EFFECT OF FREQUENCY TRANSPOSITION ON LEARNING OF AN ARTIFICIAL SPEECH IN NORMAL HEARING INDIVIDUALS

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(Audiology)

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May, 2017

CERTIFICATE

This is to certify that this dissertation entitled **"Effect of frequency transposition on learning of an artificial speech in normal hearing individual"** is a bonafide work submitted in part fulfilment for degree of Master of Science (Audiology) of the student Registration Number: 15AUD019. This has been carried out under the guidance of a faculty of this institute and has not been submitted earlier to any other University for the award of any other Diploma or Degree.

Mysuru

May, 2017

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CERTIFICATE

This is to certify that this dissertation entitled "**Effect of frequency transposition on learning of an artificial speech in normal hearing individual**" has been prepared under my supervision and guidance. It is also been certified that this dissertation has not been submitted earlier to any other University for the award of any other Diploma or Degree.

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DECLARATION

This is to certify that this dissertation entitled **"Effect of frequency transposition on learning of an artificial speech in normal hearing individual"** is the result of my own study under the guidance ofDr. Ajith Kumar U, Reader in Audiology, Department of audiology, All India Institute of Speech and Hearing, Mysuru, and has not been submitted earlier to any other University for the award of any other Diploma or Degree.

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ABSTRACT

The aim of the study is to evaluate the effect of language learning with and without frequency transposition in listeners with normal hearing individuals. A total of 120 normal hearing adults with simulated high frequency hearing loss in the age range of 18-40 years were participated in three study. Three groups randomly assigned into three separate experiments i.e. Experiment 1 with unprocessed condition (without hearing loss simulation), where Experiment 2 with frequency transposition on and Experiment 3 with frequency transposition off was evaluated. In each experiment 40 each were included. An artificial learning task was used as a stimulus to investigate their ability to learn artificial language was assessed. Of the three one group listened to unprocessed artificial speech, second group listened to artificial speech with frequency transposition on and third group listened to artificial speech with frequency transposition off. Following listening phase, actual testing was carried out where the participants were required to identify the words. Results revealed that overall performance was better for learnt words than non-words in unprocessed condition than with frequency transposition on and off condition and also performance was significantly better for words than non-words in frequency transposition on condition than with frequency transposition off condition. Hence results indicate that learning abilities were superior in frequency transposition on condition than with frequency transposition off condition.

CHAPTER I

INTRODUCTION

People with high frequency hearing loss, with high frequency thresholds of about 70dBHL will often miss high frequency information even when they wear hearing aids and cannot perceive high frequency speech sounds like /t/, /k/, /f/, /th/, /sh/ and /s/ sounds. Hence, recent advances in digital signal processing have enabled the development of hearing aids which offer frequency transposition as a new way of accessing important speech sounds. They transport a signal component, usually at higher frequencies to a lower frequency. The basic intention of frequency lowering techniques is to shift inaudible high frequency acoustic information into lower audible frequency regions. It also preserves the temporal structure of the signal so it can be easily recognized as the original source signal. This method of frequency lowering has been currently used in range of hearing aids manufactured by Oticon and Widex.

However, literature on benefit of frequency transposition on speech perception is equivocal. Several studies have reported improvement in speech identification scores with frequency transposition. Study done by Ibrahim (2009) reported an improvement in the consonant recognition as well as high frequency audibility on using linear frequency transposition. And also there was a significant improvement in vowels and consonant recognition, accuracy of fricative production after 6 weeks of use of the frequency transposition technique in school-age children (Auriemno, Kuk, & Lau, 2009). Dermott, Dorkos, Dean and Ching (1999) studied whether the frequency transposition function was effective in improving speech perception. Participants wore TranSonic frequency transposition hearing aid for 12 weeks. Speech perception was assessed and results showed four participants obtained significantly higher scores with frequency transposition while for two of the participants had little effect on the perception skills. McDermott and Dean (2000) evaluated the effect of frequency transposition on speech perception in 6 steeply sloping hearing impaired individuals and results showed that little effect on speech perception skills with frequency transposition but when scores were compared, there was no statistically significant difference with and without frequency transposition. Simpson (2006) investigated the effect of frequency compression on speech perception scores of seven individuals with steeply sloping high frequency hearing loss. Participants wore nonlinear frequency compression devices for 4-6 weeks. Speech perception was assessed at the end of trail period. Results showed no significant difference in speech perception skills with and without frequency compression. Glista (2009) reported that frequency compression resulted in minimal benefit in children and adults. However, more recently Wolfe et al (2009, 2011) reported that use of frequency compression resulted in statistically significant improvement in perception of some high frequency speech sounds in children. In a counterbalanced experimental condition children wore the hearing aid with and without frequency compression for six weeks. At the end of sex weeks speech perception was assessed in quiet using plural recognition task and in noise by estimating the signal to noise ratio required to identify 50% of BKB sentences. Results indicated that use of frequency compression significantly improved plural recognitions and there was also a small improvement in speech perception in noise.

