DEVELOPING SUBJECT-SPECIFIC HEARING LOSS SIMULATION TO APPLY DIFFERENT FREQUENCY LOWERING ALGORITHMS FOR THE ENHANCEMENT OF SENSORINEURAL HEARING LOSSES

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ABSTRACT

DEVELOPING SUBJECT-SPECIFIC FREQUENCY LOWERING ALGORITHMS WITH SIMULATED HEARING LOSS FOR THE ENHANCEMENT OF SENSORINEURAL HEARING LOSS

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The hearing and understanding problems of the people with high frequency hearing loss are covered within the scope of this thesis. For overcoming these problems, two main studies, developing hearing loss simulation (HLS) and applying new frequency lowering methods (FLMs) were carried out. HLS was developed with the suprathreshold effects and new FLMs were applied with different combinations of the FLMs. For evaluating the studies, modified rhyme test (MRT) and speech intelligibility index (SII) were used as subjective and objective measures, respectively. Before both of the studies, offline studies were carried out for specifying the significant parameters and values for using in MRT. For the HLS study, twelve hearing impaired subjects listened to unprocessed sounds and thirty six normal hearing subjects listened to simulated sounds. In the evaluation of the HLS, both measures gave similar and consistent results for both unprocessed and simulated sounds. In FLMs study, hearing impaired subjects were simulated and normal hearing subjects listened to frequency lowered sounds with the specified methods, parameters and values. All FLMs were compared with the standard method of hearing aids (amplification) for five different noisy environments. FLMs satisfied 83% success of higher speech intelligibility improvement than amplification in all cases. As a conclusion, the necessity of using subject-specific FLMs was shown to achieve higher intelligibility than with amplification only. Accordingly, a methodology for selection of the values of parameters for different noisy environments and for different audiograms was developed.

Keywords: Hearing Loss Simulation, Frequency Lowering Methods, High Frequency Hearing Loss, Speech Intelligibility Index, Modified Rhyme Test

ÖZ

SENSÖRİNÖRAL İŞİTME KAYBININ İYİLEŞTİRİLMESİNE YÖNELİK SİMULE EDİLMİŞ İŞİTME KAYBI KULLANILARAK KİŞİYE ÖZEL FREKANS KAYDIRMA ALGORİTMALARININ GELİŞTİRİLMESİ

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Bu tez kapsamında yüksek frekans işitme kaybına sahip insanların işitme ve anlama problemleri ele alınmıştır. Bu problemlerin çözümü adına tez kapsamında duyma kaybı simülasyonunun geliştirilmesi ve yeni frekans kaydırma metotlarının uygulanması olmak üzere iki çalışma yapılmıştır. Duyma kaybı simülasyonu farklı "suprathreshold" etkiler dahil edilerek geliştirilmiş; yeni frekans kaydırma metotları ise mevcut olan frekans kaydırma metotlarının farklı kombinasyonlarının birleştirilmesiyle uygulanmıştır. Bu çalışmalarının sübjektif değerlendirilmesi için değiştirilmiş rhyme test; objektif değerlendirilmesi için konuşma anlaşılabilirlik indeksi kullanılmıştır. Değiştirilmiş rhyme testte kullanılacak metotların parametre ve değerleri için her iki çalışma öncesinde de çevrimdışı çalışmalar yapılmıştır. Duyma kaybı simülasyonunun geliştirilmesi çalışmasında simule edilmemiş sesler on iki işitme kayıplı insana; simule edilmiş sesler ise otuz altı normal işitmeye sahip insana dinletilmiştir. Duyma kaybı simülasyonu değerlendirilmesinde simülasyon öncesi ve simülasyon sonrası için her iki ölçütte benzer ve tutarlı sonuçlar vermiştir. Frekans kaydırma metotlarının uygulanması çalışmasında işitme kayıplı hastalar simule edilmiş ve bu seslere çevrimdışı çalışmada her bir işitme kayıplı insana özel belirlenen metotlar, bunların parametreleri ve değerleri uygulanarak normal işitmeye sahip insanlara dinletilmiştir. Tüm frekans kaydırma metotlarının performansı beş farklı gürültülü ortam için işitme cihazlarında standart olarak kullanılan “yükseltme” metodununkiyle karşılaştırılmıştır. Uygulanan yeni frekans kaydırma metotları “yükseltme” metoduna karşı tüm durumların %83’ünde daha yüksek bir konuşma anlaşılabilirlik iyileştirmesi sağlamıştır. Sonuç olarak daha yüksek anlaşılabilirlik sağlamak için sadece “yükseltme” metodunun kullanılmasının yerine işitme kayıplı insana özel frekans kaydırma metotlarının kullanılmasının gerekliliği gösterilmiştir. Ayrıca, farklı gürültülü ortamlar ve farklı işitme seviyeleri için parametre değerlerinin seçiminin yöntemi de ortaya konmuştur.

