Efficacy of Frequency Transposition Hearing Aid In Dead Region Subjects

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Abstract

A hearing aid is an electroacoustic device which enables a hearing impaired individual to make maximum use of his residual hearing. Decreased audibility, reduced dynamic range, decreased frequency resolution and temporal resolution are common problems in individuals with sensorineural hearing loss. Sensorinueral hearing loss is also commonly called cochlear loss, inner ear loss and nerve loss. The sensory mechanism comprises of the Outer hair cells (OHC's) and the inner hair cells (IHC's). Damage to OHCs will lead to a reduction in the compressive mechanism of the cochlea. Damage to IHCs will lead to a reduction in sound transduction process. For this reason such regions are referred to as "Dead regions". Steeply sloping hearing loss is often associated with cochlear dead regions and also high frequency part of speech contributes no information in such individuals. Thus, it is essential to transpose high frequency information to the useful hearing at low frequencies in order to make high frequency information accessible. Hence, the present study aimed at evaluating 10 subjects (15 ears) with Dead regions. Subjects who were diagnosed as having dead regions using Modified Threshold Equalising Noise (TEN) test participated in the study. Frequency transposition hearing aid was fitted for individual who have dead region. Speech identification performance was evaluated with High frequency sentence and word list in Transposition and No Transposition conditions. The results revealed that with frequency transposition there is statistically significant amount of benefit than non transposed condition for individuals with steeply sloping hearing loss with dead regions.

Key words: High frequency sensorineural hearing loss, Frequency transposition, Dead region, hearing aids, TEN.

Introduction

A hearing aid is an electroacoustic device which enables a hearing impaired individual to make maximum use of his residual hearing. It takes an acoustical signal such as speech and converts into an electric signal before amplification stage. The primary goal is to amplify and deliver speech and other sounds at levels equivalent to that of normal speech and conversation. It is the most effective therapeutic approach for the majority of individuals with hearing loss. It differs in design, size, gain, ease of handling, volume control and availability of special features.

Decreased audibility, reduced dynamic range, decreased frequency resolution and temporal resolution are common problems in individuals with sensorineural hearing loss. Sensorinueral hearing loss is also commonly called cochlear loss, inner ear loss and nerve loss.

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The sensory mechanism comprises of the Outer hair cells (OHC's) and the inner hair cells (IHC's). Damage to OHCs will lead to a reduction in the compressive mechanism of the cochlea. Damage to IHCs will lead to a reduction in sound transduction process. For this reason such regions are referred to as "Dead regions" by Moore and Glasberg, (1997), Moore, Huss, Vickers, Glasberg and Alcantra, (2000). In approximately 90% of hearing impaired adults and 75% of hearing impaired children the degree of impairment worsens from 500 Hz to 4 KHz (Macrae & Dillon, 1996). Most hearing impaired individuals include a greater loss of hearing sensitivity at high frequencies than at low frequencies. High frequency sensorineural hearing loss is the most common configuration and type of hearing loss which results from destruction of inner hair cells IHCs within cochlea Engstrom (1983), Borg, Canlon and Engstrom, (1995).

Individuals with moderate to severe hearing loss at high frequencies often do not benefit from amplification of high frequencies or even perform more poorly when high frequencies are amplified (Villchur, 1973; Moore, 1986; Murray & Byrne, 1986; Hogan & turner, 1998; Moore, 2001; Vickers, Moore & Baer, 2001). It has been suggested that subjects who do not benefit from amplification of high frequencies have reduced function or complete loss of function of IHCs and or neurons.

Mc Dermott, Dorkos, Dean and Ching (1999) found that conventional amplifying hearing aids were of limited use and therefore various attempts had been made to modify them using filtering, extended frequency response, selective amplification and amplitude compression. However, the findings on effect of these manipulations can restore missing high frequency information.

