EFFICACY OF FREQUENCY TRANSPOSITION HEARING AID IN SUBJECTS WITH DEAD REGIONS

Register Number: 05AUD019
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A dissertation submitted in part fulfillment for the degree of

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APRIL 2007.

I dedicate this work to
almighty
GOD
achan, amma
uncle & aunty

CERTIFICATE

This is to certify that this dissertation entitled **"Efficacy of frequency transposition hearing aid in subjects with dead regions"** is a bonafide work in part fulfillment for the degree of Master of science (Audiology) of the student Registration no: 05AUD019. This has been carried under the guidance of a faculty of this institute and has not been submitted earlier to any other university for the award of any diploma or degree.

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DECLARATION

This is to certify that this master's dissertation entitled **"Efficacy of frequency transposition hearing aid in subjects with dead regions"** is the result of my own study and has not been submitted earlier to any other university for the award of any degree or diploma.

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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. They have similar components that include

- A microphone,
- Amplifier circuitary to make sound louder,
- A receiver (miniature loudspeaker) to deliver the amplified sound into the ear,
- Batteries to power the electronic parts.

Although standard hearing aids provide amplification of sound, the manner by which they process and control incoming signals may differ. Presently hearing aids fall into three categories.

- Analog hearing aids
- Digitally programmable devices
- Digital signal processing devices.

Analog hearing aids are designed with the most basic type of technology to provide quality amplification to a wide range of hearing losses. This type of device is designed based on particular frequency response from an audiogram.

Digitally Programmable devices have a microchip and may allow greater flexibility for amplification needs and capability. A computer was used to program the device for different listening situations, depending on the individuals hearing loss, profile, speech understanding and range of tolerance for louder sounds.

Digital signal processing devices are digitally programmable hearing aids that utilize digitalized sound processing to convert sound waves into digital signals. Some advantages of DSP include flexible gain processing, digital feedback reduction, digital noise reduction and digital speech enhancement (Ricketts, 2005). Combining DSP with directional microphones further enhance the signal-to-noise ratio. Multiple channels allow different programming for gain and compression and may be useful for digital noise reduction and feedback cancellation. Multiple memories are used to store hearing aid settings despite these improvements; some individuals continue to have problems with background noise (Ricketts, Chicchis & Bess, 2001). Hearing aid particularly overcomes the deficits associated with the hearing loss.

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 (OHC's) will lead to a reduction in the compressive mechanism of the cochlea. Damage to (IHC's) lead to a reduction in sound transduction process. For this reason such regions is referred to as "Dead regions" by Moore and Glasberg, (1997), Moore, Huss, Vickers, Glasberg and Alcantra, (2000). 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 (IHC's) 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 and 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 IHC's 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.

Individuals with steeply sloping loss, with high frequency thresholds of about 70dBHL 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. Hence, investigated Johansson (1961); Wedenberg, (1961); Raymond and Proud (1962); Ling & Druze, (1967); Foust and Gengel, (1973); Velmans and Marcuson, (1983); Rees and Velmans, (1993); Turner and Hurtig, (1999) using transposition devices and results revealed significant amount of improvement.

Mc Dermot and Dean, (2000); Mac Ardle, Bradley, Worth, Mackenzie, and Bellman (2001) reports of contradictions. Hence there is a need for additional training procedure or an alternative transposition technique which would result in perceptual benefit for atleast some individuals. Thus 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 were the sensitivity is reduced as in high frequency hearing loss.

NEED FOR THE STUDY

1) Studies have not been carried out using frequency transposition hearing aid in sensorineural hearing loss individuals with dead regions.
2) Lack of integrated signal processing in previous transposition hearing aids.
3) Lack of highly defined sound processing system which is not seen in previous transposition hearing aids.

AIMS OF THE STUDY

Considering all these factors, the following 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.

REVIEW OF LITERATURE

Hearing occurs when sound waves reach the internal structures of ear which converts the sound wave vibrations and transduction helps in the movement of "air" molecules into electrical signals in the brain. This process is made possible by external structures which detect these movements and convert them into neural energy and by circuits within the nervous system which convert these signals into what we perceive as sound. Most hearing loss results from damage to the cochlea. Tiny hairs in the cochlea may break or become bent and nerve cells may degenerate. When the nerve cells or the hairs are damaged or missing, electrical signals aren't transmitted as efficiently and hearing loss occurs.

Cochlear hearing loss is associated with complete destruction of the inner hair cells (IHC's) within the cochlea (Engstrom, 1983; Borg, etal., 1995). The inner hair cells are the transducers of the cochlea responsible for converting the vibration patterns on the basilar membrane into action potentials in the auditory nerve (Yates, 1995). When the IHC's are not functioning over a certain region of the cochlea no transduction will occur in that region. This region is referred to as "Dead region" (Moore & Glasberg, 1997; Alcantra, Moore & Vickers, 2000). The presence or absence of dead regions has important implications for the fitting of hearing aids and for the benefits that may be expected from hearing aids.

What Does Really Dead Mean

In a region of the cochlea where either the IHC's or the neurons are completely non functional, information about basilar membrane vibration in that region is not transmitted to the brain. However, a tone with a frequency falling in a dead region may be detected, if it is sufficiently intense via the apical or basal spread of the vibration pattern to places where there are functioning IHC's and neurons (Florentine & Houtsma, 1983). The detection of a tone via a place in the cochlea with a characteristic frequency (CF) different from the frequency of the tone is referred to as off-place listening or off frequency listening (Johnson-Davis & Patterson, 1979).

This concept is illustrated in Figure 2.1. for the hypothetical case of a high frequency dead region, which is associated with a high frequency hearing loss and a steeply sloping audiogram.

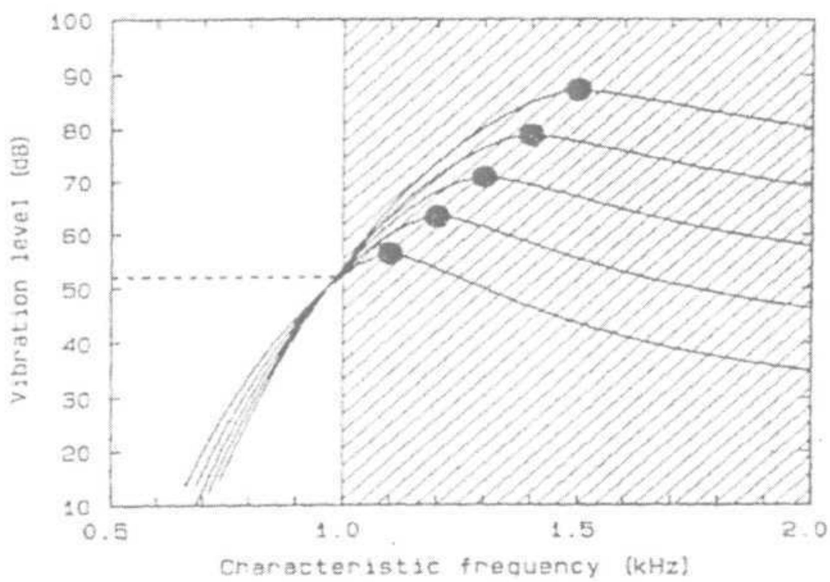


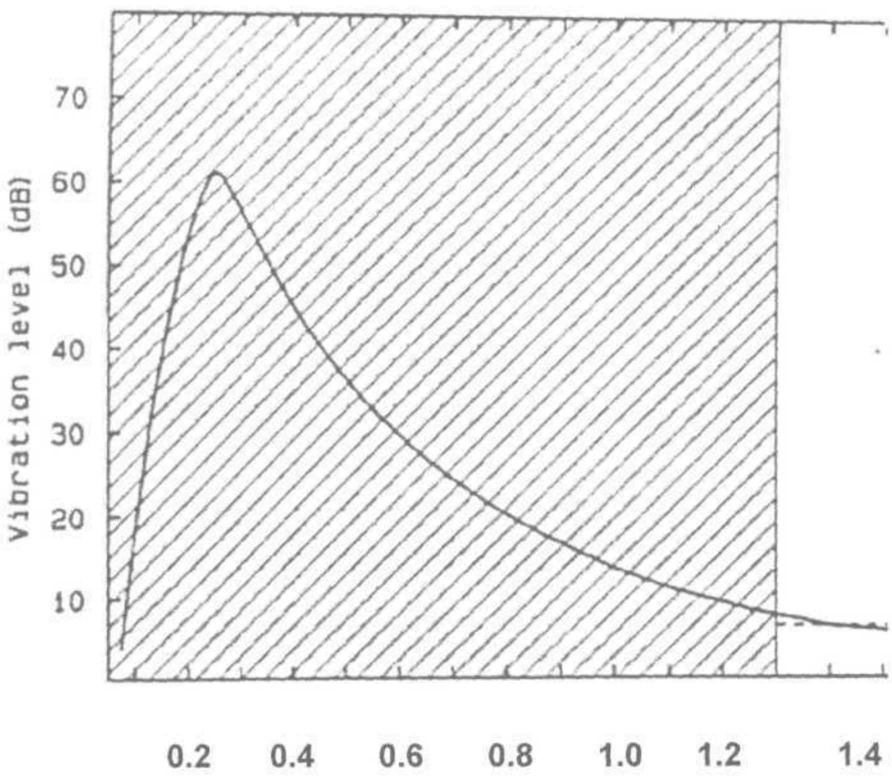
Figure 2.1: Envelopes of basilar membrane vibration patterns calculated for high frequency hearing loss with dead region.

