EFFICACY OF NON-LINEAR FREQUENCY COMPRESSION IN INDIVIDULAS WITH AND WITHOUT COCHLEAR DEAD REGIONS

Sruthy Hrishikesan & P. Manjula*

Abstract

There have been reports about different frequency lowering strategies like Non-linear Frequency Compression (NLFC) in individuals with a sloping hearing loss (Simpson, Hersbach, and McDermott, 2005, 2006). The present study investigated the usefulness of NLFC in individuals with and without cochlear dead regions. Two groups (Group I without cochlear dead region and Group II with cochlear dead region) formed the basis of the study. The hearing aid testing was done for three aided conditions- without NLFC, with NLFC initial fit settings and with NLFC fine-tuned settings. The parameters assessed were speech identification scores, Ling's six sound identification and quality judgment. The results revealed that there was a significant difference in the mean SIS scores for words only for the pair without NLFC and NLFC fine-tuned settings for Group I with no significant difference in Group II for any pair. The performance was similar for all the aided conditions for SIS for sentences in both the groups. Ling's six sound identification revealed a slight improvement in fricative identification among participants in Group I with no improvement in the Group II. The results of quality ratings showed that the mean ratings of quality were higher for the Group I compared to Group II and there was a significant difference in the quality rating between both the groups. In conclusion, the amplification needs of individuals with and without cochlear dead region are different and frequency lowering strategies like NLC may be of limited usefulness to individuals with cochlear dead region.

Key Words: Speech Identification Scores, Ling six Sound identification, quality judgment.

Introduction

The most prevalent audiometric configuration among adults with hearing loss is the sloping type which is around 50% (Pittman & Stelmachowicz, 2003). The primary goal of current hearing aid fitting strategies is to make the speech signal audible in those regions where the sensitivity is reduced, and in the case of high-frequency hearing loss this means providing high-frequency amplification. The American Speech-Language Hearing association (1998) asserts that amplification should provide audibility and comfort for soft and average input levels, and tolerance for high input levels.

It is important to point out that providing audibility of high-frequency information to listeners with severe to profound hearing impairment remains a controversial topic (Ching, Dillon, & Byrne, 1998; Ching, Dillon, Katsch, & Byrne, 2001; Hogan & Turner, 1998; Plyler & Fleck, 2006; Turner & Henry, 2002). Large variability in aided listening performance is thought to be due to both the level of high-frequency audibility the listener is receiving as well as the listener's ability to extract useful information from the audible signals.

There have been equivocal findings in the area of high frequency amplification for sloping hearing loss. Some investigators report that significant improvements in speech

* Professor of Audiology, All India Institute of Speech and Hearing, Mysore, India
email: manjula21@yahoo.co.in

understanding, especially in noisy environments, occur when listeners with sloping sensorineural hearing loss are provided with high-frequency information (Plyler & Fleck, 2006; Turner & Henry, 2002). On the other hand, listeners who are provided with audibility at frequencies where hearing levels are severe and/or sloping did not show speech recognition benefit (Ching, Dillon, & Byrne, 1998; Ching, Dillon, Katsch, & Byrne, 2001; Hogan & Turner, 1998). This is thought to be due to a limited ability to use the amplified signal in that frequency region. Other investigators have reported that, listeners with suspected dead regions in the high-frequencies perform similar to normals on speech recognition tasks when broadband amplification is used in a quiet listening environment (Mackersie, Crocker, & Davis, 2004). The listeners without dead regions are better able to make use of high-frequency cues (Moore, 2004). Thus, different outcomes may be due to factors such as the inner hair cell (IHC) loss which can be referred to as dead regions, congenital versus acquired hearing loss, and wide band versus frequency lowering technology. The results of these studies have important implications for clinical practice. If amplifying speech to audible levels in the high frequencies does not improve speech recognition, then attempts to provide gain may not be necessary or desirable in certain cases.

Various signal processing strategies have emerged to allow high-frequency information to be moved to a lower-frequency region so it can be more easily accessed by the listener. Frequency transposition or shifting and frequency compression technology are the two main types of frequency-lowering technology available even today. Frequency transposition or shifting refers to shifting each frequency component in the sound by a constant factor. This is specifically related to lower the signal by a fixed frequency value. A possible advantage of this form of transposition is that ratios among the frequency components of the signal are not changed by the processing. This may be beneficial for speech perception because frequency ratios convey important information. On the other hand, a possible disadvantage is that overall pitch of the speech signal is also lowered. Another problem with shifting is that it does not reduce the bandwidth. It only shifts the signal down. This creates very strong distortions when the shifting frequency is greater than the signal frequency.