From the above literature it can be seen that clinical studies on frequency lowering provide mixed results. However, most of the modern day digital hearing aid manufacturers advocate one or the other type of frequency lowering techniques. Of late frequency lowering techniques have been increasingly employed also in paediatric hearing aid fittings. Therefore, it is essential to evaluate the efficacy of frequency lowering techniques in language learning.

Artificial language stimuli enable more precise control over the learning environment than is found using natural language. Such control enables systematic manipulation and testing of specific structural factors in language learning. Prior learning is also controlled, permitting the separation of effects due to artificial language exposure from those associated with prior knowledge. Hence artificial language are languages of a typically very limited size which emerge either in computer simulations between artificial agents, robot interactions or controlled psychological experiments with human.

Therefore, the present study uses artificial language as stimuli to find out the effect of language learning with and without frequency transposition in normal hearing individuals.

Aim of the study

To study the effect of language learning with and without frequency transposition in listeners with normal hearing individuals

Objectives of the study

1. To study the effect of frequency transposition on learning an artificial speech

2. To study the effect of conventional amplification on learning of an artificial speech

CHAPTER II

REVIEW OF LITERATURE

Individuals with precipitous or severe to profound sloping hearing loss face a number of communication issues as they typically miss out high frequency information and also they do not benefit from conventional amplification (Moore, 2001). These individuals will not benefit from high frequency amplification because of limitations of the hearing aid in terms of restricted bandwidth, low maximum output, or feedback before the necessary level of amplification is reached (Stelmachowicz et al., 2001; Auriemmo et al., 2009). And hence has led to the development of an alternating approach (because of the failure of conventional hearing aid amplification) to restore high-frequency audibility. One such alternative strategy for potentially improving the speech perception of individuals with a high frequency hearing loss involves altering the input signal so that high frequency components are manipulated to fall within the low frequencies where residual hearing is better. There are a number of approaches to achieving this objective, including frequency transposition, slow playback and non-linear frequency compression.

2.1. Frequency transposition

Frequency transposition essentially involves moving components of a signal in a particular band of frequencies into a different frequency band. Perwitzschky (1925) was probably the first to suggest the idea of frequency transposition. The experimental work was done by Tato (1925) who achieved frequency 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 hearing aid provides more speech information to persons with no residual hearing above 1500Hz.

Two channel amplifying system is the transposer hearing aid (Foust & Gengel 1973). Channel one and channel two acts as a normal hearing aid and transforms the high frequency energy in phonemes such as /s/ and /sh/ into low frequency noise respectively and then the outputs of both channels are combined. Thus allowing the listeners to perceive amplified speech as well as high frequency information which was transposed into low frequencies. Additional cues are provided for the discrimination of speech after transposition high frequency speech sounds into the region of audible lower frequency.

Individuals with steeply sloping loss, with high frequency thresholds of about 70dBHL or greater, no information about high frequency information is accessible. Thus, it is necessary to convert high frequency information into the audible low frequencies in order to provide high frequency information. Hence, investigated Johansson (1961); Wedenberg (1961); Raymond and Proud (1962); Ling & Druze, (1967) using transposition devises and results revealed significant amount of improvement.

Wedenberg (1961) and Johansson (1966) compared the performance of transposer hearing aid and normal hearing adults with simulated hearing loss. Results revealed that there was 15% significant improvement in identification of PB words and nonsense syllables with frequency transposition hearing aid than without frequency transposition type of hearing aid and also they reported that there were greater learning effects over time with frequency transposition hearing aid than with conventional amplification in children with hearing impaired.

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

Rees and Velmans (1993) used a single group design to evaluate the effect of transposition on the untrained auditory discrimination of eight children, aged seven to twelve, with congenital high frequency hearing loss. One list of monosyllabic words was presented under linear frequency transposition (LFT), then two lists under no LFT and then one list under LFT again; repeated procedure using nonsense syllables. The group as a whole had mean scores under the transposition condition that were significantly greater than scores under the no transposition condition (overall improvement of 8.1%).

Parent et al (1998) used a single group design to evaluate the effect of frequency transposition on the experienced hearing aid users of 4 adults, aged twenty to fifty-one years, with severe to profound degree of hearing loss and also compared the performance of frequency transposition hearing system (TranSonic) and conventional hearing Aids. Word recognition task from simple to complex i.e. from closed-set to open set task was used and also used subjective measure using the Abbreviated Profile of Hearing Aid Performance (APHAB). After a trial session, above mentioned speech audiometric measures along with subjective measure were carried out to see the effect of frequency transposition on identification of words. Of the four, only two subjects showed significant improvement with the frequency transposition hearing aid than with conventional hearing aid while other two showed no significant improvement with frequency transposition hearing system. Hence, in some individual's frequency transposition improves speech understanding as well as quality of life.