Anahtar Kelimeler: İşitme Kaybı Simülasyonu, Frekans Düşürme Metotlari, Yüksek Frekans İşitme Kaybı, Konuşma Anlaşılabilirlik İndeksi, Değiştirilmiş Rhyme Testi

DEDICATION

To all individuals who are reliant on me, faithful about me and supporting me,

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ABBREVIATIONS

A: Amplification
A_ NLC: Amplification with Non-Linear Frequency Compression
A_FS: Amplification with Frequency Shifting
A_FT: Amplification with Frequency Transposition
A_NLC_FT: Amplification with Non-Linear Frequency Compression and Frequency Transposition
ABR: Auditory Brainstem Response
AI: Articulation Index
ANOVA: Analysis of Variance
ANSI: American National Standards Institute
CF: Compression Factor
dB: Decibel
DRT: Diagnostic Rhyme Test
DSP: Digital Signal Processing
EF: Ending Frequency
ESSL: Equivalent Speech Spectrum Level
FFT: Fast Fourier Transform
FLM: Frequency Lowering Method
FS: Frequency Shifting
FT: Frequency Transposition
HF-PTA: High Frequency Pure Tone Average
HLS: Hearing Loss Simulation
Hz: Hertz
IHC: Inner Hair Cell
kHz: Kilo hertz
MOS: Mean Opinion Score
MRT: Modified rhyme test
NLC: Non-Linear Frequency Compression
NLC_FT: Non-Linear Frequency Compression and Frequency Transposition
OAE: Oto-acustic Emissions
OHC: Outer Hair Cell
SA: Shifting Amount
SF: Starting Frequency

SI: Sound Intensity
SII: Speech Intelligibility Index
SNR: Signal to Noise Ratio
SPL: Sound Pressure Level
STI: Speech Transmission Index
WF: Warping Factor

CHAPTER 1

INTRODUCTION

1.1. Problem Statement

The population of hearing impaired people is rapidly growing in all countries. Hearing loss can directly affect the quality of life of those suffering from it. It also has economic effects on both the hearing impaired subjects and governments to the level of a few billion dollars. Therefore, solutions to hearing loss should be found and applied as soon as possible for the benefit of all of us.

One existing solution is the hearing aids for hearing impaired people. These devices have been under development since the 1960s. Different algorithms and methods were implemented to obtain the highest performance increment for speech intelligibility. However, the average satisfaction from those devices did not exceed the 60% level (Kochkin, 2005). The main reason for the low satisfaction was the usage of general methods to all hearing impaired subjects without taking into account the individual properties of the subjects. Like other illnesses, the causes of hearing loss, the effect on hearing attenuation and compensation system in the brain are different for every hearing impaired subject. Thus, there is a need for new algorithms with optimum parameters which should be specific to each hearing impaired subject.

In the studies of hearing loss, one of the main problems is finding hearing impaired subjects for examining the algorithms. To overcome that problem, hearing loss simulations (HLS) were developed using different approaches. Their aim was to simulate the effects of real human ear and to get a similar response with the hearing impaired subjects. However, those HLSs were applied in a very simple manner without taking into account the behavior of the human ear in the studies of high frequency hearing loss. Also, the reliability of HLS has not been studied in detail. For testing the reliability of HLS, subjective and objective measures should be used in tests involving both hearing impaired and normal hearing subjects, and then, the results of them should be compared. However, such studies are very limited. Therefore, the HLS lacks validation with all aspects of the topic and its application to high frequency hearing loss studies.