The frequency compression technology compresses the output bandwidth of the signal by a specified ratio. Also frequency compression reduces both the frequency and the bandwidth by a preset compression ratio or factor (for instance, anywhere from 1.5 to 5.0 in steps of 0.25). Because the spectrum is “squeezed” with frequency compression, operating in real-time requires a complex algorithm that maintains the critical information. This action takes place extremely rapidly, in the order of two to four milliseconds. When the next sound comes along, usually a vowel in the normal syllabic sequence, the aid reverts to its normal amplification pattern. The voiced sounds are simply passed through and processed as determined during the initial programming. When the next voiceless sound is detected, the frequency compression circuit is again activated. For setting the parameters of frequency compression, both the hearing levels at specific frequencies and the slope of the audiogram across frequencies are taken into account. For calculation of the cut-off frequency, relatively high frequencies are selected, if the hearing impairment is mild or the audiogram is flat. Lower cut-off frequencies are selected for more severe levels of impairment or for audiograms with relatively steep slopes. The frequency compression ratio is then derived from the cut-off frequency. The compression ratio effectively determines the strength of the frequency compression processing above the cut-off frequency (Ross, 2000).

Some listeners have obtained speech perception benefits when listening to proportional frequency compression (Turner & Hurtig, 1999). This method of frequency compression preserved the ratios between the frequencies of the components of natural speech, as well as the temporal envelope of the unprocessed speech stimuli. Both frequency-compressed speech and the control condition of unprocessed speech were presented with high-pass amplification. An advantage of this method is that frequency ratios are preserved. In other words, the relationship between the frequencies of different formant peaks in speech remains constant. These ratios may be particularly important cues for the recognition of vowels in speech (Neary, 1989). Frequency compression is of two types, linear compression and non-linear frequency compression.

Simpson, Hersbach, and McDermott (2005) evaluated the performance of an experimental frequency compression hearing device using tests of speech understanding and results showed that eight showed a significant improvement in score, eight participants did not show any change in the score whereas, one participant showed a significant decrease in score.

A similar study was done by the same investigators Simpson, Hersbach, and McDermott (2006) who examined speech perception in seven individuals with steeply sloping hearing loss. No significant differences in group mean scores were found between the frequency-compression device and a conventional hearing instrument for understanding speech in quiet and subjective comparisons between conventional hearing aids and the frequency compression scheme revealed that the majority of listeners preferred conventional amplification (Cox & Alexander, 1995). The authors concluded that frequency compression provided limited benefit to individuals with steeply sloping sensorineural hearing loss with suspected dead regions.

Thus, the studies on frequency lowering technologies have led to equivocal results which indicate the need for more research in the field. There is a dearth of information regarding the benefits of the non-linear compression in hearing aids among individuals with hearing impairment.

The aim of the present study was to evaluate the effect of non-linear frequency compression (NLFC) in hearing aids on the speech identification performance and also on the perceived quality of speech using NLFC in individuals having sloping sensorineural hearing loss

1. With cochlear dead region and
2. Without cochlear dead region.

Method

Twenty-four individuals with bilateral sensorineural hearing loss were selected for the study. The participants were divided into two groups. Group I, which included 13 participants

(N=15 ears) having sloping sensorineural hearing loss without any cochlear dead region. The slope of the hearing loss in the test ear was 10-15 dB threshold increase per octave. The participants were in the age range from 32 to 72 years (mean: 57.61 years; SD: 8.78 years). Group II which consisted of 11 participants (N=14 ears) having sloping sensorineural hearing loss with the presence of cochlear dead region. The slope of the hearing loss in the test ear was 15-30 dB/octave. The participants were in the age range of 35 years to 76 years (mean: 49.81 years; SD: 13.98 years). All the participants were native speakers of Kannada language and were naïve hearing aid users.

High frequency word lists and sentence material developed by Mascarenhas (2001) were used. The test material consists of three lists each with twenty five words and three lists of nine sentences each. The word lists and sentence lists were recorded using Adobe Audition software (version 1.0) spoken by a native female speaker of Kannada with normal vocal effort with the microphone kept at a distance of 5-6 inches from the mouth of the speaker. The testing was done in a sound treated single/double room, with ambient noise levels within permissible limits.