The Figure 2.1 shows envelopes of basilar membrane vibration patterns calculated for an ear with a moderate hearing loss at low frequencies and a dead region extending from 1 kHz upwards. Each of the curves represents the envelope of the vibration pattern for a tone with frequency falling in the dead region; the frequencies used are 1.1 kHz, 1.2 kHz, 1.3 kHz, 1.4 kHz and 1.5 kHz. It is assumed that each tone is detected because of downward spread of the vibration to the relatively healthy place tuned to 1 kHz and just below. To be detectable, the amount of vibration fall above the horizontal dashed line, the level of tones was chosen so that each was at the absolute threshold. Solid circles indicate the level at the peaks of the vibration patterns. Vibration levels are expressed relative to the vibration level produced by a 1 kHz tone at 0 dB SPL.

If a given place in the cochlea is so damaged that a tone producing peak vibration at the place is detected via off-place listening, then it seems likely that very little useful information for discrimination could be conveyed by that place.

Dead Region and the Audiogram

When a dead region is present the audiogram will give a misleading impression of the amount of hearing loss, for a tone whose frequency falls in the dead region Gravendeel and Plomp, (1960), Halpin, Thornton, and Hasso, (1994). The reason why the audiometric threshold can be misleading is illustrated in Figure 2.2: (Moore, 2001). The solid curves show the envelope of the basilar membrane vibration pattern that might be evoked by a 250 Hz tone in an ear with a low frequency dead region and with normal hearing at medium and high frequencies. The dead region is indicated by the shaded area. The low frequency tone is not detected via neurons innervating the apical region of the cochlea because the IHC's/neurons in that region are not functioning.



Characteristic Frequency (kHz)

Figure 2.2: show the envelope of the basilar membrane vibration pattern evoked by a 250 tone in low frequency dead region.

In this example, the 250 Hz tone needs to be presented at about 60 dB to produce detectable vibration just outside the edge of the dead region (CF's just above 1.3 kHz). The tone level was chosen so that it was at absolute threshold, the vibration in the frequency region just above 1.3 kHz lies a little above the threshold value indicated by the horizontal dashed line. Alcantara, Moore and Vickers, (2000) reported that high frequency hearing loss and a steeply sloping audiogram might be associated with dead region, also a dead region could be present when the audiogram had a shallow slope.

Only with the help of an audiogram decisions could not be made for selection of amplification devices in individuals with dead regions.

High Frequency Dead Regions:

Murray and Byrne (1986) tested 5 subjects with near normal hearing for frequencies uptol kHz and losses of 65 to 85dB between 4 and 8 kHz. Speech stimuli were amplified using National Acoustic Laboratory-Revised (NAL-R) procedures (Byrne & Dillon, 1986). The stimuli were low pass filtered with cut off frequencies of 4.5, 3.5, 2.5 orl.5 kHz. The result indicated that for people with moderate to severe high frequency hearing loss, amplification of the high frequencies in speech is not always beneficial and may sometimes impair speech reception.

There are several reports suggesting that people with moderate to severe hearing loss at high frequencies often do not benefit from amplification of high frequencies. Various studies (Ching, Dillon & Byrne, 1998; Hogan & Turner, 1998; Amos & Humes, 2001; Moore & Alcantra, 2001) revealed that the subjects who did not benefit from amplification in high frequencies had reduced function or complete loss of function of IHC's and/or neurons. The diagnosis of dead regions in hearing impaired individuals is important as their presence may influence the rehabilitation strategy. It is likely that high frequency amplification may play limited role in improving and may even impair, speech perception in patients with high frequency dead regions (Vantasell & Turner, 1984; Murray & Byrne, 1986; Rankovic, 1991, Ching et al.,1998; Hogan & Turner, 1998; Turner & Cummings, 1999; Vickers et al., 2001, Baer, Moore & Kluk, 2002, Mackersie, Kapadia, Munro & Moore, 2006). While the initial fitting of hearing aids is usually based on the shape of audiogram, this does not reliably identify or delimit dead regions (Moore, 2001).

Dead regions can be detected by measuring Psychophysical tuning curves (PTCs). PTCs are a curve showing the level of a narrow band masker required to mask a fixed sinusoidal signal, plotted as a function of masker frequency. For normally hearing subjects, the tip of PTCs occurs close to the signal frequency; the masker is most effective when its frequency coincides with the signal frequency (Vogten et al., 1974; Moore, 1978). If the frequency of the signal fell within a dead region, then the tip of the PTC was shifted away from the signal frequency (Florentine & Houstma, 1983; Turner, Burns,& Nelson, 1983; Moore, Huss, Vickers, Glasberg, & Alcantra, 2000, Moore & Alcantara, 2001. However, measurement of PTCs is time consuming and difficult to interpret (Kluk & Moore, 2005).

Moore et al., (2000) have developed a test which was intended to be more suitable for the diagnosis of dead regions which is termed Threshold Equalising Noise (TEN). The TEN test was designed to produce approximately equal excitation at each frequency within the pass band of the noise. In the absence of a dead region at a particular frequency, the masked threshold in dB SPL at that frequency is equal to the level of the TEN specified in dBSPL /ERBn, where ERBn stands for the equivalent rectangular of the auditory filter as determined for young normally hearing listeners at moderate sound levels (Glasberg & Moore, 1990). A dead region was considered to be present at a particular frequency if the masked threshold at that frequency is at least 1 OdB above the TEN level/ERBn and 10 dB above the absolute threshold (Moore, Vickers, & Alcantra, 2000). TEN test will provide information in choosing appropriate hearing aid. It is useful for people with hearing loss at high frequencies in order to define the edge frequency of dead region and hence indicating highest frequency at which amplification can be applied. For individuals with high frequency dead regions, there appears some benefit from applying amplification upto one octave above the dead region. This has important implications for the fitting of hearing aids. Markessis et al., (2006) studied 24 normal hearing subjects and 35 subjects with steeply sloping moderate to profound high frequency hearing loss with a slope of atleast 20dB/octave over atleast one octave from 1 to 8 kHz. Testing was carried out using standard TEN and TEN high pass filtered at 0.5 kHz (TEN 0.5) or 1 kHz (TEN 1). For both groups, masked thresholds did not differ across noise types for frequencies above 1 kHz. Over 50% of the hearing impaired ears tested met the criteria for a dead region at 4 kHz, using all three noise types. However, masked thresholds and the prevalence of positive TEN-test results at 1 kHz were both with the TEN 1. The TEN 1 was judged the most comfortable noise by 68% of the hearing impaired subjects. High pass filtering would allow testing at higher TEN levels for patients with steeply sloping hearing loss.

Hearing impairment varies from minimal to profound with different patterns. The input of acoustic information for the perception of the speech depends on the loss of the individual. So it is necessary to provide appropriate and adequate amplification system which codes specific speech cues. The configuration or "shape" of hearing loss refers to the extent of loss at high and low frequencies, which creates an overall "picture" of an individuals hearing ability. For example: Hearing loss that only affects high frequencies is described as a high frequency loss. The configuration shows good hearing in the low frequencies and poor hearing in the high frequencies. If only low frequencies are affected, the configuration shows poorer hearing for low tones and better hearing for high tones. Ching et al., (1998), Hogan and Turner (1998), Turner and Cummings, (1999), Vickers, Moore and Baer (2001). Various study results have revealed that speech understanding with the high frequency regions greater than 3000 kHz being most affected.

Thus several attempts have been made to shift or transpose, high frequency speech sounds with the aim of making them audible and intelligible to subjects with low frequency residual hearing. Perwitzschky (1925) was probably the first to suggest the idea of frequency transposition. The first experimental work was done by Tato (1925) who achieved transposition by recording at one speed and playing back at another speed.

In an effort to provide hearing impaired people with more acoustic information for the perception of speech, attempts have been made to produce amplifying systems which code specific speech cues. One such coding amplifier, introduced by Johansson (1961), is the transposer hearing aid. This aid provides more speech information to persons with no residual hearing above 1500Hz.

The transposer hearing aid is a two channel amplifying system (Foust & Gengel 1973). Channel one act as a normal hearing aid, while channel two transforms the high frequency energy in phonemes such as /s/ and /sh/ into low frequency noise. The outputs of both channels then are combined. Thus listeners receive amplified speech plus high frequency information transposed into low frequencies. After transposition high frequency phonemes are presented in the audible low frequency region and therefore might provide additional cues for the discrimination of speech.

Wedenberg (1961) and Johansson (1966) reported that with transposer hearing aid, normal hearing adults with simulated hearing loss demonstrated significantly better performance as much as 15% higher recognition scores for PB words and nonsense syllables with a transposer aid than with the conventional type of hearing aid. They also reported that hearing impaired children showed greater learning effects over time with the transposer hearing aid.