Dermott, Dorkos, Dean and Ching (1999) compared the performance of frequency transposition (AVR Transonic) hearing system with that of conventional amplification. 5 adults with sensorineural hearing impairment were included in the study. After 12 weeks of usage of frequency transposition hearing aid perception of speech was assessed with each setting of those parameters and with the participants' own hearing aids. Higher scores obtained with frequency transposition hearing aid than with their own conventional amplification. And also there was an improvement of consonant confusions resulted with frequency transposition condition in four individuals. For 2 of the participants there was only limited evidence whether the frequency-lowering function was effective at improving speech perception.

Turner and Hurtig (1999) studied 15 listeners with high frequency hearing loss. Nonsense syllable were used as a stimulus. A female and a male speaker was used as test material. In this study frequency was lowered uniformly using a non- real time algorithm by a factor which is ranging from 0.5 to 1.0. The signal was high pass filtered in order to increase audibility as well as the recorded and processed material was amplified for each of the subject to maintain listening comfort. Results revealed that few subjects improved with female talker material and there were significant improvements in intelligibility using transposition and few other subjects showed significant improvements from frequency transposition with male talker material.

McDermott and Dean (2000) studied 6 adults with steeply sloping high frequency hearing loss. Three conditions were involved in this study where in first condition CVC words was analyzed with SNR of 6dB and in the second and third condition were analyzed in quiet with frequency transposition on and off respectively. CVC words spoken by a female speaker and the participants were asked to identify words. In the second and third condition, 4 of the hearing impaired individuals and 5 of the normal hearing individuals were participated. And the frequency was lowered to all the speech frequencies by a factor of 0.6. Results revealed that little benefit from the frequency transposition on condition. Overall scores were not significantly different with frequency transposition on and off condition.

McArdle et al., (2001) investigated the use of frequency transposition transonic FT40 system in 36 children with profound sensorineural 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 FT40 was significantly better at 500Hz, 1kHz, 2kHz and 4kHz compared to thresholds with conventional hearing aids and a small group benefited from frequency transposition hearing system.

A further study (Korhonen and Kuk, 2008) evaluated the effect of frequency transposition on phoneme identification in nine normally hearing listeners with a 35 simulated hearing loss (stimuli were low pass filtered above 1.6 kHz). The results showed that prior to auditory training, there was no significant difference between scores obtained with and without frequency transposition. However, after thirty minutes of self-paced training (during which time the participant was able to listen to and compare different phonemes), mean scores with transposition enabled were 14.4% higher than those with the transposition setting disabled.

Auriemmo et al., (2009) studied the effect of linear frequency transpositionon phoneme recognition and fricative articulation in young children. Total of 10 children in the age range of 6 and 3 years were participated in this study. All participants had normal to moderate loss in low frequency while severe to profound hearing loss in high frequency region. The performance of phoneme recognition and fricative articulation was evaluated using NST test for /s/ and /z/ and the results revealed with linear frequency transposition there was significant improvement in consonant and vowel identification.

The literature presents contraindicating study whether the linear frequency transposition improves the perception speech in background noise. For high frequency hearing loss, high frequency speech sounds are not audible and difficulty to perceive speech in the presence of background noise and by assuming linear frequency transposition would help in better way of understanding speech especially in a noisy situation because high frequency information (inaudible) is transposed to audible low frequency region. Linear frequency transposition could produce high frequency noise but that may not cause to a hearing impaired individuals because it is not audible to these individuals but it would mask low to mid frequency which results in poorer perception of speech sounds in the presence of environmental noise with linear frequency transposition (Kuk et al., 2009). Hence this study says that with linear frequency transposition there is no significant improvement in the perception of speech in noise.

Gou et al., (2011) studied the effect of frequency transposition on speech perception in adolescents and young adults with profound hearing Loss. Total of seven individuals were included in this study with severe to profound hearing-impaired and the results showed that with frequency transposition system there was increase in audibility in the region of high frequency when compared to conventional amplification and hence there was significant improvement in the performance of identification and discrimination of phonemes (Ling test). And little improvement was seen for identification of speech sounds after 12 weeks of use. They concluded that frequency lowering is an option for severe to profound hearing loss where it helps in the perception of speech sounds and it is essential for development of language acquisition.

2.2. Nonlinear Frequency Compression

Nonlinear frequency compression (NFC) is another approach which allows high frequency information to perceive. It compresses and then shifts to low frequency region from the high frequency region. Compression happens above a specified level of frequencies are targeted which is similar to linear frequency transposition. Non-linear frequency compression maximizes the availability of high frequency information in order to facilitate better perception of high frequency consonants and environmental sounds, whilst leaving the mid and low frequency information, important for the perception of vowels and mid frequency consonants, relatively unchanged by the processing scheme. And high frequency speech sounds are not mixed with low and mid frequency speech sounds and hence helps in better way of understanding speech using the non-linear frequency compression.

Simpson et al., (2005) conducted a study to evaluate speech perception in seventeen participants with moderate-to-severe sloping SNHL. Using frequency compression, there searchers programmed a hearing aid to amplify and shift frequencies above 1,600 Hz to a lower frequency range. Researchers then compared participant's recognition of monosyllabic words using compression amplification devices to their recognition using conventional hearing aids. When using frequency compression, eight of the seventeen subjects demonstrated significant improvements in speech recognition scores.