Procedure

The testing was done in three phases

Phase I: Categorization of participants into those having cochlear dead region and without cochlear dead region

Phase II: Hearing Aid Fitting without and with non-linear frequency compression (NLFC)

Phase III: Evaluating the efficacy of frequency compression through

3.1. Speech Identification Score

3.2. Ling six sound identification

3.3. Quality judgment

Phase I

Step 1: Routine audiological testing including pure tone audiometry, speech audiometry, and immitance evaluation were carried out for each participant. Later the TEN (HL) test was administered to categorize the participants with and without cochlear dead regions.

The steps followed to select high frequency sloping sensorineural hearing loss were:

1. Pure tone audiometry was done for all the participants. Air conduction thresholds were estimated between 250 Hz to 8000 Hz at audiometric frequencies under TDH-39 headphones encased in MX-41 AR ear cushion. The bone conduction thresholds were estimated between 250 Hz to 4000 Hz using B-71 bone vibrator. Modified Hughson Westlake method (Carhart & Jerger, 1959) was used to estimate the threshold.
2. Speech audiometry was administered for all the participants in which Speech Recognition Threshold (SRT), Speech Identification Scores (SIS) and Uncomfortable Loudness Level (UCL) for speech were measured.

3. Tympanometry with a 226 Hz probe tone was carried out for all the participants. Reflexometry was carried out in which the ipsilateral and contralateral thresholds were estimated for all the participants at 500 Hz, 1000 Hz, 2000 Hz and 4000 Hz.

After the initial diagnosis of sloping sensorineural hearing loss, the participants were administered the TEN(HL) test (Moore, Glasberg, & Stone; 2004) for the identification of dead region in the cochlea.

The Threshold Equalizing Noise (Hearing Level) or TEN(HL) CD was played using a laptop computer and the stimuli were presented via the Madsen OB-922 (Version 2.0) through TDH-39 ear phones. Test frequencies were 0.5, 0.75, 1, 1.5, 2, 3, and 4 kHz. The TEN (HL) level is specified as the level of a one-ERB_N wide centered at 1 kHz. ERB_N stands for Equivalent Rectangular Bandwidth Noise of the auditory filter determined by using young individuals with normal hearing at moderate sound levels (Glasberg & Moore, 1990). Levels of the TEN noise were 50 and 70 dB/ERB_N (50, 70 dB SPL) for all participants. A TEN level of 70 dB HL / ERB_N was used for most of the frequencies and a lower level of 50 dB HL/ ERB_N was used for frequencies with lesser degree of (< 50 dB HL) hearing loss.

The level of the signal and the TEN was controlled using the attenuators in the audiometer. The TEN(HL) test was carried out as described by Moore, Glasberg, and Stone (2004), using a procedure similar to manual audiometry, that is modified Hughson-Westlake procedure (Carhart & Jerger, 1959), except that masked thresholds were measured using a 2-dB final step-size as recommended by Moore, Glasberg, and Stone (2004).

The TEN noise and pure tones were played in same channels of the audiometer. Prior to testing, calibration was done in which an individual with normal hearing was supposed to detect the tone in the presence of noise at 50 dB HL. The noise level was kept constant at 50 dB HL. The level of tone was adjusted using the level adjustment knob of the audiometer. The individual with normal hearing was asked to indicate whether he / she heard the tone in the presence of TEN which was presented continuously at a fixed level of 50 dB HL and the intensity of the tone was varied, for equal loudness. The level adjustment knob for the tone was decreased if the participant was able to hear the tone and the level adjustment knob was increased if the participant was not able to hear the tone. An up and down procedure for changing the level adjustment knob of the audiometer was done until the participant was able to detect the tone in the presence of TEN when both the tone and TEN were presented at 50 dB HL. TEN was presented ipsilaterally and the masked thresholds were obtained for each test frequency. Once the calibration was performed, the masked thresholds were compared to ascertain the presence of cochlear dead regions. The presence or absence of a cochlear dead region was based on the criteria suggested by Moore, Glasberg, and Stone (2004). The criteria to signify a dead cochlear region were:

1. If the masked threshold in the TEN was 10 dB or more than the TEN level/ ERB_N and the TEN elevated the absolute threshold by 10 dB or more, then a dead region was assumed to be present at that frequency.
2. 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 assumed to be absent.
3. In case the TEN(HL) level could not be made high enough to elevate the absolute threshold by 10 dB or more, then the results were considered inconclusive. This would happen because the noise that would have been required was judged as too loud or because the maximum output of the audiometer was reached. A "no response (NR)" was recorded when the participant did not indicate hearing at the maximum output level of the audiometer. Participants with inconclusive results were not included in the study.