In individuals with steeply sloping loss with high frequency thresholds of about 70 dBHL or greater the high frequency parts of speech contributes no information. Thus it is essential to transpose high frequency information to the useful hearing at low frequencies in order to make high frequency information accessible (Johansson 1961; Wedenberg, 1961; Raymond & Proud 1962; Ling & Druze, 1967; Foust & Gengel, 1973; Velmans & Marcuson, 1983; Rees & Velmans, 1993; Turner & Hurtig, 1999) using transposition devices and results revealed significant amount of improvement. Hence there is a need for additional training procedure or an alternative transposition technique which would result in perceptual benefit for at least some individuals. Inteo is a new advance in the technology to extend the audibility range into the high frequencies and it also provides good audibility in regions where the sensitivity is reduced as in high frequency hearing loss.

Considering all these factors the present study was designed to study the benefit of frequency transposition hearing aids and to assess the speech identification performances for individuals with dead regions in two conditions:

1. With Transposition
2. Without Transposition

Method

Subjects: 10 subjects (15 ears) with moderate to severe sloping high frequency sensorineural hearing loss with age range of 20 to 75 years were selected for the study. Subjects who were diagnosed as having Dead Regions were taken for the study.

Stimulus: Standardized high frequency word list and sentence list developed by Mascarenhas & Yathiraj (2001) was used. The test consists of three lists each with twenty five words and three sentences lists each with nine sentences.

Recording of Stimulus: These word lists and sentence lists were recorded using a unidirectional microphone using wave pad software at a sampling rate of 16,000 KHz. Noise reduction and normalization was done using Audacity software.

Procedure

Step 1: Calibration of audiometer OB922 (dual channel) was done in free field condition.

Step 2: The TEN (HL) test (Moore, 2004) was carried out for diagnosis of dead regions in the cochlea.

Step By Step Setting Up

1. Feed the left output from the CD player to the left (or A) line. Level input on the audiometer and the right output from the CD player to the right (or B) input.
2. Select the left (or A) input channel 1 on the audiometer and the right (or B) input for channel 2 on the audiometer.
3. Play track 1, set the audiometer so that both line inputs are played continuously press the interrupt buttons and adjust vu meter to read 0 dB. Turn off the two inputs (press the interrupt buttons).
4. Mix the two channels and direct the mixed channel to the desired ear (left or right).
5. Measure the absolute threshold (traditional pure tone audiogram) for each ear at each frequency using Tracks 2-8 of the CD.
6. Set the desired noise level using the channel 1 control. The level in dB HL /ERB corresponds to the dial reading on the audiometer.
7. Measure the masked threshold for each ear at each level /frequency using tracks 2-8 of the CD while playing noise continuously.
8. Repeat steps 4-6 for the other ear if desired.
9. A dead region for a particular frequency is indicated by a masked threshold that is at least 10 dB above the absolute threshold and 10 dB above the TEN (HL) level per ERB.

Step 3: The subjects who fulfilled the standard criteria were included in the study. Their pure tone thresholds from 250 to 8 KHz for air conduction and from 250 to 4 KHz for bone conduction of the test ear were fed into the NOAH software.

- The subjects were made to sit comfortably
- The hearing aid was connected to the Hipro that was in turn connected to a computer with the programming software
- The hearing aid was detected by COMPASS VERSION 4 software after switching the hearing aid “ON”

Clients data base were created and audiometric data was fed to NOAH software

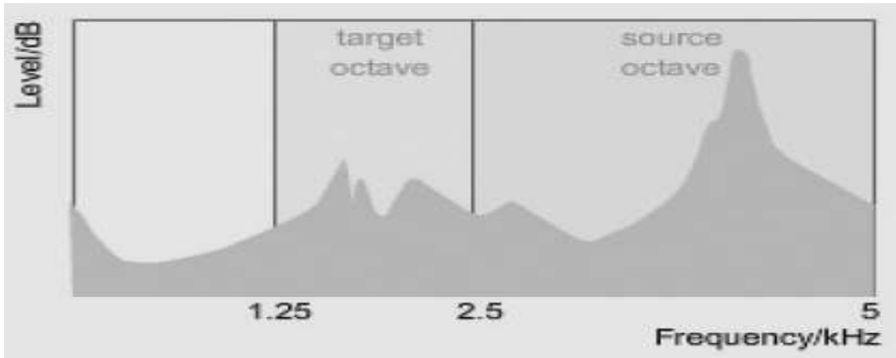

Figure I: Fq region to be transposed (Source octave) & where it should be transposed (target octave)