Simpson et al., (2006) investigated the effect of frequency compression on the perception of seven adult hearing aid users with steeply sloping high frequency. The experimental devices were worn for four to six weeks and tested was conducted towards the end of the trial period. In addition to the monosyllabic word recognition task, medial consonant recognition (both in quiet and with a male speaker) and sentence recognition in noise (with a female speaker) tests were also conducted. Results showed that there was no significant difference in group scores with and without frequency transposition in either of the tests of speech in quiet, with the group means scores showing that frequency compression lead to a deficit in performance of 2% in the consonant recognition task and of 6% in the monosyllabic word recognition task.

Glista et al (2009) studied the effect of non-linear frequency compression on perception of speech sounds. A total of 24 participants where 13 were adults and 11 were children. All participants were hearing impaired individuals with moderate to profound sloping high frequency sensorineural hearing loss. Individuals were asked to wore a non-linear frequency compression hearing aid and told them to use every day as much as possible. The results showed that group scores in the consonant and plural recognition tasks were significantly higher when with frequency compression than without frequency compression, whilst vowel recognition was not significantly affected by the processing strategy. The individual results of the adult participants revealed that one participant showed a significant increase in consonant recognition, four demonstrated a significant increase in plural recognition and one participant showed a significant decrease in vowel recognition when frequency compression was enabled.

Similarly, Boretzki and Kegel (2009) examined the benefits of NFC for subjects with mild to moderate hearing loss. These researchers utilized The Adaptive Test, designed to measure thresholds at which high-frequency consonants are decipherable. The findings of Boretzki and Kegel's study suggest that NFC has the potential to provide substantial improvement in identification of high frequency speech signals and environmental sounds when compared to the subjects' amplification devices. Users participating in this study preferred NFC processing better than their conventional digital hearing aids.

Souza and Bishop (2000) studied the effect of nonlinear frequency compression on perception of speech in individuals with sloping sensorineural hearing loss and with a flat sensorineural hearing loss. And also determined whether nonlinear frequency compression improves in identification of speech sounds in individuals with sloping SNHL, by using wide dynamic compression and also using linear amplification as a function of audibility in identification of consonant. The results of this study revealed similar improvements in recognition for subjects with flat and sloping loss when using linearly amplified speech. Results revealed that there was similar performance in identification of consonant when using with linear compression in individuals with sloping and flat sensorineural hearing loss. But in individuals with flat loss showed greater improvement in recognition when using with WDRC amplification than in subjects with sloping hearing loss.

Wolfe et al (2010, 2011) evaluated whether nonlinear frequency compression will benefit for children with moderate hearing loss. Fifteen children in the age range of 5-13 years were participated in this study. Results revealed that there was improvement in the perception of some high frequency speech sounds. However, only group mean scores were considered so it is not possible to determine the degree of variation in benefit from frequency compression between different listeners.

From the above literature it can be seen that clinical studies on frequency lowering provide mixed results. Therefore, it is essential to evaluate the efficacy of frequency lowering techniques in language learning.

CHAPTER III

METHOD

3.1 Participants

A total of 120 adults in the age range of 18-40 years participated in the study. These participants were randomly assigned to three groups for the purpose of the study. Three groups participated in three separate experiments where their ability to learn artificial language was evaluated. In each experiment, 40 individuals were involved. All the participants went through a structured interview to ascertain that none of the participants had any complaint or history of hearing loss, ear disease, head trauma, ototoxic drug intake, and ear surgery or speech language problems. Further, it was made certain that none of the participant had any illness on the day of testing.

Detailed audiological assessment was performed for all the participants before recruiting them for the study. All selected participants had pure tone hearing thresholds of less than 15dBHL at octave frequencies between 250Hz to 8000Hz for air conduction and between 250 to 4000Hz for bone conduction. Their Speech recognition thresholds (SRT) were within $\pm$12 dB of pure tone average (average threshold of 500 Hz, 1000 Hz, 2000 Hz and 4000 Hz). Also, Speech identification scores was greater than 80% at 40 dB SL (ref SRT) on the phonetically balanced word lists in Kannada (Mayadevi, 1974). Normal functioning of middle ear was indicated by bilateral ‘A’ type of tympanogram and normal acoustic reflex (ipsilateral and contralateral) threshold at levels at 500 Hz and 1000 Hz. All the participants had a formal education for at least 10th standard and they were native listeners of Kannada.

3.2 Test Environment

Pure tone audiometry was carried out in an acoustically and electrically shielded room where the noise levels were within the permissible limits (ANSI S3.1; 1999). All the other experiments were carried out in a quiet room with good illumination, ventilation and minimum distraction.