Johansson (1961) described a frequency transposition device using two channels. The vowels are passed through a channel with an amplitude compression unit, while in another channel the voiceless consonants are separated by a high pass filter, the signal from two channels are mixed and presented to the listener. The necessary information contained in the 3-6 Kc/s range is transposed downward into range below 1.5 Kc/s. Inaudible speech sounds are thus modulated from their high frequency positions into the low frequency range audible for persons with severe high frequency hearing impairment.

Wedenberg (1961) used transposition device to train 6 severely hearing impaired individuals auditorily. The apparatus provided an acoustic pattern which is confusing to the listener at first. Results indicated that training period is essential to improve discrimination among different speech sounds, especially the transposed high frequency sounds.

Raymond and Proud (1962) adapted a frequency converter to individuals with high frequency impairment. This frequency converter shifted speech frequencies into a lower frequency range by constant amounts. After training, all subjects improved in intelligibility from their initial decrease for a frequency transposed W-22 word list, but the improved intelligibility was still below their intelligibility score for a non converted

W-22 list. However, when non converted speech was presented to one ear and converted to the other ear simultaneously, some improvements were noted for a few subjects. The results of disproportionate downward frequency shifts indicated that there is an immediate loss of intelligibility which can be recovered to some extent through short period of training.

Foust and Gengel (1973) had studied nine students with moderate to profound, long term, sensorineural hearing loss. They were trained and tested in condition of "listen only" "look only" and "listen and look" with the transposer hearing aid. Results with modified rhyme test and PB-50 word lists indicate that some subjects can receive additional benefit (6-10%) from transposition. Training was provided for 8 sessions with transposition hearing aid. The results showed that in "listen only" condition if we compare the first four days of transposed v/s conventional with last four days results. On the first four days the performance was much better with conventional mode. However, on the last four days the scores were significantly higher for transposition mode. It is depicted in the Figure2.3. When the discrimination scores were compared between transposed and conventional mode for voiceless stops/ p/,/t/,/k/, as well as the voiced and voiceless stops /s/,/sh/, *IZJ, /Z/,/DZ /* subjects generally showed less confusion with the transposed mode, there was no specific pattern of errors for either mode, with exception of the phoneme /sh/.

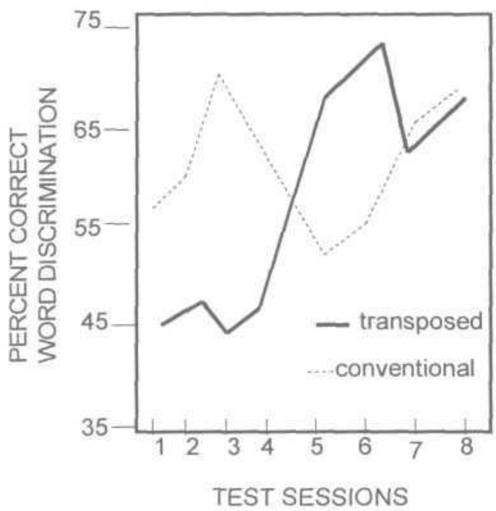


Figure2.3: Comparison of percent correct word discrimination using transposed and conventional mode

Discrimination of this phoneme was consistently better with transposed mode. Benefit from transposition does not appear to be limited to those people having only low frequency hearing. Some subjects with residual hearing through 4 kHz showed improvement in discrimination.

Johansson (1961) designed Johansson transposer (OTICON TP 72). It selects only 4-8 kHz band for transposition thereby enabling consonant information to be lowered in frequency, while avoiding the transposition of vowel information. This device is outdated because when each signal in the 4-8 kHz region is fed into a distortion circuit which converts the signal into band of noise below 1.5 kHz and this constitutes the transposed signal which is added to conventionally amplified speech. The resulting output sounded like speech with added noise.

Velmans (1973, 1974) designed a patented method of transposition that retains spectral information relating to high frequency sounds. FRED (Frequency Recording Device) is similar to body worn version of Johansson transposer. Unlike the Johansson device, FRED shifts the 4-8 kHz region to 0-4 kHz region by modulating input signals with a 4 kHz carrier frequency. This subtracts a fixed 4 kHz from every frequency component in the 4-8 kHz region, thereby shifting the signals down the frequency axis in a way that preserves their spectral envelope and energy distribution over time. Transposed signals are then added to conventionally amplified information. The resulting output sounds much like normal speech with added fricative information.

Velmans and Marcuson (1980) compared FRED with OTICON TP72 Subjects found that through FRED transposition High frequency consonants were clearly perceived than OTICON TP72. The performances were reported to be better when FRED transposition was added to conventional amplification.

Velmans and Marcuson (1983) tested the efficacy of FRED and Oticon TP72 systems. FRED maps the 4-8 kHz region onto the 0-4 kHz region in a way that preserves the spectral pattern of transposed signals. The Oticon TP72, converts signals in the 4-8 kHz region into low frequency noise (below 1.5 kHz). Both devices combine transposed information with conventionally amplified speech. Thirty six adults with acquired hearing loss were selected. They had greater residual hearing in the low frequencies than in the high frequencies. The main aim of the study was to establish whether subjects would opt to use transposition rather than conventional amplification and whether there would be a significant difference between the number of occasions subjects opted to use

FRED transposition as opposed to Oticon transposition. Consonant- vowel -consonant (CVC) nonsense words were used as a stimulus. Results revealed that

1) The frequency of the use of FRED transposition was significantly greater than that of Oticon transposition because

a) FRED device made inaudible consonants audible and identifiable.

b) It increased the loudness and identifiability of already audible consonants.

There was significant difference between subjects in their frequency of use of transposition.

2) The subjective preference for FRED transposition over Oticon transposition was significant.

Velmans, (1973); Velmans, (1975) Velmans and Marcuson (1980); carried out a study with 26 congenitally deaf children ranging in age from 7 years to 15 years who had specific difficulty with the discrimination of high frequency consonants. The children were given discrimination training on minimal pairs involving high frequency consonants. Under both Transposition (T) and No transposition (NT) condition. FRED transposition significantly enhanced ability to discriminate a variety of consonants contrasts both during training and in post training tests for the group as a whole. Whether or not individual children benefited from transposition depended on whether their high frequency loss averaged over 4 kHz, 5 kHz, 6 kHz, 7 kHz and 8 kHz was in excess of 70 dB.

Rosenhouse (1989) used AVR frequency transposing device. It enables a programmable compression and shifting of various frequency bands within the heard

The effect of this shifting is a general lowering of the speaker's pitch and better intelligibility for many previously unperceived sounds (especially high frequency sounds).

In the study by Rosenhouse (1989), subjects were seven hearing impaired individuals with sloping audiograms, 4-10years old children and 3 adults (age range 20, 23, 40). The study consisted of 3 parts 1) initial testing of speech intelligibility without and with the AVR device, 2) individual instruction was given for 2 to 3 hours of work with the AVR device over a period of 2 months, 3) repeated testing of speech intelligibility while using the AVR device, with same material as in first testing. Thus within a few months period, the results for the seven subjects in two groups (adults/children) could compare the effect of use of AVR device with and without training. The children group showed some post training advantage in performance over the adult group, which might imply that adult subjects need more training than children. It has been shown that the AVR device may contribute to speech intelligibility; longer training or adaptation to the device will yield better results.

Dermott, Dorkos, Dean and Ching (1999) evaluated five adults with sensorineural hearing impairment, subjects participated in a trial comparing the performance of the AVR transonic frequency transposition hearing aid with that of their conventional own hearing aids. They used the Transonic for approximately 12weeks, during which time systematic changes were made to the transposition parameters. Speech perception was assessed with each setting of those parameters and with the participants own hearing aid. Four participants obtained significantly higher scores with the transonic than with their own aids on at least one of the tests. However, analysis of the consonant confusions suggested that the improvement resulted mostly from the transonic low frequency electro acoustic characteristics. There was only limited evidence for 2 of the participants that the frequency lowering function was effective at improving speech perception.

Rees and Velmans (1993) evaluated 8 children with congenital, sensorineural deafness, aged between 7 and 15 years. The criteria for selecting subjects was subject should have a hearing loss greater than 70dB in the high frequencies (averaged over 4 kHz, 5 kHz, 6 kHz, 7 kHz & 8 kHz). Subject should score 17/24 or less on difficult contrast and 18/24 or more on a easy contrast in a discrimination test. The test list consisted of monosyllabic words and nonsense syllables which were recorded in quiet by adult male voice. FRED device was used and it had conventional amplifying channel and a transposing channel Velmans (1973), Velmans & Marcuson (1980, 1983). Results demonstrated that FRED transposition significantly enhanced the auditory discrimination of consonants like /s/, /ʃ/, /t/, /ts/. But /s/ and /ʃ/ is relatively difficult to distinguish without training. The reason for the difficulty is non transposed *I si* can be distinguishable from /ʃ/ by its relative high frequency fricative energy. With transposition this fricative energy is lowered by moving transposed /s/ into domain of non transposed /ʃ/. When transposed /ʃ/ is lowered the new /s/-/ʃ/ contrast, it requires training in the high speech frequencies for the subject group. This suggests that FRED transposition significantly enhanced the ability of subjects to discriminate selected consonants (with major energy components in the high frequencies) it may produce some benefits in every day situations even without formal training. This study has shown that transposition can improve the ability of congenitally deaf children to discriminate high frequency consonants. The effect of FRED transposition without training has two possible implications 1) Auditory discrimination tests with and without FRED transposition would help to select congenitally deaf individuals who would be likely to benefit from a FRED aid, 2) Formal discrimination training may not be necessary to benefit a period of familiarization may be sufficient.