This test was administered for all participants and they were assigned to either the group without cochlear dead region (Group I) or with cochlear dead region (Group II) depending on the presence or absence of a cochlear dead region. The edge frequency, that is, the frequency from which a cochlear dead region starts, was noted down for all the participants in Group II.

Phase II

A. *Hearing Aid Fitting*

Two digital BTE hearing aids of the same model with NLFC feature were used for the study. The hearing aids were programmed in three conditions

1. Without the NLFC being activated as program 1(P1) of the first hearing aid.
2. The default settings for the gain and cut-off frequency and compression ratio of non-linear frequency compression as determined by the software were saved as the program 2 (P2) of the first hearing aid.
3. The fine tuning of NLFC in the hearing aid was done by manipulating two adjustable parameters of frequency compression from the 'sound recover' feature in the software. In this feature, the Cut-off Frequency and the frequency Compression Ratio of the NLFC were adjustable.

To 'fine tune' or optimize the frequency compression parameter, the cut-off frequency (range being 1.5 kHz to 6 kHz), and the ratio of frequency compression (range being 1.5:1 to 4:1) were manipulated in such a way that the participant was able to perform better on a identification task for /s/ and /ʃ/.

The fine tuning of the ratio of frequency compression parameter was done by the following steps:

1. If the participant was able to identify both the phonemes /s/ and /ʃ/ with the initial fit setting of the frequency compression, the parameter was adjusted to weaker settings step-by-step. In other words, the cut-off frequency was increased, i.e., the strength of frequency compression was decreased when the participant was able to identify the phonemes at the default cut-off frequency till he/she was able to identify both the phonemes presented at normal conversational levels.
2. If the participant was not able to identify one or both the phonemes correctly, the frequency compression parameter was made stronger step-by-step. In other words, the cut-off frequency was decreased, i.e., the strength of frequency compression was increased when the participant was not able to identify the two phonemes. An up and down procedure was used until consistent correct responses were obtained from the participants when the phonemes were presented randomly. This was done each time by testing the identification ability for /s/ and /ʃ/. The frequency compression ratio at which he/she was able to identify correctly at least for 50% of the time being presented was used. If the client was not able to identify the phonemes through auditory mode alone, then training was given for a brief period of about ten minutes along with the visual modality. Later, the fine tuning was continued with the auditory modality alone. If any participants were not able to identify the two phonemes even after fine tuning of the cut-off frequency and compression ratio, the cut-off frequency at which the maximum number of times the participant identified the phonemes were finalized as the cut-off frequency and compression ratio of the participant. This fine tuned cut-off frequency and frequency compression ratio of the NLFC was stored in as Program 1 (P1) of the second hearing aid. After programming the hearing aid, Speech Identification Score and Quality Judgment were evaluated.

For each participant, if the non-test ear was the poorer ear, then the testing was done without masking. However, if the non-test ear was the better ear, then the better ear was masked with speech noise at 65 dB using ER-3A insert ear phone fitted with an appropriate ear tip. This was done to avoid the participation of the non-test ear in the test.

Phase III: Hearing Aid Verification

A. Measurement of Speech Identification Score (SIS)

The participants were made to sit comfortably on a chair in the test room at a distance of one meter from the loud speaker of the audiometer at 45^0 A on the aided ear side. The recorded word list was presented through a computer routed through the Madsen OB-922 (Version 2.0) audiometer. The presentation level was set at 40 dB HL. Level adjustment was done for the calibration tone so that the VU-meter deflections averaged '0'. The SIS was obtained in quiet condition.

The order of testing the participants was unaided testing followed by aided testing in which the enabling and disabling of the Non-Linear Frequency Compression feature, was randomized across and within the participants to avoid any order or learning effect. The SIS was measured in unaided and three aided conditions.

1. *SIS in unaided condition*

   This was done without a hearing aid being worn by each of the participant.

2. *SIS in aided condition*

   Three aided conditions were evaluated for each participant from both the groups.