3.3 Instrumentation

A calibrated two channel Inventis *piano* diagnostic audiometer with the transducers TDH-39 headphone (Telephonic 81broad hollow road, farming dale, New York11735) and B-71 bone vibrator (Radioear, KIMMETRICS,smithbergs, MD 21783) were used to assess air conduction and bone conduction threshold respectively. GrasonStadler Inc. Tympstar system (GSI VAISYS Healthcare, Wisconsin, USA) was used to measure middle ear functioning. A HP Pavilion Core i3 laptop with Intex headphones was used to assess the learning of artificial speech.

3.4 Stimuli

An artificial language learning task adopted from Aslin and Newport (2014) was used to investigate the adult participant's ability to use transitional probabilities cues for word boundary. Transitional probability between two sounds will be generally higher when they follow one another as in words, whereas transitional probability between two sounds spanning word boundary will be relatively low. We created an ideal language (artificial) where transitional probability within word was one and across word was zero. For this purpose, we used seven consonants (/ʃ/, /s/, /z/, /ʤ/, /ʧ/, /m/ and /n/) combined with five vowels (/a/, /e/, /i/, /o/, /u/)to create consonant-vowel syllables. These syllables were spoken by an adult female speaker. The spoken syllables were recorded using a condenser microphone connected to MOTU microbook II sound card. Recording was done through Praat software (Boersma, 2002)at 44100 Hz sampling frequency. These syllables were combined to create twelve try-syllabic words such as *sujamo*, *majuse*. Four hundred tokens of such try-syllabic words were concatenated into syllable string in random order, with the stipulation that same word will not occur twice in a row. A commercially available speech synthesiser converted these syllable string (using the pre stored recorded syllables) in to speech without any intonation or word boundaries. The output of the synthesizer was then saved on to a computer hard disk for further use. For the test phase, six words (tri syllable string with high transitional probabilities) and six non words (tri syllable string with low transitional probabilities) were created.

3.4.1 Simulation of hearing loss: A digital BTE hearing aid (Dynamo SP 4) with frequency transposition facility was used to assess the effect of frequency transposition on artificial language learning. Hearing aid was first connected to HI-PRO using connecting cable and was programmed to asteeply sloping high frequency hearing loss (simulated loss) based on NAL-NL2 formula. Figure 1 shows the audiogram for which the hearing loss was simulated. Simulated high frequency hearing loss may be more desirable because the effect of different variables like the degree of hearing loss of the individuals, distortion and re-organization within the auditory system and the setting of the optimal parameter may be minimized. Other features of hearing aid like noise reduction, directional microphone and feedback management settings were kept off. Hearing aid was enabled to have two programs. In programme one frequency transposition was kept on. Frequencies between 7.5- 4.3 kHz and was transposed to between 2-2.8 kHz. In programme 2 conventional amplification was provided.

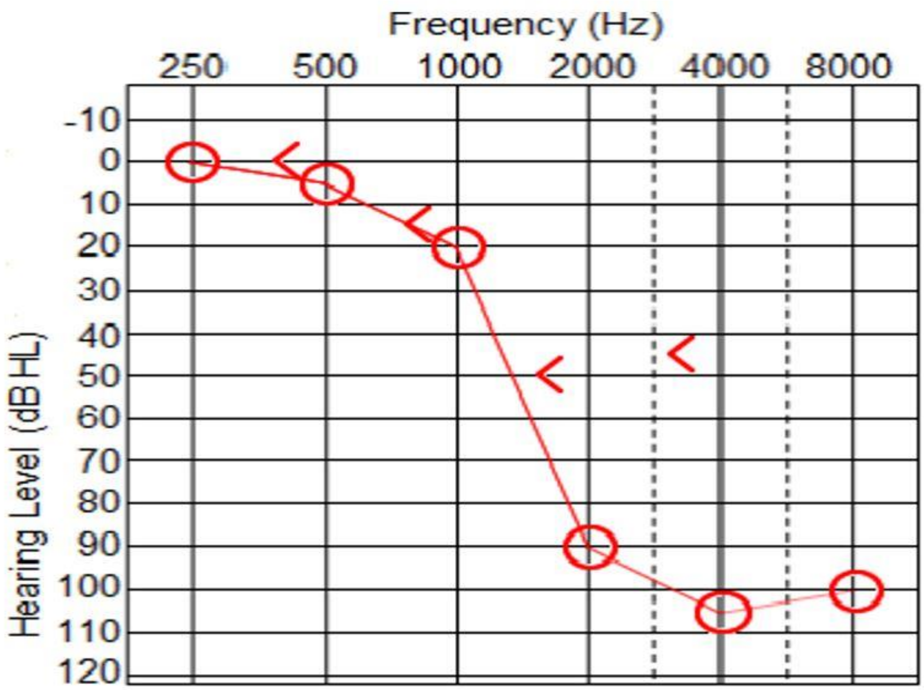

Figure3.1 Audiogram of steeply sloping hearing loss

The hearing aid was connected to a sound level meter (SLM, B&K 2270) using HA2 2cc coupler. Artificial language synthesized was played at 60 dB SPL from a speaker kept at a distance of 1 meter from the hearing aid. The output of the hearing aid was recorded once with the frequency transposition on and once with frequency transposition off. To simulate the high frequency hearing loss in normal hearing participants the recorded stimuli was low-pass filtered with the same audiogram with which it was initially programmed using Tiger CIS software (Fu, 2010).