A relatively simple form of frequency lowering technique was used to shift each frequency component in the sound by a constant factor. For e.g., if the factor equals 0.5, all frequencies are shifted downwards by one octave. A possible advantage of this form of transposition is the ratios among the frequency components of the signal are not changed by the processing. This may be beneficial for speech perception because frequency ratios such as that between the first and second formants convey important information.

Turner and Hurtig (1999) studied 15 listeners with high frequency hearing loss. Nonsense syllable spoken by a male and a female speaker was used as test material. It was uniformly lowered in frequency by factors ranging from 0.5 to 1.0 using a non-real time algorithm. The recorded and processed material was amplified and was high pass filtered in order to maximize the audibility for each subject by maintaining listening comfort. Results revealed that there were significant improvements in intelligibility using transposition with the female talker material for about half of the subjects. Few subjects obtained significant benefit from transposition with male talker material.

McArdle et al., (2001) investigated the use of frequency transposition transonic FT40 system in 36 children with profound sensori-neural hearing loss. The performance of the long term FT40 user was investigated using the following outcome measures; aided sound field hearing threshold, closed set speech test and speech intelligibility rating score. At the time of fitting, the aided sound field thresholds with the FT 40 was significantly better at 500 Hz, 1 k Hz, 2 k Hz and 4 k Hz compared to thresholds with conventional hearing aids and a small subgroup benefited from frequency transposition hearing system.

Unlike the above studies, the following studies report that frequency transposition is not superior to other devices. Ling (1967) studied a new type of transposition instrument. Matched groups (N = 4) of deaf children with classical low tone residual hearing were assigned for training to transposing instrument and to a speech training aid. Four aspects of hearing for speech were measured using phonetically balanced list developed by Watson (1957):

1) Measure discrimination between back, mid and front vowels
2) Measure discrimination between classes of consonants
3) Measure discrimination within classes of consonants
4) Discrimination between intonation patterns

The tests were administered using transposition and conventional hearing aid at the beginning and at the end of the experiment. Results on the transposing instrument did not prove to be superior to those obtained on the speech training aid. The gains made by the control group indicate that this form of frequency transposition is also effective in the training of children with profoundly impaired hearing, in that it permits them to hear and to learn to discriminate between voice patterns as well as between many speech sounds.

McDermott and Dean (2000) studied 6 adults with steeply sloping high frequency hearing loss. Speech perception was assessed using consonant vowel nucleus consonant (CNC) words spoken by female speaker. In the first condition, their ability to identify phonemes with SNR of 6 dB was measured in the remaining two conditions 4 of the hearing impaired subjects and a control group of 5 normal hearing subjects listened to speech in quiet with and without frequency transposition. The transposition was lowered for all speech frequencies by a factor of 0.6. Results revealed that frequency transposition had little effect overall on the perception of speech. When score of transposed was compared to non transposed speech the mean difference was very small and statistically insignificant.

Recent advancement in Hearing Aid Technology:

The recent advancement in technology like frequency lowering/ frequency compression /frequency transposition can help in benefiting individuals who have sloping high frequency hearing loss.

Frequency Lowering:

Kuk, Korhonen, Peeters, Keenan, Jessen, & Anderson (2006) report about the earlier attempts to achieve audibility for high frequency sounds, is the use of frequency lowering techniques. These are simply nonlinear operations in which high frequency sounds are moved to a lower frequency region. When these techniques are applied to hearing aids, the objective is to provide audibility of the "unaidable" high frequency cues by changing them into an audible lower frequency substitute. The target beneficiaries of this technique are people with a severe-to-profound loss in the high frequencies who cannot benefit from conventional amplification.

Various approaches had been attempted in frequency lowering. The first attempts were done well before non-linear and digital technology was applied to hearing aids.

Methods such as slow-playback, time-compressed slow-playback, frequency modification with amplitude modulation, vocoding, zero-crossing rate division, frequency shifting and frequency transposition were all major approaches that have been summarized by Braida, Lippman, Durlach, Hicks, Rabinowitz, Reed (1978). More recent strategies in the area include proportional frequency compression Turner, and Hurtig, (1999) and approaches that "sharpen" the spectrum of the transposed sound Aguilera-Munoz, Peggy, Rutledge and Gago, (1999) or the various transposed features (e.g. voiceless v/s voiced). Although these approaches resulted in better aided thresholds, their acceptance has been relatively limited as they are significantly more complex than earlier attempts.

Considerations in Frequency Lowering

Minimization of Artifacts and Unnatural Sounds:

Minimal artifacts or unnaturalness will result if the frequency lowering method retains the relationships of the original frequency components in the final signal. Preferably, the relationships of the harmonic components remain the same, the spectral transitions move in the same direction as the original un-transposed signal and the segmental-temporal characteristics remain untouched. One should not remove any acoustic cues that the listeners are using before frequency lowering. In addition, the processed speech signal should retain the extra-linguistic (prosodic) cues, such as its pitch, tempo and loudness. Otherwise, it will make it more difficult for the listeners to accept the new sound images initially and lengthen the training and re-learning period. One criterion is to lower only the frequencies that are necessary to be lowered (instead of the full range of frequencies). For example, if an individual has aidable hearing upto

3,000 Hz, one should only process (or lower) sounds above 3,000 Hz. This has the advantage of focusing only on sounds that are relevant. Another criterion is to apply the "right" amount of processing for the individual. This is because the more aggressive the lowering (e.g. higher frequency compression ratio), the more unnatural the sound percept becomes. A conservative or less aggressive approach will minimize the disturbance on the original signals and avoid any potential interaction between the original signals and the processed signals.

A final criterion is to preserve the temporal structure of the original signal in order to retain any transition cues. This means the frequency lowering system must have the flexibility and specificity to meet individual wearer's needs. In cases where the unnaturalness is unavoidable because of the extent of frequency lowering, a strategy to minimize the exposure of artifacts is to make the frequency lowering algorithm optional. That is, the wearer will only listen to the processed sounds when he/she needs to. In situations where such a program is not needed or not beneficial, the program may be deactivated.

Extending audibility via linear frequency transposition:

These considerations guided the development of the new, patent-pending Audibility Extender (AE) algorithm in the recently introduced Widex Inteo hearing aid. The AE is one form of frequency lowering technique that uses Linear Frequency Transposition to move the unaidable high frequency sounds to the aidable low frequency regions. A feature of this algorithm is its inclusion in the Integrated Signal Processing (ISP) platform used in the Inteo. Briefly, ISP integrates information of the wearers, the environments, as well as the intermediate processing of each algorithm into the Dynamic

Integrator (DI). In turn, the DI coordinates all the activities and dispatches the appropriate commands to each algorithm so that the processed sounds would be as natural as possible with little or no artifacts. In order to appreciate how this integration is realized, the Inteo signal processing can be functionally grouped into four main components /modules. They include the dynamic integrator (DI), the high definition sound analysis (HDSA), the high definition sound processing (HDSP) and the system optimization(HDSO) modules.

Other Considerations:

To ensure ease of use of the Audibility Extender (AE) program, simple default rules are implemented that consider the degree and slope of the audiogram in deciding the default start frequency (for transposition). The optimum start frequency is critical in ensuring acceptance and successful use of the AE. By definition, the start frequency is the frequency where the hearing loss is unaidable. Thus, instead of amplifying that frequency, the AE transposes it without amplification. Consequently, too low a start frequency (below the optimum) will result in some of the aidable frequencies not being amplified. This removes some of the acoustic cues that are usable by the wearers to result in distortion and unnaturalness of the signal. Too high a start frequency will leave some of the unaidable high frequencies inaudible. In both cases, it will unnecessarily decrease the initial acceptance of the AE and prolong the time to fully realize it's potential. To meet the individual hearing needs of the wearers and to increase the flexibility of the AE program, options to manually adjust the start frequency from 630 Hz to 6,000 Hz at 1/3 octave intervals (as well as individualized fitting guidelines) are available. Another advantage of the AE is that it is an optional program. This means one can set this program as the master default program for use in all listening situations;

alternatively, it can be used only in situations where the wearer desires. The former may be a pediatric fitting where the child uses the AE all the time so he or she can hear all the high frequency sounds in many environments for speech and language purposes. The latter may be an adult who is satisfied with the default settings of the hearing aids in most situations, but desires the AE program for listening to birds, music, or other sounds. In this way, individual preferences and usage habits are considered.

How is the Audibility Extender Different?

The Audibility Extender is different from other frequency lowering schemes in several aspects:

1. It transposes only the high frequency sounds (above the start frequency) regardless of their voicing characteristics (e.g., voiced or voiceless). Thus, it is equally effective on periodic and aperiodic sounds. Systems that are active only for voiceless signals may miss high frequency periodic signals including music and bird songs.