Inteo includes a unique, patent-pending linear frequency transposition algorithm called the Audibility Extender (AE) which allows people with an unaidable high frequency hearing loss to hear the missing high frequencies in the lower frequency region. The following description summarizes the action of the Audibility Extender (AE). First, the inteo AE receives information of the wearers hearing loss from the dynamic integrator to decide which frequency region will be transposed. The Audibility Extender picks the frequency within the area ‘to be transposed’ or ‘source octave’ region with the highest intensity i.e. peak frequency and locks it for transposition.

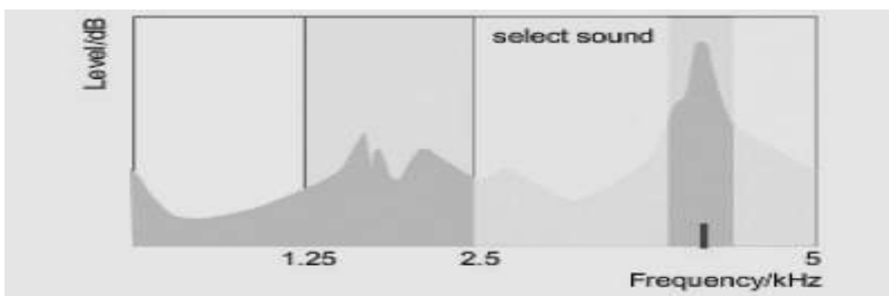

Figure II: Audibility Extender identifies the frequency at 4 KHz in the source octave region to have the highest peak

In this example, 4000 Hz has the peak intensity

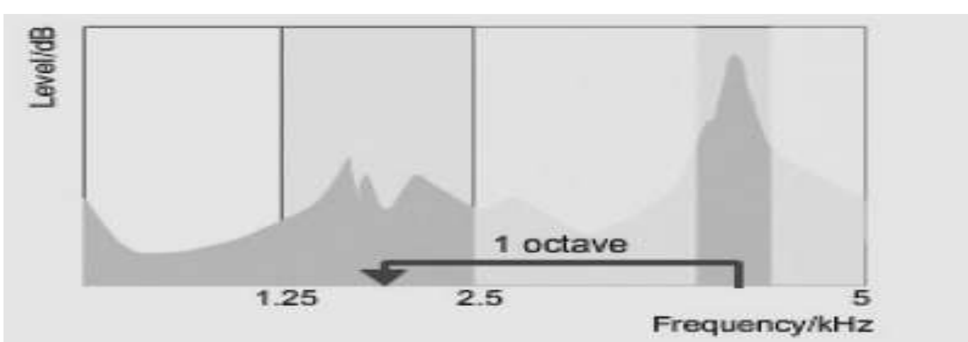

Figure III: Sound with the peak at 4 KHz transposed down by one octave to 2 KHz

Once identified, the range of frequencies starting from 2500 Hz will be shifted downward to the target frequency region. In this case, 4000 Hz will be transposed linearly by one octave to 2000 Hz.

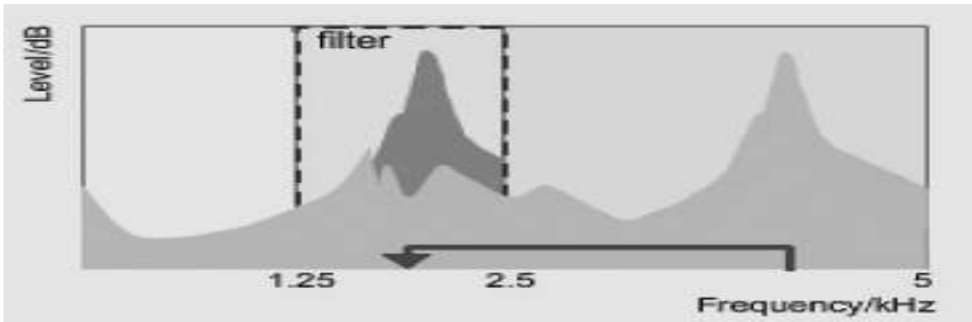

Figure IV: Sounds beyond the one octave band width of the 2000 Hz signal will be filtered out