3.5 Procedure

Basic audiological evaluations were done preliminary to the actual experiment for recruiting the participants.

3.5.1 Basic audiological evaluations: Following evaluations were carried out to select the participants for the study.

1. Pure tone hearing thresholds were measured using modified Hughson Westlake method (Carhart & Jerger, 1959). Threshold were obtained across octave frequencies from 250 Hz to 8000 Hz for air conduction and 250 Hz to 4000 Hz for bone conduction using a calibrated two channel Inventis *piano* diagnostic audiometer. Thresholds were tracked using bracketing method.
2. Uncomfortable loudness level measurement for speech was done for all the clients.
3. Tympanometry was carried out with a probe tone frequency of 226Hz at approximately 85dBSPL by varying the air pressure in the ear canal from +200dapa to -400dapa. Ipsilateral and contralateral acoustic reflexes thresholds were measured for 500, 1000, 2000 and 4000Hz.

And then all the participants were made to sit comfortably in a quiet room with adequate illumination. They were instructed to listen to synthesized artificial speech played through Intex headphones using HP Pavilion Core i3 laptop. One group listened to the unprocessed artificial speech, second group listened to artificial speech with the frequency transposition on and the third group listened to artificial speech with the frequency transposition on. They were told that language contains words but no grammar or meaning. No information was given to the participants regarding the length or the structure of the words or how many words does it contain. They were informed that following listening phase there will be a testing phase where they need to identify the words. In the testing phase participants were made to listen to tri-syllabic words (words and non-words of artificial speech) and were asked to identify them as words or non-words by pressing the respective keys on the keyboard. The presentation of the stimuli and collection of the response was done using DMDX (Forster & Forster, 2003).

CHAPTER IV

RESULTS AND DISCUSSION

Primary aim of the study was to evaluate the effect of frequency transposition and conventional amplification on learning of an artificial speech. Analysis was performed on all 120 participants using SPSS software version 16.0. Normality of the data was assessed via Shapiro-Wilk test. As data was normally distributed parametric tests, One-Way ANOVA was used to compare between the groups. The results are explained under the following headings,

1) Evidence of learning of an artificial language
2) Comparison between frequency transposition on and off

Evidence of learning

It is important to establish the learning process before comparing the performances on frequency transposition on and off condition. Under this section comparison was made between identification word and non-word in unprocessed conditions (without simulation of hearing loss). This was done by calculating the number of words and non-words identified correctly. Figure 4.1 shows mean along with one standard deviation of identification of word and non-word tokens. For the word tokens mean score is 44.6 of a possible 60, where chance performance is equal to 30. A one-sample t test (two-tailed) showed that overall performance was significantly different from chance ($t(39) = 14.3$, $p<0.01$). Performance of participants on non-word tokens was worse. The mean score was 31.1 of a possible 60, which was not significantly different from chance performance ($t(39) = 0.91$, $p>0.01$). The overall correct score (correct identification of both word and non-word tokens) was 75.7 of a possible 120, which was significantly different form chance (t (39) = 37.05, p<0.01). As the performance on non-word tokens were bad, *d-prime* (d') was calculated to nullify the effects of false alarms. The mean sensitivity was 0.67 and standard deviation was 0.34. A single sample t test showed that overall d' scores were significantly different from chance (t (39) = 12.2, p<0.01). These results show that participants could use the transitional probability cues effectively to distinguish the word boundaries with just 7 minutes of exposure to artificial language.

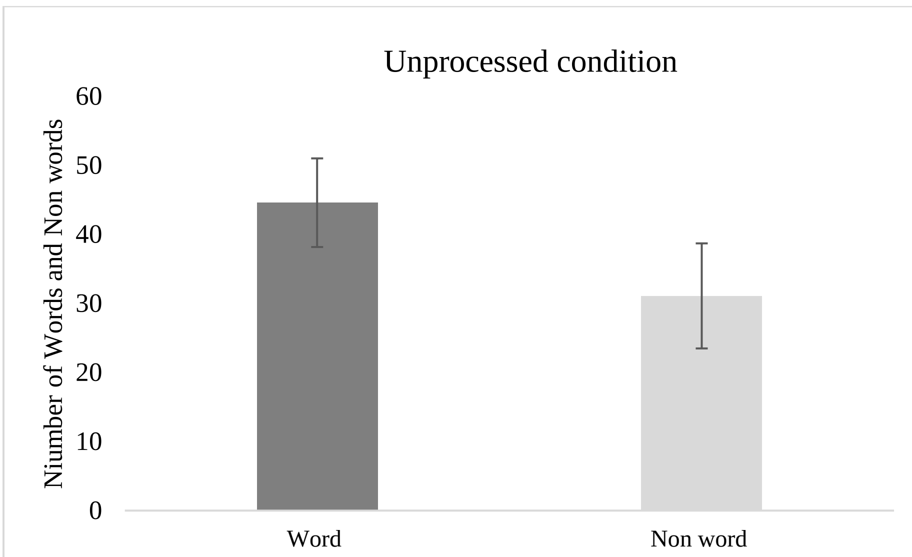

*Figure 4.1.*Mean and standard deviation (SD) for identification of Words and Nonwords in Unprocessed condition.