2. It is active during all segments of speech and not at specific linguistic segments, (e.g. voiced versus voiceless).

3. Typically only one octave (although two octaves may be allowed) of high frequency sounds above the start frequency is transposed to a lower octave. Frequencies higher and lower than the transposed region are filtered. This limits the amount of masking and avoids the need for compression.

4. For simple stimuli, it preserves the transition cues and the harmonic relationship between the transposed signal and the original signal. This preserves as much of the original signal as possible.

5. The transposed signal is mixed with the original signal to give a richer, more "natural" sound perception. Systems that do not overlap the transposed sounds would risk "exaggerating" any unnaturalness of the transposed sounds.

6. By transposing frequencies linearly, the temporal structure of the signal is preserved. Thus, it can be easily recognized as the original source signal but at a lower frequency.

Kuk et al., (2006) carried out a study on 16 individuals with hearing impairment, primarily with high frequency sensorineural hearing loss. Subjects were tested to examine their preference for the AE for bird songs, music and discourse speech stimuli. Of these subjects, 5 individuals had a precipitously sloping hearing loss with normal hearing below 1000 Hz and 11 had a sloping high frequency hearing loss of moderate to severe degree. There are several observations when the preference data across subjects and stimuli were examined. First, subjects with a sloping high frequency hearing loss subjectively prefer the AE when listening to birds, music and speech. Second, the preference for the AE-On varied with the complexity of the stimuli. Bird songs are simpler in spectral content than music and speech and the preference for the AE was the highest for birds (over 60%), less for music (55%) and least for running speech (33%). This suggests that the simpler the stimuli, the higher the preference for the AE. Every subject preferred the AE-On for at least one stimulus. Lack of reports on viewing the efficacy of hearing aid (Inteo) on Dead Region individuals (high frequency sloping sensorineural loss) instigated our interest to the present study. Individual listening needs in setting the optimal transposition parameters was evaluated in our present study.

METHOD

The present study was aimed to find out the effect of frequency transposition in amplification for patients with dead regions.

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.

There was no significant history of middle ear problems or neurological disorders.

Kannada speaking subjects were selected.

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. These word and sentence list are given in Appendix A (1).

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.

Hearing Aid Description

The INTEO high definition sound processing system consists of integrated major processing features.

> High definition sound analysis

> Dynamic integrator.

> High definition sound processing

> High definition system optimizer

The high definition sound processing gives positive effect on speech intelligibility and background noise. This system consists of five integrated major processing features.

> High definition locator (to improve S/N ratio).

> Multi directional active feed back canceling.

> Speech enhancer.

> Audibility extender,

> 15 channel enhanced dynamic range compression.

Instrumentation

A calibrated diagnostic audiometer (dual channel) was used

1) To establish pure tone thresholds

2) To identify speech identification scores

3) To administer TEN Test.

Immitance meter was utilized to rule out middle ear problems.

A Pentium 4 computer along with NOAH 2(Compass version 4) software was used to programme the Widex Inteo hearing aid. Appropriate cable and audio shoe were used.

The hearing aid was connected to the programming interface with Hipro Box.

Test Environment

The testing was carried out in a sound treated double room, with ambient noise levels within permissible limits as recommended by (ANSI S3.1-1991, cited in Wilber, 1994).

Procedure

Step 1

Calibration of audiometer OB922 (dual channel) was done in free field condition. The output of the loudspeaker were at the approximate position of the subjects head. 250 Hz to 4000 Hz was within lOdB of the output at 1000 Hz. The output sound pressure levels below 250 Hz and above 4000 Hz was not exceeding more than 15dB of the output at 1000 Hz.

The input to the loud speaker was speech noise and the condenser microphone of the sound level meter was placed at the approximate position that a subject's head would be. The sound level meter was set in 'A' weighting position and the out put from the speakers was compared with the standard reference equivalent threshold sound pressure levels according to ANSI S3.6-1989 and calibration was carried out.

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.

LEFT	RIGHT
Channel 1	Channel 2
(Type A)	(TypeB).

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 OdB. Turn off the two inputs (press the interrupt buttons).

LEFT	RIGHT
(TYPE A)	(TYPE B)

4) Mix the two channels, and direct the mixed channel to the desired ear (left or right).

To test Left ear			To test Right ear	
LEFT	RIGHT	(OR)	LEFT	RIGHT
TYPE A				TYPE A
TYPE B				TYPE B

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.

TEN (HL)	PURE TONE
RIGHT	RIGHT
50 - 50 dBHL/ ERB	0

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 lOdB above the absolute threshold and lOdB 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 Hz 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 subjects were fitted with the hearing aid on the test ear using an appropriately sized ear tip.

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"

The following general setting was selected for

Test ear (right ear or left ear).

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

History Questionnaire

The NOAH software has inbuilt questionnaire which included general history of clients which is given in Appendix A (2). Clients hearing thresholds and hearing aid history was fed into the software used.

Goals Questionnaire

Subjects expectations of the hearing aid were considered while selecting the goals for hearing aid fitting.

After detecting the hearing aid, sensogram was measured using a standard ascending method audiometric procedure. Particular frequency, and a level, was selected and Tone button was pressed to play the tone. After establishing the sensogram thresholds for the four frequencies (500 Hz, 1 kHz, 2 kHz, 4 kHz), feedback test was carried out. After this desired programme was selected which was ideal for an individual user.

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).

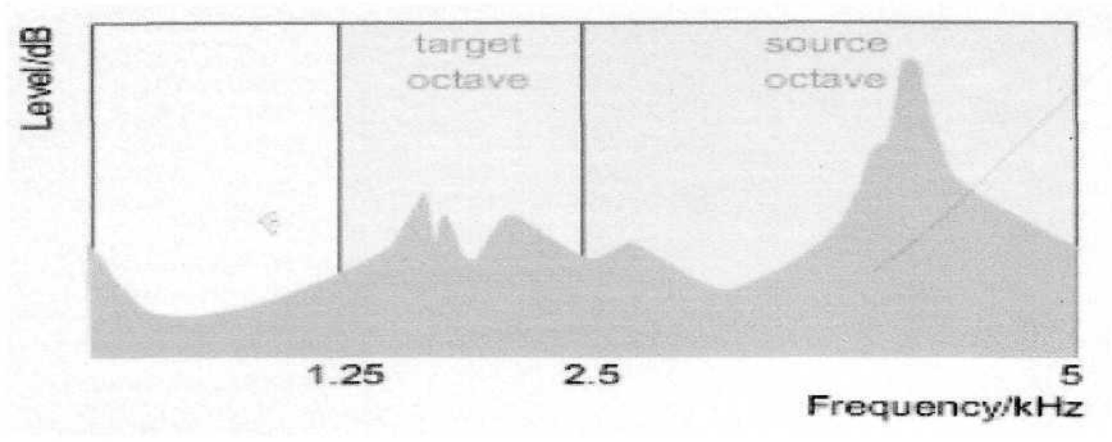


Figure 3.1a: Frequency region to be transposed (Source octave) and where it should be transposed (target octave).

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.

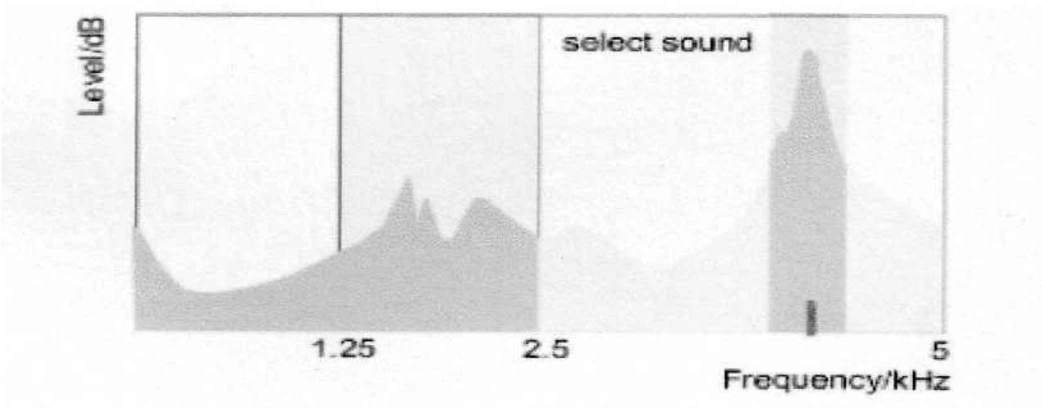


Figure 3.1b: Audibility Extender identifies the frequency at 4 kHz in the source octave region to have the highest peak

In this example, 4000Hz has the peak intensity.