The modified rhyme test (MRT) is a subjective testing methodology in HLS studies. Although there are different versions of MRT for different languages, there was not any study using Turkish language in the literature. In this study, a six words grouped MRT test was developed in Turkish and applied to all subjects.

For overcoming the problem of high frequency hearing loss, many frequency lowering methods (FLM) have been attempted in order to lower the high frequency components to the lower parts of the spectrum. The first attempt of those studies was in the 1930s. Efforts for finding more efficient methods with different algorithms still continue today, however, the benefit obtained in terms of speech intelligibility improvement and the user satisfaction from them have been very limited so far (average performance increment in word scores of 8% and user satisfaction of 28%). Suspecting that a single method does not fit everyone in all acoustic environments, new methods should be developed using suitable combinations of frequency lowering techniques with parameters specific to each hearing impaired subject's hearing loss and the acoustic conditions.

Abstract information about the mentioned problems associated with high frequency hearing loss can be found in the next sections of this chapter.

1.1.1. Health Problem: Hearing Loss

The sensing of the sounds and the ability to understand speech are the main properties of hearing. Complexity of the hearing mechanism increases by processing combined information from two ears in the brain.

Hearing loss is becoming a serious problem in modern life, since there are several factors that cause hearing loss, such as high level noise, aging, side effects of diseases, side effects of some medicines and genetic problems.

The effect of hearing losses can be different according to the type of the loss, degree of the loss and location of the problem in the auditory system. Generally, for people with better perceptual ability, moderate losses may not be noticed as a problem, because the declaration of the hearing loss is usually done by self reporting.

Audiometric hearing testing has a subjective test quality. However, audiometric hearing testing is used as the gold standard for hearing loss diagnosis and treatment. Audiometric hearing testing gives the hearing loss information for specified frequencies. The level of hearing loss can be constructed into a graph according to the seven standard frequencies (125, 250, 500, 1000, 2000, 4000, 8000 Hz). This graph is called an audiogram. By using cardinal speech frequencies (500, 1000, 2000 Hz) as a summary of the audiogram, the pure tone average (PTA) of the subject is obtained. While PTAs increases, the hearing loss increases and so hearing sensation decreases.

In children, the main factor responsible for hearing loss is genetic abnormalities (Morton and Nance, 2006). Genes are affecting 50%-60% of newborns and among those newborns, 20% of them have a specific syndrome. Certain infections of the mother during pregnancy or other complications in the birth can affect the hearing ability in up to 30% of newborns with hearing loss (Morton and Nance, 2006). Hearing loss is not the only problem for newborns, also approximately one quarter of hearing impaired children have other developmental disabilities (Bhasin et al., 2006). On the other hand, hearing loss is also an economical problem for the community. According to the study of Grosse (2007), the lifetime total cost for each hearing impaired child was estimated as $115.600 in USA. For all children who were born after 2000, that lifetime total cost estimation reaches $ 2.1 billion.

In adults, there are two main reasons for hearing loss. The first reason is the condition, presbycusis, which has a progressive nature and increases with age, especially with the high frequency sounds. The second reason is the noise. Noise-induced hearing loss is caused by being exposed to very loud sounds over a long duration. Powerful headphones, big cities and airport traffic or hair dryers are other noise sources of noise-induced hearing loss.

1.1.2. Life of Hearing Impaired People

The most comprehensive picture of hearing impaired people was given in the report of the Aging Society in the USA (National Academy on an Aging Society, 1999). According to that report, approximately 8% of the U.S. population has a hearing problem with different loss levels. That population costs the U.S. economy approximately $56 billion, because they are decreasing the productivity of the country and some special education and medical cares are required for them.

As given in the report, 12% of the general population are 65 years of age or older and 43% of hearing loss in the general population is related to older people. That statistic shows that aging is dominantly affecting hearing loss in older people. 52% of all all hearing loss cases occur in people aged between 18 and 64 and 5% (about half a million) in children. Among the entire population, men are more likely to have hearing loss than women (61% to 39%, respectively).