To limit the masking effect from transposed signal, frequencies that are outside the one octave bandwidth of 2000 Hz will be filtered out. This keeps the frequency ratio between original and transposed signal.

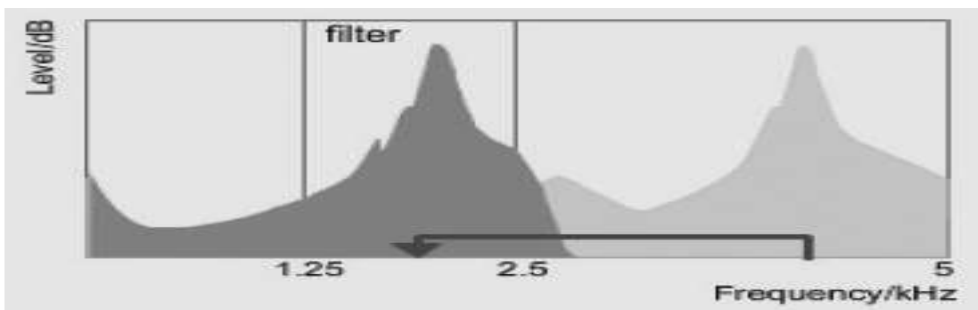

Figure V: The filtered and transposed signal is amplified and mixed with original signal

The level of transposed signal will be automatically set by the Audibility Extender. A manual gain adjustment of the transposed signal is also possible. The linearly transposed signal is mixed with the original signal as the final output. The procedures described above will be adopted to transpose high frequency sounds to low frequency. In order to see whether sufficient amplification was provided to the subjects, hearing aid evaluation of performance was carried out using two programmes 1) INTEO MASTER 2) AUDIBILITY EXTENDER. The subjects' task was to repeat back the words and sentences heard. The words and sentences were presented at 40 dBHL through the speakers of the audiometer. For each subject the level was constant during unaided and aided conditions. In subjects with asymmetrical hearing loss and hearing loss in the non test ear, the non test ear was blocked in order to avoid its participation.

Step 4: In the next step the subjects were presented with the standardized list. The list consisted of 3 lists of 25 high frequency words and 3 lists of 9 sentences in a list which was recorded using a female voice and was presented through loudspeakers. Different lists were used in each of the unaided and aided conditions. All subjects were first evaluated with INTEO MASTER Program and then with AUDIBILITY EXTENDER program.

Unaided Condition: In quiet, with high frequency words and sentences presented at 40 dBHL

Aided Condition: Two aided conditions were evaluated: In quiet, with high frequency words and sentences presented at 40 BHL; Without transposition (Inteomaster) and With transposition (Audibility Extender)

The order of testing was unaided condition, Inteo Master Programme, followed by Audibility extender programme. Hence a total of 25 words, 9 sentences, in all 3 lists were presented randomly. The subjects were instructed to repeat the words he/she heard and the responses were noted down in a response sheet. In speech identification testing each correct response was given the score of 'one' and the total number of correct responses was noted down for each condition for each subject. The speech identification scores for words and sentences were taken and appropriate statistical analyses were done.

Step 5: Unaided audiogram and the aided audiogram with the Audibility Extender programme were obtained from 250 Hz to 8 KHz and appropriate statistical analyses were done.

Results

The data obtained from 10 subjects (15 ears) having high frequency sloping hearing loss with dead regions were analyzed to investigate the benefits of frequency transposition (Audibility Extender) over Non-transposed (Inteo master) on speech identification scores for word and sentence using High frequency word and sentence list using Statistical Package for Social Sciences (Version 10) for windows. The results can be tabulated under the following.