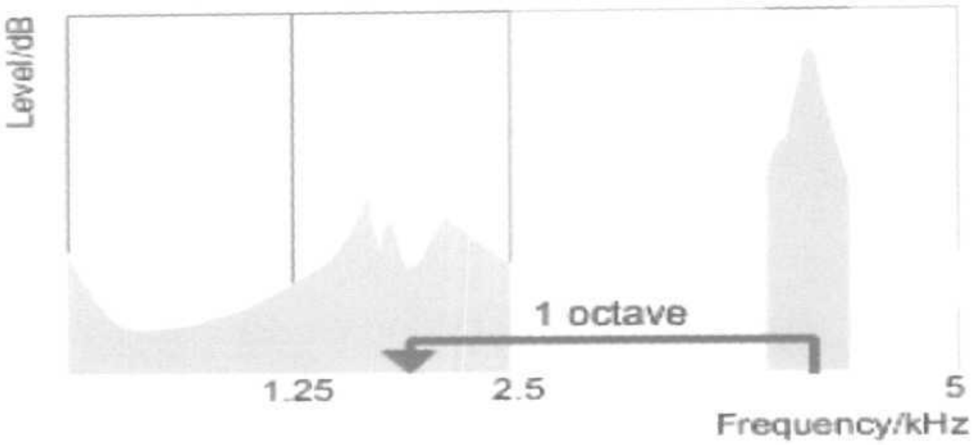


Figure 3.1c: Sound with the peak at 4 kHz transposed down by one octave to 2 kHz.

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

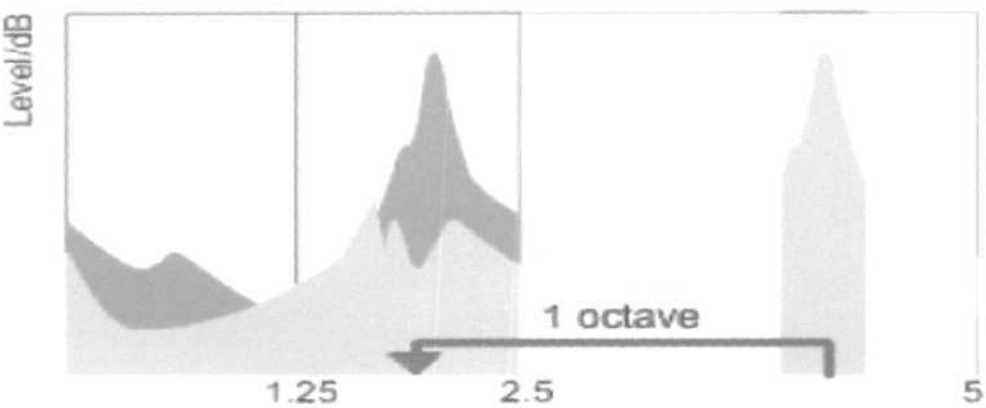


Figure 3.Id: Frequencies around the 4000 Hz will be transposed linearly by 2000 Hz

Here the 4000Hz signal will be placed at 2000Hz and every frequency will be shifted by 2000Hz. For example 3000Hz will now be at 1000Hz and 4500Hz will be at 2500Hz.

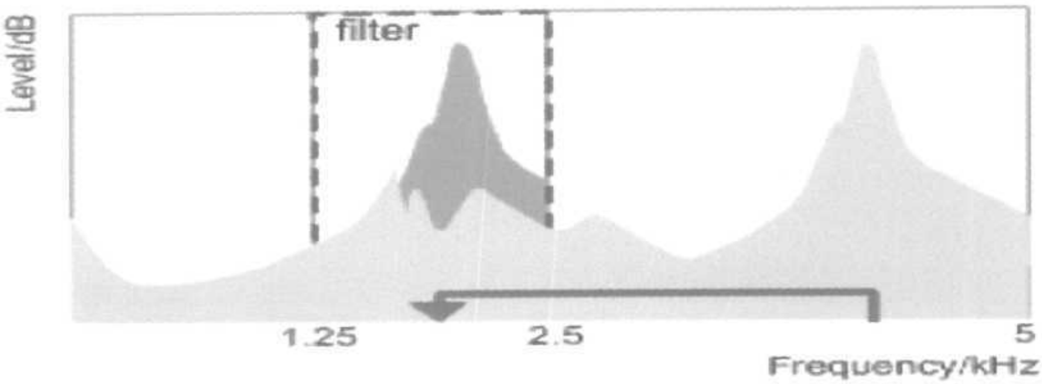


Figure 3.le: Sounds beyond the one octave band width of the 2000 Hz signal will be filtered out.

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

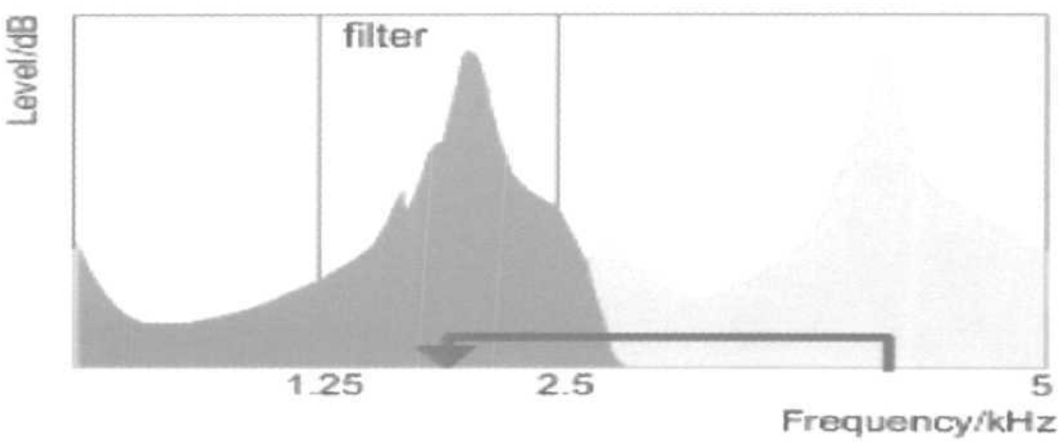


Figure 3.If: The filtered and transposed signal is amplified and mixed with original signal.

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, lnorder 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 programmes. The subjects task was to repeat back the words and sentences heard.

The words and sentences were presented at 40dBHL 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 inorder 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 40dBHL.

Aided Condition:

Two aided conditions were evaluated.

In quiet, with high frequency words and sentences presented at 40dBHL.

1) Without transposition. (Inteomaster)

2) 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 & SPSS, Statistical Package for Social Sciences (Version 10) for windows was used. The results can be tabulated under the following.

1) Comparison between frequencies in aided and unaided conditions and the interaction between frequencies in both conditions.
2) Comparisons of frequencies in unaided condition.
3) Comparison of frequencies in aided condition.
4) Comparison between aided and unaided within each frequencies.
5) Comparison of high frequency speech identification scores for words within subjects for Inteo Master and Audibility Extender.
6) Comparisons of high frequency sentences identification scores within subjects for Inteo Master and Audibility Extender program.

Stage 1:

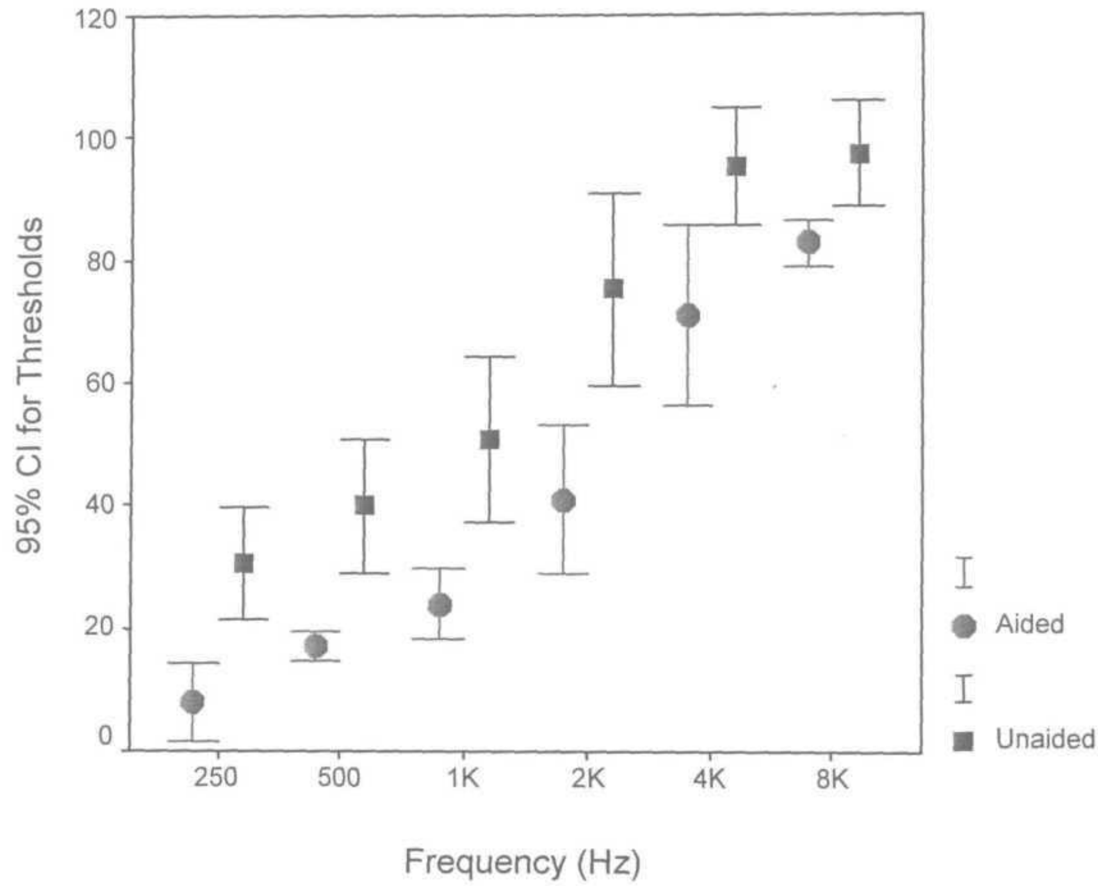
Comparison between Frequencies in Unaided and Aided Conditions:

Comparisons were made for the aided and unaided conditions of frequency transposition for different frequencies from 250 Hz to 8 kHz.