   1. With Non-Linear Frequency Compression disabled
   2. With Non-Linear Frequency Compression enabled - Initial Fit setting
   3. With Non-Linear Frequency Compression enabled - Fine Tuned setting

As there were three lists of words and sentences, none of the words or sentences list was repeated for any participant during the data collection. The participants were instructed to repeat the recorded words that he /she heard which were presented through a computer and routed through the auxiliary input of the audiometer. The responses were noted down in the International Phonetic Alphabet by the tester. The total number of correct responses was noted down for each test condition for each participant.

For the purpose of the study, scoring for words and sentences were done. For word identification, the response was considered incorrect if he/she failed to repeat or if it was repeated incorrectly. For sentences, it was taken as a correct response only if the participant repeated the entire sentence verbatim. The response was considered as incorrect if any word was missed or reworded or any phoneme in a word being replaced by another phoneme. Each correct response was given a score of 'one'. The total number of correct responses was calculated after testing in each condition, for a maximum score of 25 for words and 9 for sentences.

Further, the ability of the participant to identify the Ling six speech sounds (/a/, /i/, /u/, /s/, /ʃ/, /m/) was done for each condition at 40 dB HL and the sounds which were not identified by the participant were noted down. The sounds were presented in random order. This was done using monitored live voice through the audiometer. For each correct identification, a score of 'one' was given and 'zero' for each incorrect identification. All the sounds were presented once and the responses were noted down. If any client found difficulty in identifying the phonemes, then the sounds were presented once more. After the presentation, the identification scores were converted to percentage scores.

B. Quality Judgment

The participants were asked to rate the hearing aid in terms of its quality of speech output in all the four conditions tested. For this, the recorded Kannada passage was routed through the audiometer at 40 dB HL. The participants were instructed to rate on six parameters of quality. The instructions were made simple in Kannada and it was explained to the participant.

The parameters and the rating scale for evaluating the quality judgment were loudness, clearness, sharpness, fullness, naturalness, overall impression. Each parameter was rated on a 10 point scale. That is 0 for very poor, 2 for poor, 4 for fair, 6 for good, 8 for very good, 10 for excellent. The participants were asked to rate the odd numbers if they found the quality to be intermediate between two points.

Results and Discussion

The data for the above parameters were analyzed using Statistical Package for the Social Sciences (SPSS for windows, Version 16) software. The mean and standard deviation of performance for words and sentences in terms of SIS was obtained for unaided condition (UA), without NLFC (WNFC), with NLFC-initial fit settings (NFCIF), and with NLFC- fine tuned (NFCFT) settings across the two groups. The mean and standard deviation of Group I (N=15 ears without DR) and Group II (N=14 ears with DR) for the SIS in the four test conditions have been tabulated.

Table 1: Mean and standard deviation (SD) of groups with cochlear dead regions (Group I) and without cochlear dead regions (Group II) in the four different conditions for words and sentences

			Test conditions			
			Unaided	*Without NLFC*	*With NLFC-initial fit settings*	*With NLFC-fine tuned settings*
Words Max. Score = 25	Group I	Mean	3.53	14.47	15.93	17.40
		SD	5.12	2.97	2.66	2.75
	Group II	Mean	6.00	11.50	11.21	11.71
		SD	6.52	6.25	5.86	5.88
Sentences Max. Score = 9	Group I	Mean	2.0667	6.27	7.007	7.0000
		SD	2.46	1.91	1.36	1.20
	Group II	Mean	3.57	5.79	5.86	5.79
		SD	3.82	2.97	3.21	2.86

For Group I, among the aided conditions, the performance for words was best with NLFC- fine tuned settings followed by NLFC-initial fit settings, compared to that without NLFC. However for the Group II, the mean SIS values revealed that the performance improved in the aided condition, but remained similar in all the three aided conditions for words. For sentences, the performance in the aided condition improved when compared to that in the unaided condition with no difference between the three aided conditions in both the groups. In order to find out if the slight differences in the mean scores of the performances were significantly different, mixed ANOVA was performed. It showed that among the aided conditions, a significant difference was found between with NLFC-fine tuned settings and without NLFC. Whereas, there was no significant difference between the pairs with NLFC-initial fit settings and with NLFC- fine tuned settings for both words and sentences. The NLFC-initial fit settings and without NLFC conditions were not statistically significant even at 5% level of significance.