Stage 1: Comparison between Frequencies in Unaided and Aided Conditions: Comparisons were made for the aided and unaided conditions of frequency transposition for different frequencies from 250 Hz to 8 KHz.

Table I: The mean and standard deviation (SD) for different frequencies from 250 Hz to 8 KHz and frequency transposition (Audibility Extender aided condition)

Frequency transposition	Frequency (Hz)	Mean	Standard deviation
Unaided	250	27.9167	16.3009
	500	37.0833	20.7209
	1K	45.4167	23.6891
	2K	69.1667	27.8660
	4K	94.1667	15.9307
	8K	97.5000	13.5680
Aided (with Transposition)	250	8.7500	12.4545
	500	17.0833	4.5017
	1K	23.3333	10.7309
	2K	35.0000	19.5402
	4K	63.7500	24.7832
	8K	82.0833	6.8948

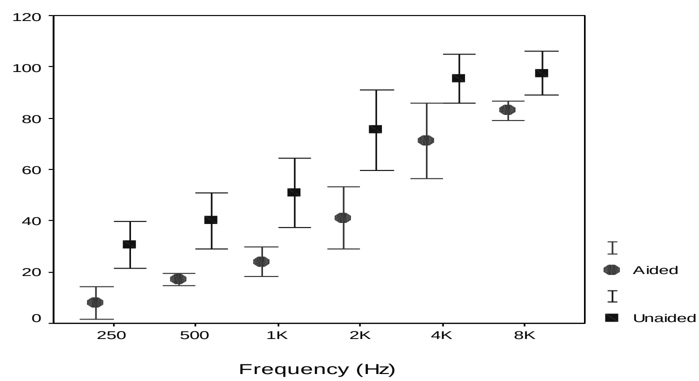

Figure VI. The unaided and aided performance with audibility extender

The error bar indicates 95% confidence interval, mean and (+) and (-) standard deviation. Aided condition variation is less compared to unaided condition. The variation is more in 4 KHz compared to 500 Hz and 8 KHz. Aided condition is statistically significant compared to unaided condition.

Comparison on Effect of Unaided and Aided Conditions, Frequencies and the Interaction between Unaided and Aided Conditions and Frequencies:

Table II: The results of Two-Way Repeated Measure ANOVA

Factor	F(df)	P
Hearing aid condition	F(1,11)=39.33	p<0.001
Frequencies	F(5,55)=129.941	p<0.001
Hearing aid conditions *frequencies	F(5,55)=1.886	p<0.005

From table II it is evident that there is a significant difference between hearing aid conditions. There is significant difference between frequencies and there is no significant interaction between hearing aid conditions and frequencies.

Since there is significant difference between frequencies pair-wise comparisons were made with Bonferroni's multiple comparison test. Based on this test result it is evident that for frequencies 500 Hz, 1 KHz & 4 kHz, 8 KHz no significant difference was found and all other pairs of frequencies were significantly different at 5% level of significance. Inorder to clearly understand the effects of frequency and hearing aid conditions, stepwise analysis was performed by taking each frequency and each hearing aid condition separately.

Stage 2: Comparison across Frequencies within Unaided Condition:

One-Way Repeated measure ANOVA was performed to see the effect of frequency in unaided condition. There is significant difference between frequencies in unaided conditions. $F(5,55)=67.913$,$p < 0.001$. Since there is significant difference between frequencies in unaided condition pair-wise comparisons were made with Bonferroni's multiple comparison test. Based on Bonferroni's test, it is evident that for frequencies 250 Hz, 500 Hz and 500 Hz, 1 KHz, 4 KHz and 8 KHz no significant difference was found and all other pairs of frequencies were significantly different at 5% level of significance.