Table 4.1: 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
	IK	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
	IK	23.3333	10.7309
	2K	35.0000	19.5402
	4K	63.7500	24.7832
	8K	82.0833	6.8948

Figure 4.1. 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 4.2: The results of Two-Way Repeated Measure ANOVA

Factor	F(df)	P
Hearing aid condition	F(l,ll)=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 4.2: It's 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:

Table 4.3. The mean, standard deviation (SD) for different frequencies from 250Hz to 8 kHz in unaided conditions.

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

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 comparison 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 and 4 kHz, 8 kHz, no significant difference was found, and all other pairs of frequencies were significantly different at 5% level of significance.

Stage 3:

Comparison across Frequencies within Aided Condition

Table 4.4: The mean, standard deviation (SD) for different frequencies from 250Hz to 8K Hz in aided condition (with Transposition).

Frequency (Hz)	Mean	Standard deviation
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 & 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 4.5: The mean, standard deviation (SD) for aided and unaided condition within each frequency.

Frequency (Hz)	Mean	Standard deviation
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 Ik	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 4.6. 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(ll)=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 4.7: The mean, standard deviation for unaided, Inteomaster, Audibility extender programmes for high frequency words.

Conditions	Mean	Standard deviation
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:

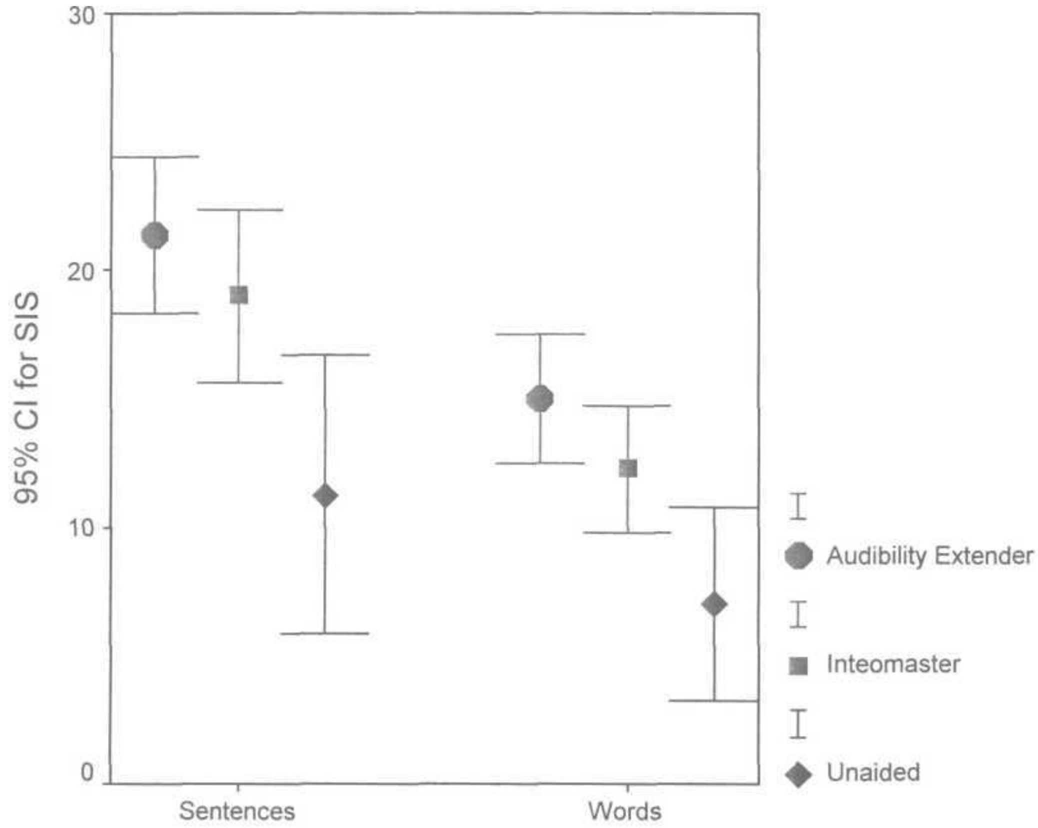
*Comparison of SIS between Unaided, Inteomaster, Audibility Extender for Sentences^*

Table 4.8: Shows the mean & standard deviation for unaided, Inteomaster, and Audibility Extender programmes for high frequency sentences.

Conditions	Mean	Standard deviation
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 4.2. 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

1) Sequential processing
2) Parallel processing

Sequential processing:

In this type of processing the flow of information is always in one direction. Because of this sequential nature, no two components may be working simultaneously.

Parallel processing:

Here processing by different components occurs at same time. The limitation of both strategies is that the information from different functional units are not shared among each other. As a result, wearer satisfaction may not be ensured in all situations.

Integrated signal processing (ISP):

Thus, 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 functions 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 1200Hz. 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) were 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. 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 will be 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.

SUMMARY AND CONCLUSION

Frequency transposition through audibility extender program is a typical means by which individuals with dead regions can benefit. The general aim of the transposer hearing aid is to transpose high frequency information which is inaudible to region were it is audible (Velmans et al., 1993). Although several research have been done using transposition devices there was no standard method/factor for the transposition, mainly because there was not much developments in the technology in such frequency transposition devices. There are number of studies done (Johansson, 1961; Wedenberg, 1961; Raymond & Proud, 1962; Ling, 1967; Foust & Gengel, 1973; Velmans & Marcuson, 1983; Rees & Velamns, 1993; Turner & Hurtig, 1999) and results revealed that frequency transposition can be beneficial for individuals with high frequency sloping hearing loss. Hence the present study aimed at investigating the effect of transposition and without transposition on speech identification scores using high frequency words and sentences for subjects with high frequency sloping hearing loss with dead regions.

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.

Limitations:

Though the trend in the present study showed that most of the cases with high frequency sloping hearing loss with dead regions performed well with Audibility Extender program, there were two participants who could not get substantial benefit from the Audibility extender programme. The possible reason for this deviation could be that the two cases had more severe sensorineural hearing loss in the high frequency region.

Future Implications:

The present study aimed only at finding out speech identification performance with and without frequency transposition in moderate to severe sensorineural hearing loss cases.

- Future research can be focussed on finding out the relationship between various degrees of hearing loss and frequency transposition.

- Future research can be aimed at finding out whether there is any effect of training on the desired benefits from the frequency transposition hearing aids.
- Future research can also be undertaken to study how frequency transposition would help children with high frequency sensorineural hearing loss.

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APPENDIX

WORD SUBTEST I

1.	ಕೇಳು	/ke:ḷu/
2.	ಇಲ್ಲೆ	/ille/
3.	ರಸ	/rasa/
4.	ಇಷ್ಟ	/iʃta/
5.	ಇಟ್ಟ	/iṭṭa/
6.	ಇಲಿ	/ili/
7.	ಸೇರಿಸಿ	/se:risi/
8.	ಹೊಟ್ಟೆ	/hoṭṭe/
9.	ವಿಚಾರ	/vitʃara/
10.	ಚಿಕ್ಕಿ	/tʃikki/
11.	ಸಿಟ್ಟು	/siṭṭu/
12.	ಚಕ್ರ	/tʃakara/
13.	ಹಸಿವು	/hasivu/
14.	ಸಿಕ್ಕು	/sikku/
15.	ಚಿಟ್ಟೆ	/tʃiṭṭe/
16.	ತಲೆ	/tale/
17.	ಕೋತಿ	/koti/
18.	ಕುಳ್ಳಿ	/kuḷḷi/
19.	ಚಮಚ	/tʃamatʃa
20.	ಶಿಲೆ	/ʃile/
21.	ಸರಿಯೆ	/sarije/
22.	ಸಾಲು	/sa:lu/
23.	ಇರಲಿ	/irali/
24.	ಇರುವೆ	/iruve/
25.	ಕಟ್ಟೆ	/kaṭṭe/

SENTENCE SUBTEST I

1. ಎಲೆ ಹಸಿರು ಬಣ್ಣ.
2. ಚಿಕ್ಕ ಚಮಚ ಬೇಕು.
3. ಇದು ನನ್ನ ಸರ
4. ನಾನು ಚಿಟ್ಟೆ ನೋಡಿದೆ.
5. ನನಗೆ ಇಡ್ಲಿ ಇಷ್ಟ.
6. ನನ್ನ ಮಾತು ಕೇಳು.
7. ನನಗೆ ಹೊಟ್ಟೆ ಹಸಿವು.
8. ಇದು ದೊಡ್ಡ ಕಿಟಕಿ.
9. ರಾತ್ರಿ ಸೂರ್ಯ ಇರಲ್ಲ.

