Frequency Transposition Enhancement Study for High-Frequency Hearing Loss

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Abstract. With this study, software that includes a detailed audiogram and an enhancement algorithm was developed for high frequency hearing loss subjects. Software performs all the enhancements according to the subject's audiogram. Amplification, compression and transposition are the three enhancement methods. For low frequencies (0-1000 Hz), only amplification method was used; for mid and high frequencies (1000-4000, 4000-8000 Hz), both compression and transposition methods were used together. Ten subjects were added to the study for 5 weeks. But for subjects' special reasons that subject number decreased to four in the fifth week. In the study, environmental, music and speech sounds were used. While the perceptual mean performances of the subjects were in the range of (25,33%-63,77%) in the first week, those values increased to (68,75%-95,75%) in the fifth week. But the reliability of the study should be tested with more subjects and compared with their own hearing aids.

Keywords. Amplification, compression, transposition, audiogram, high frequency, hearing loss

Yüksek Frekans Duyma Kaybının Frekans Kaydırma Metodu İle İyileştirme Çalışması

Özet. Bu çalışma ile yüksek frekans duyma kaybı hastaları için hem ayrıntılı odyogram hem de iyileştirme algoritması içeren bir yazılım geliştirilmiştir. Yazılım hastaların odyogramlarına göre işlemektedir. Yükseltme, sıkıştırma ve kaydırma üç adet temel iyileştirme metodudur. Düşük frekanslar (0-1000 Hz) için sadece yükseltme metodu uygulanırken; orta ve yüksek frekanslar (1000-4000, 4000-8000 Hz) için hem sıkıştırma hem de kaydırma metodu uygulanmıştır. Bu iyileştirme 10 adet hasta üzerinde 5 hafta boyunca denenmiştir. Fakat hastaların bazı özel nedenlerinden dolayı beşinci haftada bu rakam dörde inmiştir. Çalışmada çevre, müzik ve konuşma sesleri kullanılmıştır. Hastaların genel ortalama performansları ilk haftada [25,33%-63,77%] iken bu rakamlar beşinci haftada [68,75%-95,75%] değerlerine yükselmiştir. Fakat bu çalışmanın güvenilirliği hem daha fazla hasta sayısıyla hem de kendi kullandıkları işitme cihazlarıyla karşılaştırılarak test edilmelidir.

Anahtar Kelimeler. Yükseltme, sıkıştırma, kaydırma, odyogram, yüksek frekans, duyma kaybı

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Introduction

Up to now, researches tried many different enhancement methods for high frequency hearing losses in the literature. Amplification, compression and transposition are mostly tried among these methods. But all three methods have some advantages and disadvantages for different part of the frequency spectrum. Although conventional amplification can provide usable low frequency information, the amplified high-frequency sounds of speech are often inaudible due to the severity and configuration of the hearing loss. Until recently, the findings have suggested that an increase in high-frequency gain may not improve, also in some cases may degrade, speech recognition for listeners with high frequency hearing losses, [1,2].

An alternate approach might be the use of frequency compression or transposition schemes, whereby high frequency signals are shifted to lower frequencies to provide adequate audibility. This type of approach has produced mixed results, with some studies showing substantial improvement and others showing no improvement or degradation in performance [3, 4].

Being no spectral overlap between the shifted and unshifted signals can be said as an advantage of the frequency-compression. On the other hand, not preserving frequency ratios for those high frequencies can be said as a disadvantage of the frequency-compression.

Various sound-processing schemes have been developed over the past decades that have attempted to present information from high-frequency regions of speech at lower frequencies. In extreme cases, frequency lowering (‘frequency shifting’ or ‘transposition’) may be the only way of providing this extra information acoustically.

One scheme implemented disproportionate frequency shifting and several studies of these early types of frequency-lowering methods reported little success in providing speech understanding benefits [5]. Those schemes may have provided some additional high frequency information at the expense of other perceptual cues by overlapping the shifted and un-shifted signals.

Proportional frequency shifting, using a ‘slow play’ method, is an alternative sound-processing technique [6]. Segments of the speech signal are recorded and then played back at a slower speed than employed for recording. Incoming signals dominated by components at frequencies above 2.5 kHz are shifted down by a factor that is programmable for each listener. Positive outcomes were reported when the TranSonic was fitted to a small number of hearing-impaired children.