Some statistics about dissatisfaction with different aspects of the daily life for hearing impaired people were also given in the report. That dissatisfaction includes emotional situations, physical conditions, financial incomes and coping with problems faced on a daily basis. For 26% of those people, the report specifies that "They experienced four or more symptoms of depression during the past week. They are dissatisfied with various aspects of life or unlikely to participate in social activities. For example, people of all ages with hearing loss are more likely to need help with instrumental activities of daily living, or preparing meals, shopping, or handling money, than people without hearing loss."(National Academy on an Aging Society, 1999)

Employment and the kinds of work for the hearing impaired population were very important problems according to the report. The report specifies that "Labor force participation rates are lower for people with hearing loss (67%) than for people without hearing loss (75%). In addition, 13% of workers aged 51 to 61 with hearing loss report that hearing loss limits the type or amount of paid work they can do."

Another effect of hearing loss is in the decision to retire. The retirement ratio among hearing impaired people is 33% higher than people without hearing loss.

1.1.3. Capabilities of Hearing Aids

The historical survey of the digital hearing aids was reviewed by different studies in recent years (Hamacher et al., 2005; Levitt, 2007; Edwards, 2007). The first step for the digital hearing aid was developing the analog to digital converter and digital to analog converter for audio signals in the 1940s (Milman, 1984). In the next step, sampling theorem and its methods provided a great opportunity for having efficient sampling of audio signals (Levitt, 1987). With the advances of signal processing, digital signal processing (DSP) exceeded the capability of analog signal processing. The vast majority of the developments in DSP were realized in the speech analysis and processing, which was a great opportunity for hearing aids (Milman, 1984).

In the first days of hearing aids, processing was done offline and stimuli could be prepared in several days (Black and Levitt, 1969). In the 1960s, that inefficient processing was eliminated by the invention of small laboratory computers and this situation allowed real time processing in hearing aids. However, hearing aid technology had to wait until the middle of 1970s when hearing aids could be fitted in an adaptive manner (Levitt, 1978). The acoustic amplification was being used after the 1980s and then, noise reduction algorithms were being implemented on the hearing aids (Graupe et al., 1987). For severe high frequency hearing loss, nonlinear algorithms of frequency lowering were developed as a new era of hearing aids. The detailed literature about frequency lowering methods (FLMs) is given in the fourth chapter of this thesis.

The first patent about general terms in hearing aids was obtained by Moser (1980); however, those hearing aids were very big and not suitable for daily usage. The first prototype of a wearable hearing aid was developed by Nunley et al. (1983). After these inventions, some attempts for commercial devices were made by different firms. Audiotone System 2000 was presented as the first commercial hearing aid in 1988 (Stypulkowski, 1994); however, the first successful commercial hearing aid was developed by Widex in 1996 (Bernard, 2002).

Despite all improvements made in the digital hearing aids, the customer satisfaction rates for eleven different properties of hearing aids were in the range of 49% and 74% according to a market research (Kochkin, 2005). In that research, the mean value for the customer satisfaction for all properties was 61%. Thus, there are open areas in the study of the digital hearing aids for increasing customer satisfaction. On the other hand, hardware and power limitations are having a negative effect on the customer satisfaction of hearing aids. Wireless technology consumes more power and its programming capacity is restricted to a few tens of thousands of words. These limitations also restrict the implementation of new algorithms. The technology trends in hearing aids are going to be more subject oriented than uniform, more scene specific than for general purpose, and more having an individual therapy than having a universal treatment (Burrill, 2005).

Today's hearing aids have proved limited in their ability to provide adequate audibility for high frequency hearing loss. Although, frequency-lowering hearing aids appear to be a good solution for children and adults, frequency lowering methods have not provided very favorable results (McDermott and Dean, 2000; Simpson, Hersbach and McDermott, 2006; Gifford et al., 2007).

1.1.4. Hearing Loss Simulation (HLS) Studies

In order to understand the nature and underlying principles of hearing impairments, simulators are used as important and useful research tools. Normal hearing subjects listen to the simulated sounds and respond to tests like hearing impaired subjects. Successful hearing loss simulation (HLS) provides an opportunity for preventing the problems that occur with hearing impaired subjects. The primary goal of the HLS studies is to get similar of correct responses between hearing impaired subjects and normal hearing subjects.

