF and FHF in frequency 'B'/ edge frequency 2 kHz in both Group 1 and Group 2. Table 7 shows the results of paired sample t-test for speech identification scores in edge 2 kHz / corresponding frequency 'B'.

Table 7: t value and significance for frequency 'B'/ edge frequency 2 kHz for different filtering conditions for speech for both groups 1 and 2.

	Group 1		Group 2	
Speech condition (Comparison Pair)	t value	Significance	t value	Significance
UMF- FMF	0.64	0.53	8.70	0.00**
UHF- FHF	2.52	0.27	12.31	0.00**
UMF- UHF	2.88	0.01*	1.58	0.13
FMF- FHF	0.22	0.82	4.19	0.00**

Note. ** Significant at 0.001 level; * significant at 0.05 level.

Results revealed that there was statistically significant difference between UMF and FMF and between UHF and FHF within the Group 2 [t (13) = 8.70, p<0.001] and [t (13) = 12.31, p<0.001] respectively. However, there was no statistical significant difference between the speech identification scores of UMF and FMF and between the speech identification scores of UHF and FHF within the Group 1 (p>0.05).

Paired sample t-test was performed to compare the speech identification scores of UMF and FMF and UHF and FHF in frequency 'C'/ edge frequency 4 kHz in both Group 1 and Group 2. Table 8 shows the results of paired sample t-test for speech identification scores in edge frequency 4 kHz / corresponding frequency 'C'.

Table 8: t value and significance for frequency 'C'/ edge frequency 4 kHz for different filtering conditions for speech for both groups 1 and 2.

	Group 1		Group 2	
Speech condition (Comparison Pair)	t value	Significance	t value	Significance
UMF- FMF	0.41	0.68	4.22	0.001*
UHF- FHF	0.39	0.70	4.58	0.00*
UMF- UHF	1.76	0.10	0.69	0.50
FMF- FHF	1.07	0.30	1.32	0.20

**Note.* Significant at 0.01 level

Results revealed that there was statistically significant difference in speech identification scores between UMF and FMF and also between the speech identification scores of UHF and FHF within the Group 2 [t (13) = 4.22, p<0.01] and [t (13) = 4.58, p<0.01]. However, there was no significant difference between the speech identification scores of UMF and FMF and also between the speech identification scores of UHF and FHF within the Group 1 (p>0.05). There was also no statistical significant difference between the speech identification scores of two unfiltered conditions of UMF and UHF and also between the speech identification scores of two filtered conditions of FMF and FHF in both group 1 and 2.

It was observed that there was a significant difference between the speech identification scores of ULF and FLF condition in both Group 1 and Group 2. This was also evident by the increased mean speech identification scores for the filtered condition (Mean: 4.83 and 4.06 for Group 1 and 2 respectively) with the cut-off being 1 kHz as against the unfiltered condition (Mean: 3.75 and 2.62 for Group 1 and 2 respectively). This may be attributed to the fact that the distortion produced due to the off-frequency phenomenon (Patterson & Moore, 1986) may be avoided by filtering the unnecessary frequencies. These effects may reflect cortical plasticity induced changes by the dead regions.

Similar to the 1 kHz edge frequency, results also showed that there was improved performance with filtered speech in individuals with dead region at 2 kHz and 4 kHz edge frequency. This is also supported by Turner and Brus (2001), which revealed that below 2.8 kHz, amplification provided positive benefit for recognition scores regardless of degree of loss. These results have also been found in the present study, that is, better scores in filtered condition than the unfiltered condition. Similar studies have also been reported in individuals with high frequency DR, where in their performance was better for low pass filtered speech stimulus than wide band speech stimulus (Vickers et al., 2001; Baer et al., 2002).

Results also revealed that there was significant difference in speech identification scores of FMF and FHF in individuals with cochlear dead regions at 2 kHz edge frequency. It was also observed that the mean speech identification scores for FHF was higher (mean = 7.78) as against the mean for speech identification for FMF (mean = 6.85). This can be attributed to the fact that more cues are obtained from the FHF than FMF. FMF has a low pass cut-off of 2 kHz presented to the individuals with edge frequency 2 kHz. It is known that the off-frequency phenomenon is predominant in individuals with DR. This, FMF filtering condition will further create an overload on the mid frequency fibers together with off frequency, which in turn decreases the cues for perception of the stimuli; thus lowering the scores for FMF individuals with 2 kHz DR.