In a more recent study of [7], a fe parameter was selected as an edge frequency of dead region. A band from fe to 1.7fe was selected as the destination for the transposed frequency components. High frequency components from a source band well within the dead region (2fe to 2.7fe) were shifted into this band, but no frequency compression was applied. In the algorithm used, frequencies below fe were left unchanged. Transposition only occurred if the short-term spectrum was dominated by high frequencies. The results of the tests showed that although there was no significant overall benefit of transposition, the processing did not impair consonant identification.

In our study, we try to use all the three methods (amplification, compression, transposition) to provide high frequency audibility in high frequency hearing loss patients. Because, each of them has an advantage for a specific range of spectrum and we planned to benefit from all. For doing this, software was developed for doing the signal processing automatically according to the patient’s audiogram. By this way, we want to exceed the generalization of the same algorithm for every patient which may be the main reason for unsuccessful results of the past studies. So, we developed a patient-specific algorithm based on detailed audiogram.

1. Materials and Methods

1.1. Subjects

Ten hearing-impaired adults, comprising two women and eight men, participated in the study. All subjects had participated to the detailed audiogram measurements at the time of testing, but three subjects did not follow the study after one week. For software sounds testing, majority of the subjects were followed the study (seven subjects for two weeks, five subjects for three weeks and four subjects for five weeks). The number of the subjects decreased because of their special personal reasons.

1.2. Software

All signal processing was done by our own software. Software was developed with MATLAB. Mainly, program has two parts. In the first part, detailed audiogram of the patients can be taken in 31 different frequency points. In the second part, main signal processing can be done according to patient's detailed audiogram. Both have user friendly graphical user interfaces. Flow chart of enhancement processing can be seen from figure 1.

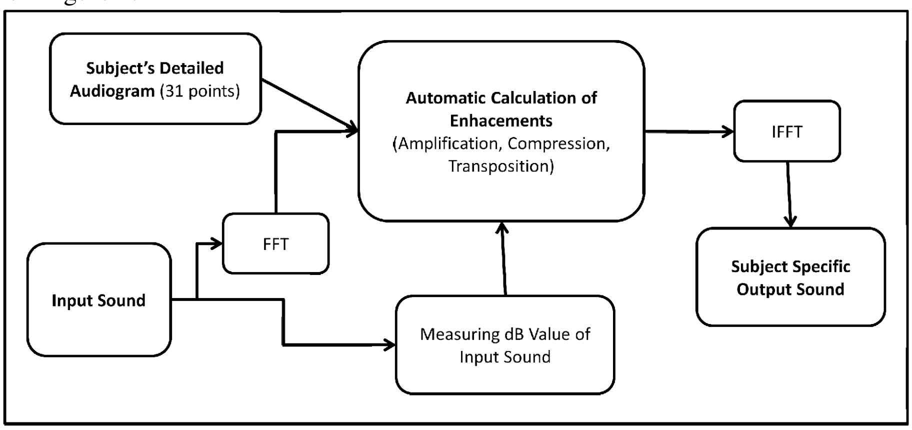

Figure 1. Flow chart of enhancement processing

1.3. Signal Processing

Frequency spectrum was splitted to three parts ([0-1KHz] as low frequency, [1-4 KHz] as mid frequency and [4-8 KHz] as high frequency) by taken into consideration of the studies in the literature [1, 2, 7]. Low frequency part consists of 3 octaves ([125-250], [250-500], [500-1000]); mid frequency part consists of 2 octaves ([1000-2000], [2000-4000]) and high frequency part consists of 1 octave ([4000-8000]). Each octave's value was determined as an average value of its audiogram dB values. Audiogram frequency points were determined as giving enough information for low frequencies and detailed information for mid and high frequencies. Low, mid and high frequency regions have 3 ranges of points for determining the enhancement parameters.

For low frequency part, only the amplification process was applied to the sounds. This application was done according to octaves' dB value. This gain was calculated by taking the decibel difference of the input signal and patient's hearing loss for each octave. So, unneeded high amplification was not applied to the subjects (for example; for 40 dB input sound, 10 dB amplification was applied for 50 dB hearing loss for that frequency range).

For mid and high frequency parts, frequency compression and transposition was applied as an enhancement. Frequency compression was applied for mid frequencies; frequency transposition was applied for high frequencies. But the algorithm was working by taking into account the both mid and high frequency parts. Frequency compression and transposition parameters (compression region, compression rate, transposition region, transposition rates) were determined automatically by the software algorithm according to the audiogram of the patient.

The criteria of the determination of the enhancement parameters were occurring no gap and no overlapping between compressed and transposed parts.