Table III. The mean, SD for different frequencies from 250 Hz to 8 KHz in unaided conditions

Frequency (Hz)	Mean	SD
250	27.9167	16.3009
500	37.0833	20.7209
1K	45.4167	23.6891
2K	69.1667	27.8660
4K	94.1667	15.9307
8K	97.5000	13.5680

Stage 3: Comparison across Frequencies within Aided Condition

Table IV: The mean, SD for different fqs from 250 Hz to 8 KHz in aided condition (with Transposition)

Frequency (Hz)	Mean	SD
250	8.7500	11.3074
500	17.0833	4.1404
1k	23.3333	10.5560
2k	35.0000	21.8926
4k	63.7500	26.6056
8k	82.0833	6.7612

One-Way repeated measure ANOVA was performed to see the effect of frequencies in aided conditions [$F (5, 70) = 73.052$, $p < 0.001$]. There is a significant difference between frequencies in aided condition. Pair-wise comparisons were made with Bonferroni's multiple comparison test. Based on this test it is evident that for frequencies 250 Hz, 500 Hz and 500 Hz, 1 KHz & 4 KHz, 8 kHz no significant difference was found and all other pairs of frequencies were significantly different at 5% level of significance.

Stage 4: Comparison between Unaided and Aided Conditions within each Frequency

Table V: The mean, SD for aided and unaided condition within each frequency

Frequency (Hz)	Mean	SD
Unaided 250	30.6667	16.5688
Aided 250	8.0000	11.3074
Unaided 500	40.0000	19.9105
Aided 500	17.0000	4.1404
Unaided 1k	51.0000	24.2899
Aided 1k	24.0000	10.5560
Unaided 2k	75.3333	28.0603
Aided 2k	41.0000	21.8926
Unaided 4k	95.3846	15.8721
Aided 4k	66.5385	25.7702
Unaided 8k	97.5000	13.5680
Aided 8k	82.0833	6.8948

Comparison of Difference between Aided and Unaided Condition within each Frequency: Paired t-test was administered to see the difference between aided & unaided conditions within each frequency.

Table VI. Paired t-test results between aided and unaided conditions within each frequency

Frequency	t(df)
250Hz	t(14)=4.208*
500Hz	t(14)=4.271*
1kHz	t(14)=4.876**
2kHz	t(14)=6.871**
4kHz	t(12)=3.977*
8kHz	t(11)=3.890*

* indicates significant at 0.05 level; ** indicates significant at 0.001 level

Stage 5: Comparison of Speech Identification Scores between Unaided, Inteomaster, Audibility Extender Programmes for Words

Table VII: The mean, SD for unaided, Inteomaster, Audibility extender programs for high fq. words

Conditions	Mean	SD
Unaided	7.0000	6.7823
Inteomaster	12.2667	4.5272
Audibility extender	15.0000	4.5356

One-way Repeated Measure ANOVA was performed to see the difference between Unaided, Inteomaster, Audibility extender programmes for words. There is a significant difference between speech identification scores for word in all three conditions [$F(2,28)=34.161$, $p<0.001$]. Since there is a significant difference, pair-wise comparison was made with Bonferroni's multiple comparison test. Based on this test results it is evident that all are significantly different from one another at 0.001 level.

Stage 6: Comparison of SIS between Unaided, Inteomaster, Audibility Extender for Sentences

Table VIII: Shows the mean & SD for unaided, Inteomaster, and Audibility Extender programmes for high frequency sentences.

Conditions	Mean	SD
Unaided	11.2667	9.7722
Inteomaster	19.0000	6.0710
Audibility extender	21.4000	5.5136

One-way repeated measure ANOVA was performed to see the difference between Unaided, Inteomaster, Audibility extender programmes for sentences. There is significant difference between sentence speech identification scores, $F(2, 28) = 32.768$, $p < 0.001$. Since there is a significant difference between sentences speech identification scores, pair-wise comparison were made with Bonferroni's multiple comparison test. Based on this test results, it is evident that all are significantly different at 0.001 level.