Figure 1 depicts the mean scores for all the four conditions for words and sentences as stimuli. It can be seen that the mean scores were higher for Group I (without DR) than Group II (with DR) in all the three aided conditions.

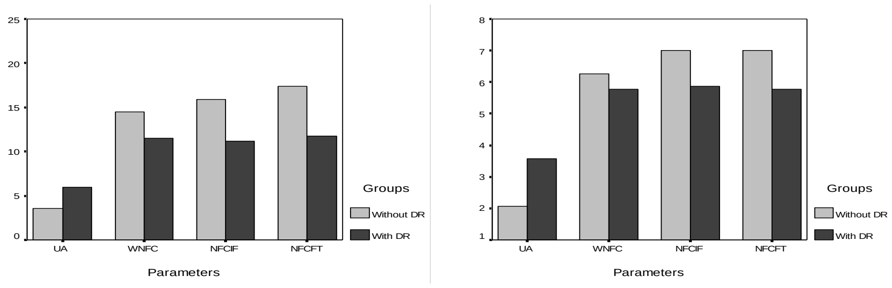


Figure 1: The graphical representation of the mean SIS for words and sentences for both the groups.

Independent samples t-test for SIS for words was done to check the group differences within each condition. The results showed a significant difference between the NLFC-initial fit settings [t (27) = 2.826, $p < 0.05$] and fine tuned settings [t (27) = 3.376, $p <0.05$] across the two groups at 5% level of significance while no significant difference for other pairs. But for sentences, no significant difference was seen for any pair. One way repeated measures ANOVA was done to compare the SIS between the unaided condition and the three aided conditions in both the groups. Results of the analysis showed that for Group I, significant difference was found only for the NLFC fine tuned settings and without NLFC at 5% level of significance for words and sentences and no significant difference for any other pairs for Group I. No significant difference for Group II for both words and sentences even at 5% level of significance was noted.

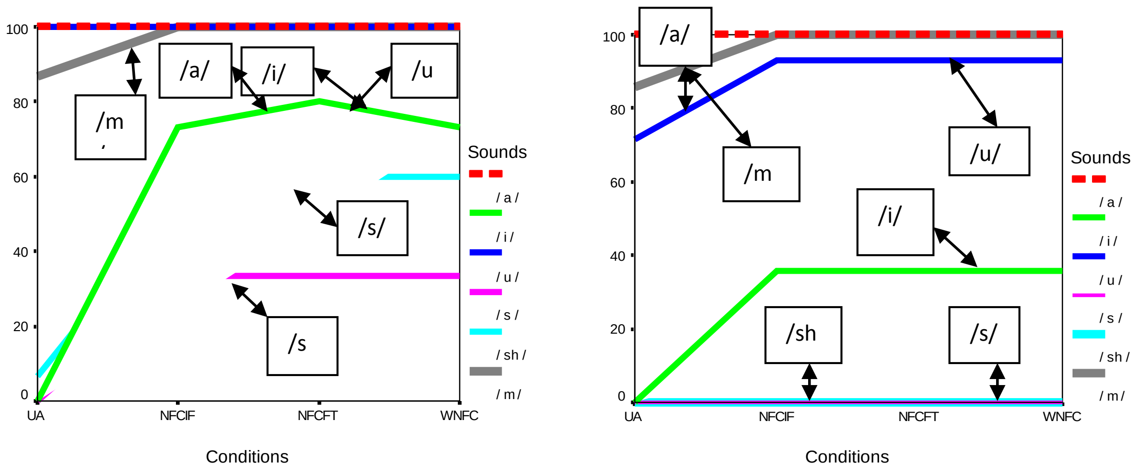
The results support the findings of the studies on speech perception through non-linear frequency compression by Simpson, Hersbach, and McDermott (2005, 2006). In their study, it was reported that a significant improvement for individuals with gradually sloping hearing loss but no improvement for individuals with steeply sloping hearing loss was reported. They attributed the cause for lesser improvement in steeply sloping hearing loss to the presence of a "cochlear dead region". An improvement might have been present if the amplification was given within half to one octave above the estimated edge frequency (Vickers, Moore & Baer., 2001).