1.4. Test Procedure

For the tests, in the first meeting, the detailed audiogram was taken. Then, according to subject's audiogram, all sounds were enhanced with the software and stored in CD. In the second meeting, a few days later, prepared patient specific sound CD and patient listening follow-up form were given to subject and in the same day, the first test with enhanced sounds was done as a control study. And, after every 7 days, the test with same enhanced patient specific sounds was done and follow-up form was controlled.

2. Results

In our study, all subjects listened the sounds and gave responds like hearing/non-hearing and understanding/no understanding. And the percentages of both hearing and understanding responds were calculated for each subject for every week. These values are shown in figures from 2 to 4. From all subjects, seven subjects came to second meeting, for other three subjects; no comparisons were obtained for this study. At the end of the five weeks, only 4 subjects completed the study. Others did not come to the study because of personal reasons.

For the evaluation of the results, non-parametric Friedman test was applied to all results for only 4 subjects (Subject 9, subject 6, subject 8, subject 3). For environment sounds, all subjects showed no significant scores (x2 =2,933; p=0.569) during the five weeks. For music sounds, all subjects obtained a significant (x2 =10, 27; p=0.036) phoneme score. Also, the difference of the first week's results and fifth week's results showed significant score (p<0.05, 2,87 (difference of mean rank)). Again, for speech sounds, all subjects obtained a significant (x2 =14,154; p=0.007) phoneme score. Also, the difference of the first week's results showed significant scores both fourth (p<0.05, 3,25 (difference of mean rank)) and fifth week's results (p<0.05, 3,25 (difference of mean rank)). For all subjects participated in the study, the mean, minimum and maximum values of the results are shown in table 1.