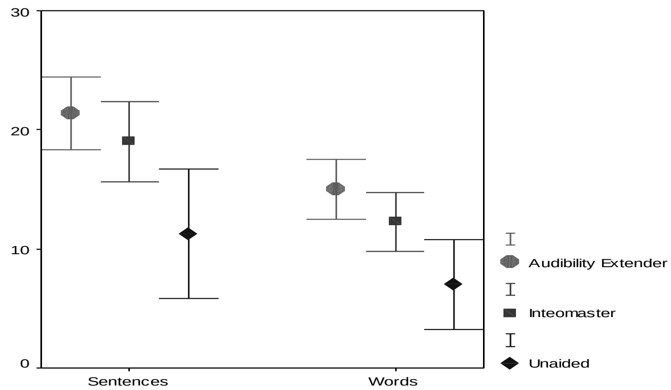

Figure VII. Depicts the speech identification scores for Audibility Extender, Inteomaster and unaided conditions for sentences and words

Error bar depicts the 95% confidence level the mean and (+) and (-) standard deviation, for audibility extender the variation is less compared to inteomaster and unaided condition for sentences and also for words.

Discussion

Like in the previous studies evaluating FRED transposition with hearing impaired individuals (Velmans, 1975; Velmans & Marcuson 1980; Velmans et al., 1982; Velmans et al., 1988; Rees & Maxvelmans, 1993) the present study has also shown that transposition to be beneficial. In the present study 10 individuals (15 ears) with moderate to severe high frequency steeply sloping hearing loss with dead region participated. Dead region was evaluated using a TEN test. Word and sentence identification task was carried out using high frequency word and sentence list which was recorded using a female voice. INTEO device were used it has an integrated signal processing stratergy (ISP). Currently there are two main approaches to signal processing: Sequential processing and Parallel processing.

In Sequential processing the flow of information is always in one direction. Because of this sequential nature no two components may be working simultaneously. In Parallel processing different components occurs at same time. The limitation of both strategies is that the information from different functional units is not shared among each other. As a result wearer satisfaction may not be ensured in all situations.

Integrated signal processing (ISP): ISP is newest approach to hearing aid signal processing where not only the input signal shared among the different functional units but the results of the processing from each functional unit are also shared amongst each other to result in a highly complex and integrated network of information flow. All the processes within the hearing aid function as a unit. This improves the quality of the processed sounds. Because the information is shared among all components the use of more complex algorithms which further enhance the performance of the hearing aid and wearer satisfaction are possible. Results of the present study reveals that transposition helps in improving the identification of high frequency words and sentences and also when unaided and aided performance was compared results show a statistically significant difference between both conditions.

Unlike the present study McDermott and Dean (2000) carried out study on six adults with a very steeply sloping high frequency hearing loss. A control group of 5 adults with normal hearing participated in the study. Normal hearing individuals listened to speech material through a low pass filter with a cut off frequency of 1200 Hz. The transposition was lowered by the factor of 0.6. Results revealed that frequency transposition had little effect overall on the perception of speech.

The result of the above study was different from present study because the study by McDermott and Dean (2000) was carried out in a simulated condition in normal individuals. And a relatively simple form of frequency lowering technique was used that is to shift each frequency component in a sound by a constant factor. For e.g., when the factor equals 0.5 all frequencies are shifted downwards by one octave. The disadvantage of this method is that overall pitch of the speech signal is lowered. This may cause female speaker to sound like male speaker. But in the present study the region with the highest intensity i.e. peak frequency is selected and locks it for transposition. Once identified the transposition is done linearly by one octave. They also maintain the frequency ratio between original and transposed signal so that the speech does not get distorted. The linearly transposed signal is mixed with the original signal at the final output. Thus helps in better understanding of missing high frequency information.