SENTENCE SUBTEST I

1. /yele hasiru baṇṇa/
2. /tʃikka tʃamatʃa be:ku/
3. /i$\underline{\text{d}}$u nanna sara/
4. /naanu tʃiṭṭe no:ḍi$\underline{\text{d}}$e/
5. /nanage idli iʃṭa/
6. /nanna ma:$\underline{\text{t}}$u ke:ḷi/
7. /nanage hoṭṭe hasivu/
8. /i$\underline{\text{d}}$u $\underline{\text{d}}$oḍḍa kitiki/
9. /ra$\underline{\text{t}}$ri surya iralla/

WORD SUBTEST II

1. ರೊಟ್ಟಿ /roṭṭi/
2. ಕೊಕ್ಕು /kokku/
3. ಕುಟ್ಟು /kuṭṭu/
4. ಚರ್ಚಿಸು /tʃartʃisu/
5. ಇರ್ಲಿ /irli/
6. ಕೆಲವು /kelavu/
7. ತಾಳಿ /t̪a:ḷi/
8. ಯೋಚಿಸು /yotʃisu/
9. ತೋಟ /t̪oṭa/
10. ಉಯ್ಯಾಲೆ /uyya:le/
11. ಕೋಸು /ko:su/
12. ಇಳಿಸಿ /iḷisi/
13. ಚರ್ಚೆ /tʃartʃe/
14. ಸಲಹೆ /salahe/
15. ಸಂಕೋಚ /saŋko:tʃa/
16. ಹಿಟ್ಟು /hiṭṭu/
17. ಹುಚ್ಚು /hutʃtʃu/
18. ಇಷ್ಟೆ /iʃṭe/
19. ಇರಿ /iri/
20. ಸೇರಿ /se:ri/
21. ಇಳಿ /iḷi/
22. ತಳ್ಳು /t̪aḷḷu/
23. ಸುಲಿ /suli/
24. ಕೋಟಿ /ko:ṭi/
25. ಅಳು /aḷu/

SENTENCE SUBTEST II

1. ಮನೇಲಿ ಇರುಳ್ಳಿ ಇದೆ.
2. ನಾನು ಊಟ ಸರಿಯಾಗಿ ಮಾಡಿದೆ.
3. ಯಾತ್ರೆ . ಸುಖವಾಗಿತ್ತು.
4. ಕೆಂಪು ಚೀಟಿ ಕೊಡಿ.
5. ಅಲ್ಲಿ ಹಾವು ಇತ್ತು.
6. ನನ್ನ ಕೆಲಸ ಆಯ್ತು.
7. ಕಾಫಿಯಲ್ಲಿ ಸಕ್ಕರೆ ಜಾಸ್ತಿ ಇದೆ.
8. ನಾಯಿ ಕಚ್ಚುತದೆ.
9. ನೂರು ರುಪಾಯಿಗೆ ಚಿಲ್ಲರೆ ಕೊಡಿ.

SENTENCE SUBTEST II

1. |mane:li iruḷḷi id̪e|
2. |avaḷu u:ṭa se:riyage maḍid̪aḷu|
3. |yat̪re sukʰavagit̪t̪u|
4. |kempu tʃiṭi koḍi|
5. |alli ha:vu it̪t̪u|
6. |nanna kelasa ait̪u|
7. |coffee yalli sakkare jasti ide|
8. |nai katʃtʃu tad̪e|
9. |nu:rupayige tʃillare koḍi|

WORD SUBTEST III

1.	ಸೂಚಿಸಿ	/su:tʃisi/
2.	ಕಿವಿ	/kivi/
3.	ಲೀಚೆ	/li:tʃe/
4.	ಚಿಕ್ಕ	/tʃikka/
5.	ಹಚ್ಚು	/hatʃtʃu/
6.	ರುಚಿ	/rutʃi/
7.	ಕುಳ್ಳ	/kuḷḷa/
8.	ಕೊಳೆ	/koḷe/
9.	ಸೊಸೆ	/soṣe/
10.	ಸುಖ	/sukʰa/
11.	ತಟ್ಟೆ	/taṭṭe/
12.	ಕೋಟೆ	/ko:ṭe/
13.	ಕೆಲಸ	/kelasa/
14.	ಇರುಳ್ಳಿ	/iruḷḷi/
15.	ಅವಳು	/avaḷu/
16.	ಇಟ್ಟೆ	/iṭṭe/
17.	ಅಳತೆ	/aḷate/
18.	ಕಾಲು	/ka:lu/
19.	ಏಳು	/ye:ḷu/
20.	ಶಾಲೆ	/ʃa:le/
21.	ಸರಿ	/sari/
22.	ಅಷ್ಟು	/aʂṭu/
23.	ಅಚ್ಚು	/atʃtʃu/
24.	ಚಿಲ್ಲರೆ	/tʃillare/
25.	ತಾಳು	/avaḷu/

SENTENCE SUBTEST III

1. ಕಸ ಗುಡಿಸಿ ಆಯ್ತು.
2. ನನಗೆ ನಡೆಯೋದು ಕಷ್ಟ.
3. ಆಕಾಶದಲ್ಲಿ ಹಕ್ಕಿ ಹಾರುತ್ತೆ.
4. ನಾವು ಸೇರಿ ಆಡೋಣ.
5. ಇದು ರಾಗಿ ಹಿಟ್ಟು.
6. ಹುಡುಗ ಚೇಷ್ಟೆ ಮಾಡ್ತಾನೆ.
7. ಹೂವಿನ ತೋಟ ಚೆನ್ನಾಗಿದೆ.
8. ಮಾಡಿಯಿಂದ ಇಳಿ ಬೇಕು.
9. ಅಮ್ಮ ರೊಟ್ಟಿ ಮಾಡಿದರು.

SENTENCE SUBTEST III

1. | Kasa guḍiṣi aiṭu |
2. | nanage naḍiyoḍu kaʃṭa |
3. | Aaka:ʃaḍalli hakki haraṭe |
4. | Avaru se:ri ha:ḍiḍaru |
5. | Idu ragi hiṭṭu |
6. | Huḍuga tʃeʃṭe maḍutane |
7. | Huvina ṭo:ṭa tʃanaag iḍe |
8. | ma:ḍi inḍa iliyabeku |
9. | Amma roṭṭi ma:ḍiḍaru |

APPENDIX 2

History and goal questionnaire

Birth date:

Last name:

First name: —

Client no.: —

Print date: —

Printed by: —

Hearing loss history

1. How long has your client experienced hearing problems?

D Less than 12 months

• Between 1 and 5 years

• More than 5 years

2. Does your client experience any of the following hearing loss complications?

• Hearing loss is asymmetric	•	Right ear • Left ear
• Reduced speech intelligibility		• Right ear • Left ear
• Reduced sound tolerance		• Right • Binaural • Left
• Tinnitus		• Right • Binaural • Left
• Sudden hearing loss	•	Right • Binaural • Left

• Fluctuating sensorineural hearing loss • Right • Binaural • Left •

• Fluctuating conductive hearing loss D Right D Binaural • Left •

• One ear is unaidable • Right ear unaidable • Left ear unaidable

• Central auditory processing disorder

• Balance problems

• Other Abnormal shape (please specify) Skin disorders that affect the outer ear (please specify)

3. Are there any issues associated with the outer ear?

• Discharge

• Perforated eardrum

• Excessive wax

4. Are there issues that may influence the handling of the hearing aids?

• Eyesight problems

• Dexterity problems

• Memory problems

• Reduced mental acuity

Hearing aid history

1. How much does your client use his hearing aids?

o 8 or more hours per day

o 4-8 hours per day

0 1-4 hours perday

O Less than 1 hour per day, but more than 1 hour per week

O Less than 1 hour per week

O Never

2. Which type is your client's current hearing aid?

oBTE

o ITE/ITC

oCIC

3. How satisfied is your client with his current hearing aids?

o Very satisfied

o Satisfied

o Neither satisfied nor dissatisfied

o Dissatisfied

o Very dissatisfied

4. Please select all the attributes that apply to your client's current hearing aids,

o Omnidirectional

o Fixed directional

o Switchable between omni and dir

o Adaptive directional system

5. Does your client experience any of the following problems with his hearing aids?

Lack of audibility

Poor speech intelligibility in background noise

Loudness discomfort

Occlusion

Acoustic feedback

Internal noise

Cosmetic concerns

6. Difficulties when handling the hearing aids

Does your client currently use any assistive listening devices?

Teleloop system

Telecoil-telephone

FM system

Direct audio input

Other

7. How long has your client been using hearing aids altogether?

Specify model

Microphone:

Digital

Non-linear

Noise reduction system

Active feedback cancellation

Multiple listening programs

Open fit

FM system

Direct audio input

Others.

Goal questionnaire:

Present ability	Expected ability	Agreed ability	Final ability	Degree of chance

Notes: **Ability** 1: Hardly ever (10%) 2: Occasionally (25%) 3: Half the time (50%) 4: Most of the time (75%) 5: Almost always (95%)

Degree of change 1: Worse 2: No difference 3: Slightly better 4: Better 5: Much better

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