The above results revealed that, identification of words were better than nonword in unprocessed condition. Since the training phase involved presentation of words and not the non-words, training would have cause better identification of word than non-words. Hence learning process would have taken place which helped to distinguish the word from nonword.

Comparison between frequency transposition on and off

Next, assessed was whether the frequency transposition on or off conditions played any role on participants learning. Figure 4.2 shows Mean along with one SD identification scores of word and non-word tokens in unprocessed, frequency transposition on and off condition. From the Figure 4.2 it can be seen that for both words and non-words tokens identification scores were better in unprocessed condition (without hearing loss simulation) compared frequency transposition on or off. However, performance was better than chance (50%) for word tokens in both frequency transpositions on and off conditions. A single sample t test showed that participants identified words significantly better than chance in frequency transposition on ($t(39) = 8.2$, $p<0.01$) and frequency transposition off conditions ($t(39) = 6.5$, $p<0.01$). However, identification of non-words were poorer compared to words, and was significantly below chance in both frequency transposition on ($t(39) = -1.7$, $p<0.01$) and frequency transposition off ($t(39) = -5.4$, $p<0.01$). Figure 4.3 shows the overall d' scores and was significantly above chance performance in frequency transposition on ($t(39) = 3.3$, $p<0.01$) condition but not in off condition ($t(39) = 0.31$, $p>0.01$).

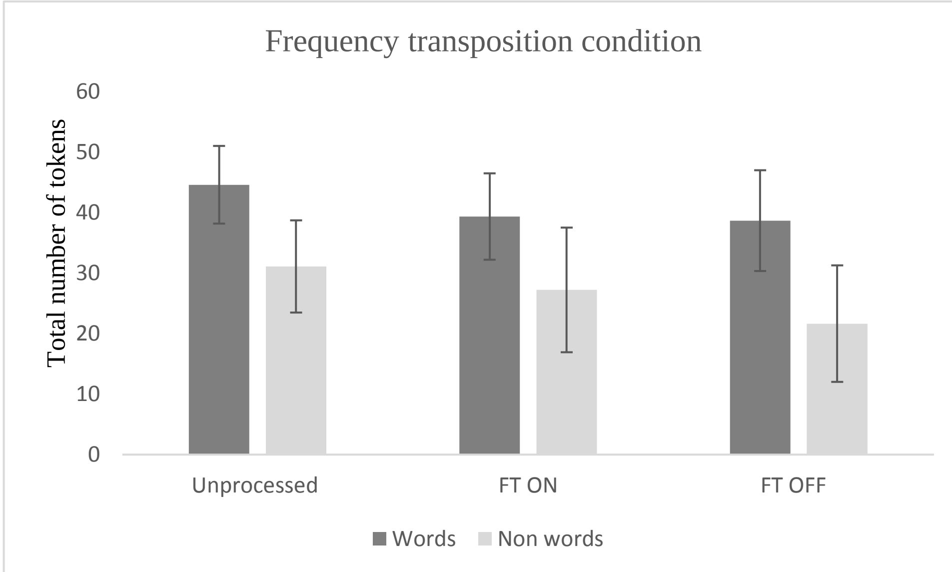

*Figure 4.2.*Mean and standard deviation (SD) for identification of Words and Nonwords in Unprocessed, frequency transposition on and off condition.

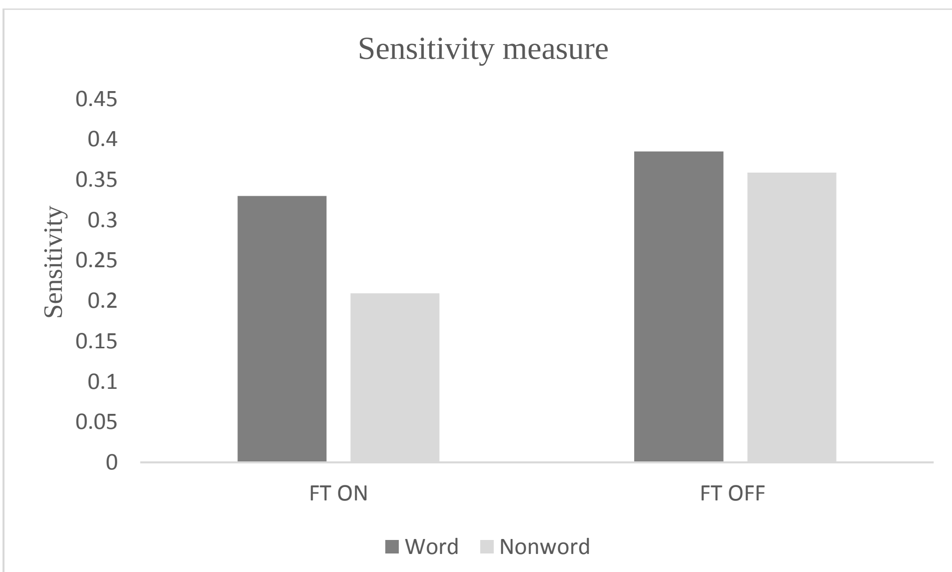

*Figure 4.3.*Overall sensitivity scores of Words and Nonwords in Unprocessed, frequency transposition on and off condition