In this thesis, the developed HLS were tried by both hearing impaired and normal hearing subjects. While hearing impaired subjects listened to the unprocessed sounds, normal hearing subjects listened to the simulated sounds. The performances of both results were compared with both objective and subjective measures. The general workflow of HLS studies is shown in Figure 1.1.

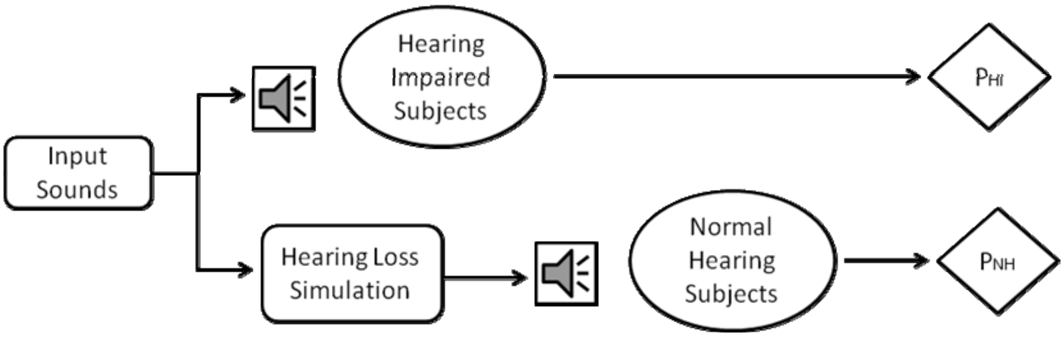


Figure 1.1: Workflow of HLS studies (P_{HI}: Performance of hearing impaired subjects; P_{NH}: Performance of normal hearing subjects)

In FLM studies, the usage of HLS with normal hearing subjects is very restricted and uses a very simple approach. Although there were some studies which used HLS (Korhonen and Kuk, 2008; Rosengard, Payton and Braida, 2005; Stone and Moore, 1999; Chaudhari and Pandey, 1997), the general applications in these studies were to apply low-pass filtering, to attenuate with a level detector or to mask the noise of speech signal for simulating the high frequency loss. There is not any frequency lowering study using comprehensive HLS which takes into account the characteristics of the human ear. The detailed studies about the HLS in the literature can be found in the third chapter of this thesis.

1.1.5. Modified Rhyme Test (MRT) for Turkish Language

For evaluating the effectiveness of the HLS, there are both subjective and objective speech intelligibility measures. The developed objective speech intelligibility indexes are articulation index (AI), speech transmission index (STI) and speech intelligibility index (SII). The most widely used tests as subjective speech intelligibility measures are the diagnostic rhyme test (DRT), modified rhyme test (MRT) and mean opinion score (MOS). The details of those measures are given in the section of 3.2.

There are MRTs constructed for different languages by considering the phonetic characteristics of that language (House et al., 1965 for English; Li et al., 2000 for Chinese; Tihelka and Matoušek, 2004 for Czech). However, there was not any study related to MRT for Turkish. Up to now, only DRT has been developed for the Turkish language by Haşim et al. (2006).

1.1.6. Deficiencies of Frequency Lowering Methods (FLMs)

A gradual decrease in hearing above 4 kHz can be defined as high-frequency hearing loss. High-frequency hearing loss affects speech perception and learning of grammatical rules, especially for children who are growing up with a hearing impairment (Bench & Bamford, 1979). In a classical way, the desired amount of gain can be applied to the impaired frequencies for improving audibility. Unfortunately, although applied gain may have success in low frequencies, the desired audibility for higher frequencies does not occur. Therefore, frequency lowering can be an alternative way for presenting the high-frequency information in extreme cases of sloping hearing loss.

To find a solution for hearing loss, several methods were experimented with from the early years of 1900s. However, there has been no satisfaction with the results of any frequency lowering methods up to now. The only improvements in the studies were potentially smaller performance increments (Robinson, Baer and Moore, 2007). Thus, new subject-specific algorithms should be designed to obtain more benefit from the frequency lowering methods.