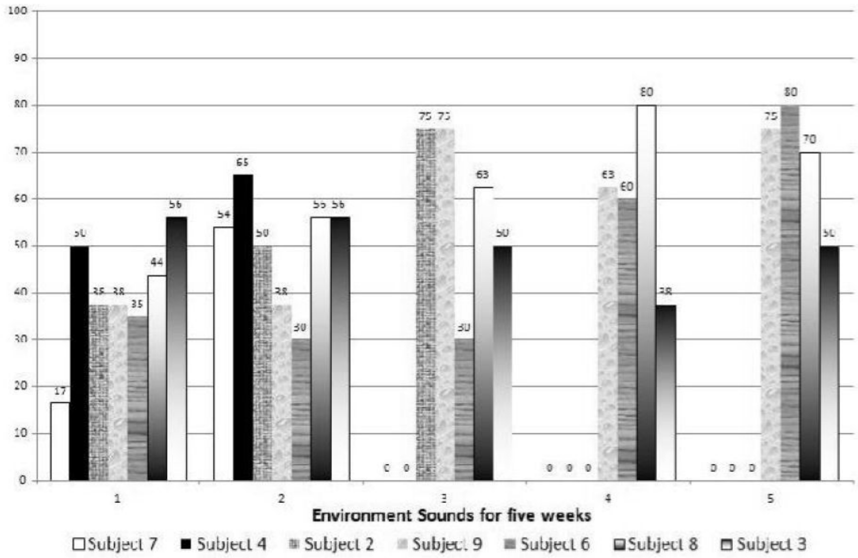

Figure 2. Percentage values of environment sounds for five weeks

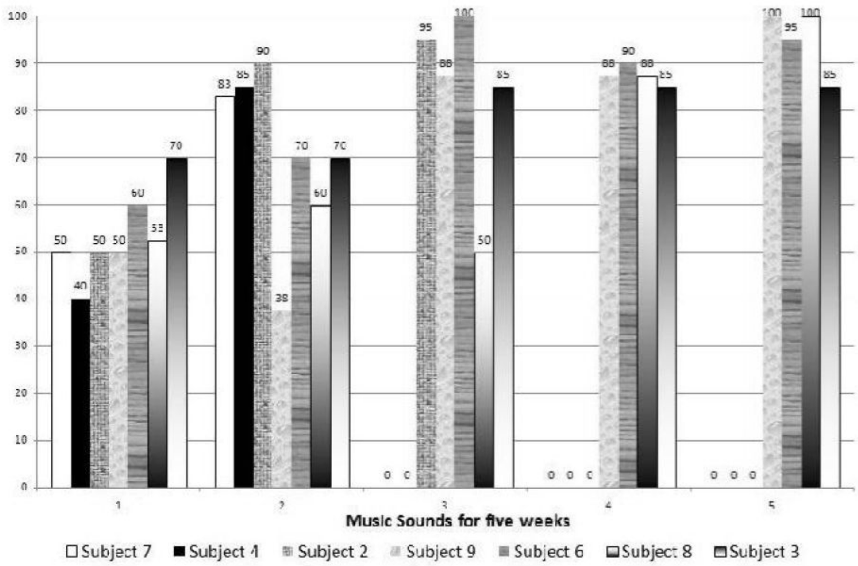

Figure 3. Percentage values of music sounds for five weeks

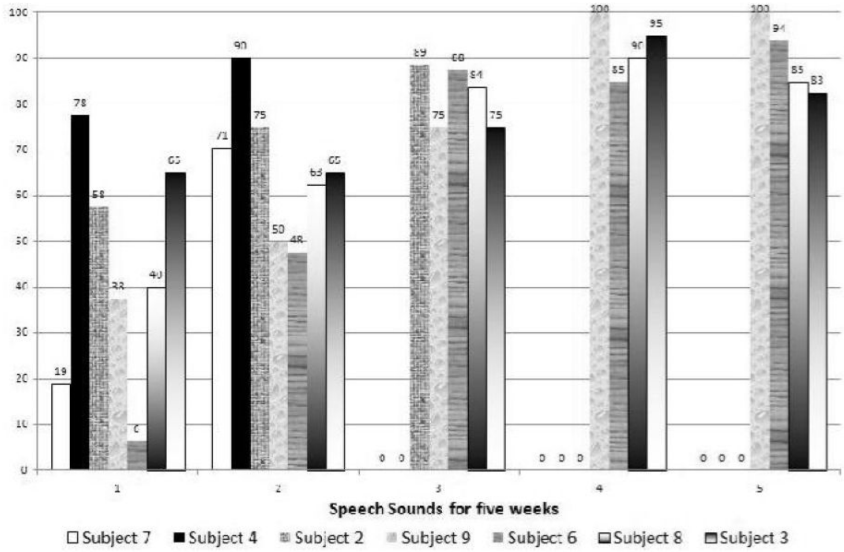

Figure 4. Percentage values of speech sounds for five weeks

	1. Week Mean (Min - Max)	2. Week Mean (Min - Max)	3. Week Mean (Min - Max)	4. Week Mean (Min - Max)	5. Week Mean (Min - Max)
Env. Sounds	35 (0-56)	49,85 (30-65)	58,6 (30-75)	60,25 (38-80)	68,75 (50-80)
Music	56,44 (40-75)	70,85 (38-90)	83,6 (50-100)	87,75 (85-90)	95 (85-100)
Speech	42,33 (6-78)	66 (48-90)	82,2 (75-89)	92,5 (85-100)	90,5 (83-100)

Table 1. Summary of the percentage values of all types of the sounds

3. Discussion

The main goal of our study is to offer a patient specific fitting that uses the suitable methods to the suitable frequency regions. Differences between patients include lifestyle, speech understanding and cognitive ability. Each of these differences may result in one patient requiring different fitting than another patient who has similar levels of hearing loss. Also any difference in the audiogram must be taken into account for better satisfaction and life quality.

The most important and vital role in determining the hearing aid algorithm or fitting is the patients' audiogram, because most of the processes were mostly done according to it. So, true measurement is becoming very crucial. Using more points in the audiogram measurement provides more accurate fitting algorithms for the patients and this provides more satisfaction from the hearing aids of the patients. This improvement, of course, is important and specific for high frequency loss patients and our study's methodology.

The least performance was achieved in environmental sounds test. But the mean percentages occurred in the range of 35%-68,75%. Highest improvement was showed in subject 6 (80%) individually.

The highest mean perceptual performance obtained for music sounds at the fifth week. These sounds were selected from the parts of instrumental songs. Although at the beginning of the study, the mean percentage was high (56,44%), it climbed to 95% at the end of the study. So, this shows the significant effect on understanding the music sounds of our method.

Also significant achievement obtained in speech sounds test after five weeks training. These sounds are selected from the Turkish films' cues which have different speaking properties. Only two subjects (subject 8 and 3) had a declined at last two weeks. But overall success is enough for showing the reliability of the application.

In general, most of the mean percentages increased 50% at the end of the study compared to first week. This study was the one of the parts of the Ph.D. thesis and methods are now available only as software. The structure and complexity of the software were designed by thinking the implementation standards of hearing aids and that implementation studies will be completed in near future.

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