To assess the statistical significance of these differences one-way ANOVA was performed with identification scores as depended variable and different conditions as between the subject factors (unprocessed, frequency on and off). Results revealed a significant main effect of condition on identification scores words [$F(2, 117) = 7.8$, $p < 0.01$], non-words [$F(2, 117) = 10.5$, $p < 0.01$], total [$F(2, 117) = 23.1$, $p < 0.01$] and *d-prime* [$F(2, 117) = 22.8$, $p < 0.01$]. Table 4.1 shows the follow-up post hoc test with Bonferroni's correction for multiple comparisons. From the Table 4.1 it can be seen that identification scores were significantly higher for unprocessed condition compared to both frequency on and off in most of the measures. Identification scores and d' was significantly better in frequency transposition on condition compared to frequency transposition off condition for overall scores. These results indicate that the learning abilities were superior in frequency transposition on condition compared to frequency transposition off condition.

Table 4.1.

Follow-up post hoc test results for multiple comparisons

Dependent variable	Groups	Mean difference
Words	Frequency transposition on vs off	6.15*
	Frequency transposition on vs Unprocessed	9.13*
	Frequency transposition off vs Unprocessed	15.28*
Non-words	Frequency transposition on vs off	.68
	Frequency transposition on vs Unprocessed	5.25*
	Frequency transposition off vs Unprocessed	5.93*
Total	Frequency transposition on vs off	5.58*
	Frequency transposition on vs Unprocessed	3.88
	Frequency transposition off vs Unprocessed	9.45*
Sensitivity total	Frequency transposition on vs off	.267*
	Frequency transposition on vs Unprocessed	.40*
	Frequency transposition off vs Unprocessed	.66*

The purpose of this study is to assess the effect of frequency transposition on learning of an artificial language. An artificial learning task was used as a stimulus to investigate their ability to learn artificial speech was assessed. In the present study compared with frequency transposition on, off with simulated high frequency hearing loss and with unprocessed condition (without simulation of hearing loss).

The above results revealed that the overall scores were better with unprocessed condition than frequency transposition on and off condition. The reason might be attributed to the normal cochlear functioning while in other two condition involves simulated hearing loss which mimic impaired cochlear functioning. When the comparison was made between the frequency on and off condition, it was found that, frequency transposition on was significantly better than with frequency transposition off condition for overall scores. These observations suggest that, there is greater learning effect and high frequency information is accessibility with frequency transposition. Similar results are reported by Wedenberg (1961) and Johansson (1966) where they have showed that performance of identification was better (about 15%) for PB words and nonsense syllables in normal hearing individuals with simulated hearing loss with frequency transposition on condition than with frequency transposition off condition following training phase. Hence, concluded that there are greater learning effects over time with the frequency transposition hearing system. Further, a study done by Korhonen and Kuk (2008) compared the results prior to and after auditory training. The results showed the performance of phoneme identification was poorer prior to auditory training while there was significant improvement in the perception of phoneme after auditory training. Similar studies were also reported by Foust and Gengel (1973) wherein they have compared the results of frequency transposition on and off condition. The results showed with frequency transposition hearing aid allows to perceive high frequency information. Hence artificial speech can also be used as a stimulus to see the effect of frequency transposition.

CHAPTER V

SUMMARY AND CONCLUSION

Frequency transposition hearing aids transpose inaudible high frequency information into audible low frequency information. Present study was taken up to study the effect of frequency transposition on learning of an artificial speech.

The objectives of the present study are as follows

1. To study the effect of frequency transposition on learning an artificial speech
2. To study the effect of conventional amplification on learning of an artificial speech

Hundred and twenty normal hearing adults in the age range of 18-40 years recruited for the study. Three groups randomly assigned into three separate experiments and in each experiment 40 each were included. Of the three one group listened to unprocessed artificial speech, second group listened to artificial speech with frequency transposition on and third group listened to artificial speech with frequency transposition off.

Results revealed that overall performance was better for learnt words than non-words in unprocessed condition than with frequency transposition on and off condition and also performance was significantly better for words than non-words in frequency transposition on condition than with frequency transposition off condition. Hence results indicate that learning abilities were superior in frequency transposition on condition than with frequency transposition off condition.

Implications

The current study will provide the insight about effect of learning language with and without frequency transposition.

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