There are studies which show that reduction of hearing aid gain in the frequency range of dead regions may be desirable in some listeners who have them (Preminger, 2004). Probably in the present study, an improvement in performance of Group II might have been noticed if amplification was restricted to within half to one octave above the estimated edge frequency, as reported by Vickers, Moore, and Baer (2001). Kluk (2005) concluded that if for subjects with DRs, a larger than normal region of the auditory cortex is devoted to the analysis of frequencies just below *fe*, then it is possible that this auditory cortex re-organization makes subjects with DRs more effective at extracting "useful" information from lower frequencies in the speech. The frequency lowering strategies like non-linear frequency compression shifts the inaudible high frequency information to the lower frequencies where there is more useful hearing. So, it may be possible that the individual with a cochlear dead region may benefit better if the higher frequencies are shifted to the frequencies around the edge frequencies where it is more effective in extracting the information.

Table 2: The identification of Ling's six sounds in four test conditions

Test Conditions	*Group*	*/ a/*	*/ i /*	*/ u /*	*/ s /*	*/ ʃ /*	*/ m /*
Unaided	Group I	100%	0%	100%	0%	6.7%	86.7%
	Group II	100%	0%	71.4%	0%	0%	85.7%
Without NLFC	Group I	100%	73.3%	100%	33.3%	60%	100%
	Group II	100%	35.7%	92.9%	0%	0%	100%
With NLFC-initial fit settings	Group I	100%	73.3%	100%	33.3%	53.3%	100%
	Group II	100%	35.7%	92.9%	0%	0%	100%
With NLFC- fine tuned settings	Group I	100%	80%	100%	33.3%	60%	100%
	Group II	100%	35.7%	92.9%	0%	0%	100%

The Figure 2 is the line graph depicting the percentage scores of identification of scores for both the groups.



A B

Figure 2: Line Graph depicting the percentage scores for the identification of Ling's Sounds, UA - Unaided, WNFC - Without NLFC, NFCIF - With NLFC Initial Fit settings, NFCFT - With NLFC Fine Tuned settings, A- Group I, B- Group II.

The NLFC slightly improved the identification of fricatives in Group I comprising of participants without a cochlear dead region. The high frequency amplification did benefit the Group I having participants without a cochlear dead region. However, the NLFC did not aid in the identification of fricatives in the Group II with participants having a cochlear dead region. This may be due to the non-functioning or absent inner hair cells in the Group II because of which the benefit from high frequency amplification is less. This finding supports that in the literature which reports of limited benefit for individuals with high frequency amplification in individuals with a cochlear dead region (Gordo & Iorio, 2007; Baer, Moore, & Kluk, 2002; Mackersie, Tracy, & Davis, 2004; Vickers, Moore, & Baer, 2001) while improvement in performance for individuals without a cochlear dead region (Gordo & Iorio, 2007). This may be due to the fact that at frequencies where dead region is present, those individuals will not receive usable speech cues despite “sufficient” aided gain (Preminger, Carpenter, & Ziegler, 2005).

Quality Judgements

The Figure 3 depicts the mean ratings for all parameters of quality across all the three aided conditions. It shows that the maximum score or rating obtained for any parameter is ‘6’.

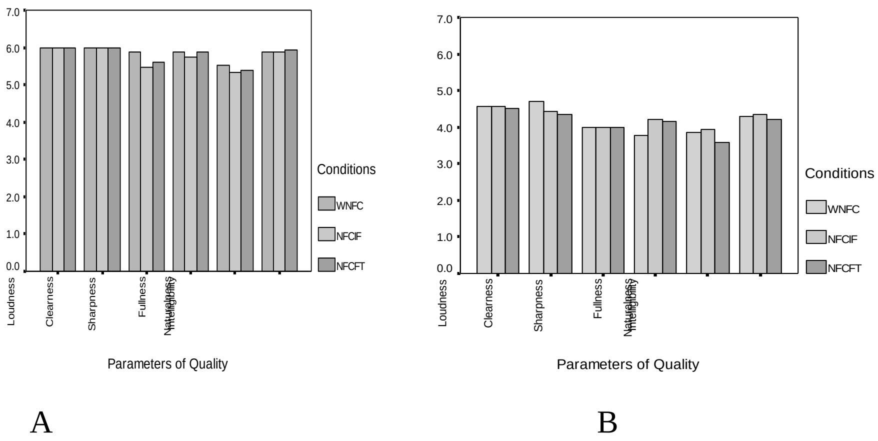


Figure 3: The mean ratings of the subjective quality across the aided conditions for six parameters for both the groups, UA - Unaided, WNFC - Without NLFC, NFCIF - With NLFC Initial Fit settings, NFCFT - With NLFC Fine Tuned settings.