It was also observed that the two unfiltered conditions UMF and UHF were significantly different in individuals without dead regions at corresponding frequency 'B' (2 kHz). It was also seen that the mean speech identification score for UHF was higher (Mean = 5.93) than the mean speech identification score for UMF (Mean = 5.30). Higher scores for UHF can be attributed to the fact that the UHF consonants were in the vowel context of /i/ and /e/. This combination will provide more energy than compared to UMF consonants that comprised of /a/ vowel context having relatively lower energy.

Overall, these results support the idea that individuals with dead regions at high frequencies do not make as effective use of audible speech information at high frequencies as individuals without dead regions. Furthermore, the results support the idea that increasing the audibility of speech for frequencies well inside a dead region does not lead to concomitant increases in speech intelligibility.

Correlation of frequency discrimination scores and speech identification scores in Group 1 and Group 2.

To establish the relationship between the frequency discrimination scores and speech identification scores in Group 1 and Group 2 Spearman's correlation was performed. Results revealed that there was a negative correlation between frequency discrimination and the speech identification scores in Group 1, that is, in individuals without DR.

However there was no correlation between frequency discrimination and the speech scores in Group 2, that is in individuals with DR ($p>0.05$).

The FMDL scores of F_F and F_N correlated well with speech identification scores of ULF, UMF and FMF in Group 1. This is also in support with the fact that the speech identification scores of ULF, UMF and FMF have the same frequency composition as that of frequency of F_F and F_N which ranged from 500 to 3.8 kHz.

There are several studies correlating the frequency selectivity and speech scores in individuals without DR. Dubno, Dirks and Langhofer (1982) suggested there is one to one correlation between the speech recognition errors and audiogram patterns observed.

However, in individuals without DR, there was absence of any correlation between the frequency discrimination and speech identification scores. Even though the filtered speech scores were significantly higher in individuals with DR as against without DR, there was no correlation seen between the frequency modulation difference limen scores and the speech identification scores. This may be attributed to the mis-match in the frequency place representation due to the presence of off-frequency listening in individuals with DR. Thai-Van et al., (2003) suggested that local improvement in difference limen frequency (DLFs) represents a side effect of neurophysiological mechanisms that have no major perceptual consequences on speech or music perception. This hypothesis of Thai-Van et al., (2003) may be true in individuals with cochlear DR.

Summary and Conclusions

Dead region is often described in terms of the edge frequency (*fe*). It is seen from earlier research that the presence of dead region led to improved frequency discrimination near the edge frequency. The present study aimed at analyzing the frequency discrimination across the edge frequencies in individuals with dead regions and start of slope matched individuals without cochlear dead regions. The study also aimed at measuring the speech identification scores under unfiltered and filtered conditions and also to correlate the frequency discrimination scores and the speech identification scores in individuals with and without dead regions.

Analysis revealed that FMDL scores were lower (better) for individuals without dead regions near the edge frequency as against individuals without dead regions. It was also noticed that as the edge frequency was lower, that is at 1 kHz, the FMDL scores were higher (worse) as against 4 kHz in individuals with and without cochlear dead regions. These results also suggest that the enhanced frequency discrimination near the edge frequency in individuals with cochlear dead regions, which was due to cortical re-organization.

The speech identification scores were better for filtered conditions, with cut - off being the frequency of the edge, in individuals with dead regions at edge frequency 1 kHz and 4 kHz. These results again reveal that the individual with dead regions do make use of the full band speech information specially the high frequency information and the identification improves in the filtered conditions with the filter cut- off being the frequency of the edge.

There was some correlation between the frequency discrimination scores and speech identification scores in both filtered and unfiltered conditions in individuals without dead regions as against in individuals with dead regions. This may be due to the mis-match in the frequency- place representation due to the presence of off-frequency listening in individuals with DR.

Implications for future research

- The study can be replicated with different speech filtering conditions and estimating the condition where the individuals with cochlear dead region perform the best and the condition which best correlates with the frequency discrimination.
- Speech material in the form of words and sentences can be taken and filtered sharply without degrading the stimuli and can be used to find the correlation of speech identification scores and frequency discrimination abilities.
- Similar studies can also be carried out with amplification/ hearing aids.

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