Conclusion

In the present study 10 subjects (15 ears) with moderate to severe high frequency sloping hearing loss with dead regions were tested. The speech identification scores were measured using high frequency word and sentences list for three different conditions unaided, aided (Inteomaster), aided (Audibility Extender) in quiet at 40 dBHL. The frequencies in unaided and aided ranging from 250 Hz to 8 KHz were also compared. The data obtained were statistically analyzed using One-way and two-way repeated ANOVA and paired-t test. Based on the results the following conclusions are drawn from the study:

1. There was significant difference between unaided and aided (Frequency transposition) conditions from 250 Hz to 8 KHz.
2. There was significant difference in speech identification scores obtained between Inteomaster (without transposition) and Audibility extender (with transposition). Thus it can be inferred that there is statistically significant difference between speech identification scores in Inteomaster and Audibility Extender conditions and subjective preferences was for frequency transposition. Majority of individuals who were unable to

perceive high frequency information were able to perceive the same after transposition in the aided condition.

References

Borg, E., Canlon, B. & Engstrom, B. (1995). Noise induced hearing loss-literature review and experiments in rabbits. *Scandinavian Audiology,* 21, *Supplement,* 40, 1-147.

Engstrom, B. (1983). Stereocillia of sensory cells in normal and hearing impaired ears. *Scandinavian Audiology. Supplement,* 19, 1-34.

Foust, K. O. & Gengel, R. W. (1973). Speech discrimination by sensori neural hearing impaired persons using a transposer hearing aid. *Scandinavian Audiology,* 2 (3), 161-170.

Hogan, C. A. & Turner, C. W. (1998). High frequency audibility: Benefits for hearing impaired listeners. *Journal of the Acoustical Society of America,* 104(1), 431-441.

Johansson, B. (1961). A new coding amplifier system for the severely hard of hearing. *Proc 3rd Int Congr Acoust,* 2, 655-657.

Ling, D. & Druze, W. S. (1967). Transposition of high frequency speech sounds by partial vocoding of the speech spectrum: Its use by deaf children. *Journal of Auditory Research,* 7, 133-144.

Macrae, J. H. & Dillon, H. (1996). Gain, frequency response and maximum output requirements for hearing aids. *Journal of Rehabilitation and Research Development,* 3, 363-376.

McDermott, H. J., Dorkos, V. P., Dean, M. R. & Ching, Y. C. (1999). Improvements in speech perception with use of the AVR transonic frequency transposing hearing aid. *Journal of Speech, Language and Hearing Research,* 42, 1323- 1335.

Moore, B. C. J. (1986). Parallels between frequency selectivity measured in simultaneous and forward masking. *Scandinavian Audiology Supplement,* 25, 139-152.

Moore, B. C. J. & Glasberg, B. R. (1997). Factors affecting thresholds for sinusoidal signals in narrow band maskers with fluctuating envelopes. *Journal of the Acoustical Scociety of America,* 3, 289-311.

Moore, B .C. J., Huss, M., Vickers D. A., Glasberg, B. R., & Alcantra, J. I. (2000). A test for the diagnosis of dead regions in the cochlea, *British Journal of Audiol*ogy, 34, 205-224.

Murray, N. & Byrne, D. (1986). Performance of hearing impaired and normal hearing listeners with various high frequency cutoffs in hearing aids. *Australian journal of Audiology,* 8, 21-28.

Velmans, M. & Marcuson, M. (1980). A speech like frequency transposing hearing aid for the sensorineural deaf. children. *British Journal of Audiology,* 17, 221- 230.

Vickers, D. A., Moore B. C. J. & Baer, (2001). Effects of low pass filtering on the intelligibility of speech in quiet for people with and without dead regions at high frequencies. *Journal of the Acoustical Society of America,* 110 (2), 1164-1175.

Villchur, E. (1973). Signal processing to improve speech intelligibility in perceptive deafness. *Journal of Acoustical Society of America,* 53, 1646-1657.

Raymond, T. H. & Proud, G.O. (1962). Audiofrequency conversion. *Archives of Otolaryngology,* 76, 436-446.

Ress, R. & Velmans, M. (1993). The effect of frequency transposition on the untrained auditory discrimination of congenitally deaf children. *British Journal of Audiology,* 27, 53-60.

Turner, C. W. & Cummings, K. J. (1999). Speech intelligibility for listeners with high frequency hearing loss. *American Academy of Audiology,* 8, 47-56.