These results reveal that mean scores of subjective quality rating was higher for the Group I - without cochlear dead region, when compared to Group II - with cochlear dead region. This finding support that reported by Preminger, Carpenter, and Ziegler, (2005) which showed that the performance of participants with no dead region was similar to the normative group in APHAB sub-scales, whereas, the subjects with dead region scored poorer. In other words, the group that closely resembled the “successful” hearing aid users in subjective hearing aid performance was the group without a cochlear dead region.

Mann-Whitney U test was done to investigate the significant difference between the quality ratings by participants in the two groups across the three aided conditions for each of the six parameters of quality. The results of Mann-Whitney U test showed significant difference across the three aided conditions for all the six parameters of quality between the two groups with the Group I (without a cochlear dead region) performing better than the Group II (having a cochlear dead region).

From the present study, it can be concluded that high frequency amplification does help individuals with sloping hearing loss without a cochlear dead region. Also, frequency lowering strategies like NLFC, with the compression ratio optimized can be of help in speech understanding in individuals with sloping sensorineural hearing loss without a cochlear dead region. The implication of the present study is that unlike the individuals without cochlear dead region, individuals with cochlear dead region did not seem to benefit either with any high frequency amplification or NLFC. Thus, prescription of such technology should be done with caution for individuals with a sloping hearing loss. However further research is required to validate the benefits of NLFC in individuals without cochlear dead region. The study throws light on the limited benefit from amplification for individuals with sloping hearing loss with cochlear dead region. Their amplification needs are different from those with sloping hearing loss without dead regions.

References

American Speech-Language-Hearing Association (1998). Guidelines for hearing aid fitting for adults. *American Journal of Audiology, 7,* 5-13.

Baer, T., Moore, B. C. J., & Kluk, K. (2002). Effects of low-pass filtering on the intelligibility of speech in noise for people with and without dead regions at high frequencies. *Journal of the Acoustical Society of America*, *112*, 1133–1144.

Carhart, R. & Jerger, J. (1959). Preferred method for clinical determination of pure-tone thresholds. *Journal of Speech and Hearing Disorders, 24,* 330-345.

Ching, T. Y. C., Dillon, H., Katsch, R., & Byrne, D. (2001). Maximizing effective audibility in hearing aid fitting. *Ear and Hearing, 22*(*3*)*,* 212-224.

Ching, T. Y., Dillon, H. & Byrne, D. (1998). Speech recognition of hearing impaired listeners: predictions from audibility and the limited role of high-frequency amplification. *Journal of the Acoustical Society of America, 103*, 1128-40.

Glasberg, B. R. & Moore, B. C. J. (1990). Derivation of Auditory Filter Shapes from Notched Noise Data. *Hearing Research 47*: 103-137.

Gordo, A., and Iorio, M. (2007). Dead regions in the cochlea at high frequencies: implications for the adaptation to hearing aids. *Brazilian Journal of Otorhinolarynogology, 73(3),* 299-307.

Hogan, C. A. & Turner, C. W. (1998). High-frequency audibility: benefits for hearing-impaired listeners. *Journal of the Acoustical Society of America*, *104*, 432-41.

Kluk, K. (2005). *Measuring and characterizing dead regions*. Unpublished doctoral thesis, University of Cambridge, Cambridge.

Mackersie, C. L., Crocker, T. L., & Davis, R. (2004). Limiting high-frequency hearing aid gain in listeners with and without suspected cochlear dead regions. *Journal of the American Academy of Audiology, 15*, 498-507.

Mascarenhas, K. E. (2001). A high frequency Kannada speech identification test (HF-KSIT). Unpublished Masters Dissertation submitted to the Univ. of Mysore, Mysore.

Moore, B. C. J., Peters, R. W & Glasberg, B. R. (1993). Detection of temporal gaps in sinusoids: Effects of frequency and level. *Journal of the Acoustical Society of America, 93,* 1563-1570.

Moore, B. J. (2004). Dead regions in the cochlea: Conceptual foundations, diagnosis, and clinical applications. *Ear and Hearing, 25(2),* 98-116.

Neary, T. (1989). Static, dynamic, and relational properties in vowel perception. *Journal of the Acoustical Society of America; 44:* 2088–2113.