It should be noted that, such methods distorts the signal as they transfer the high frequencies to lower frequencies. These distortions can be listed as extended durations, unnatural sounds, reversed spectrum and arrhythmic patterns for the speech signals.

For overcoming the problem of distorted sounds, training can be applied to the subjects so that they get used to the frequency lowered sounds. However, it was shown that when participants were trained using materials different from the test material, no significant differences were found in participants' abilities to perceive speech (Velmans, 1975; Blamey, Clark, Tong, and Ling, 1990; McDermott and Dean, 2000).

A summary of the studies using frequency lowering methods in the literature between 1968 and 2009 for adults and children was given by Simpson (2009). That study shows the general characteristics of the frequency lowering studies; 12 studies were reviewed for adults and 9 studies were reviewed for children. Those studies were investigated according to their processing methods, number of hearing impaired subjects, outcome measures, training durations and results. Generally, the number of hearing impaired subjects was very limited in those studies (in the range of 1-19 with mean of 9). In most of the studies, monosyllabic words and nonsense syllables were used as a measure. From the total 198 hearing impaired subjects, only 56 of them (28%) showed statistically significant improvement and approximately 8% average performance increment was achieved for the hearing impaired. Except the studies with no training (Rees and Velmans, 1993) and 48 months take-home usages (MacArdle et al., 2001), the mean training session was 3.5 weeks.

1.2. Aim and Objectives of the Study

The aim of this study is to investigate the new frequency lowering methods (FLMs) and optimum values of their parameters to obtain better speech intelligibility improvement for each individual hearing impaired subject. This is for the hearing problems of the sensorineural hearing loss and will be achieved by using hearing loss simulation (HLS), which includes the suprathreshold effects of the human ear.

The general objectives of the study are:

- Developing an HLS with combined suprathreshold effects
- Developing MRT for Turkish Language
- Analyzing the HLS with both objective and subjective measures
- Developing new combined FLMs
- Applying HLS in FLMs to be able to carry out extensive testing with normal hearing subjects
- Determining the subject specific FLMs and values of their parameters for the highest speech intelligibility increment.

In this study, for achieving the general objectives, five experiments were carried out. As the first part of the study, developing and testing of the HLS were realized. In this part, an offline study was done to obtain the significant suprathreshold effects and parameters of the HLS (Experiment I). The MRT was applied to both hearing impaired subjects and normal hearing subjects to investigate the reliability of the HLS (Experiment II).

In the second part of the study, subject specific FLMs were developed and optimum values of their parameters were found. In this part, again, an offline study was done for determining the significant methods for each subject and values of their parameters (Experiment III). The MRT was applied to both hearing impaired and normal hearing subjects to investigate the reliability of the subject specific FLMs (Experiment IV). At last, for general comparison of both HLS and FLMs, an extra MRT was applied to hearing impaired subjects (Experiment V).

1.3. Organization of Thesis

In this thesis, there are eight chapters for explaining the studies carried out. The thesis starts with the problem statements and includes the information about the current developments in these areas.

In the second chapter, some background information is given about sound, human hearing, hearing loss and its measurement techniques. To introduce the terminology used throughout the thesis, the basic and important parts of the topics are shown.

In the third chapter, a literature review for HLS studies is given. Different approaches for realizing HLS and suprathreshold effects are discussed in the chapter. Also, objective and subjective measures for evaluating the HLS are described and their usage areas are depicted. Especially detailed information is given about the speech intelligibility index (SII), which was used as a metric in the experiments.

In the fourth chapter, a literature review for FLM studies is given. All FLMs are divided into three parts as methodology, early attempts and recent developments about the methods; detailed information is given for each FLM.

In the fifth chapter, there are explanations about the first two experiments for implementation of the HLS. The objectives, methodology, results and discussions of these experiments are explained in detail.

In the sixth chapter, there are explanations about the other three experiments for developing the FLMs and general comparison of HLS and MRT. The objectives, methodology, results and discussions of them are explained in detail.

In the seventh chapter, although discussions were included with the results for each chapter, the general discussion of the thesis is provided.

In the eighth chapter, conclusions of the thesis and core findings are given.

CHAPTER 2

BACKGROUND OF THESIS SUBJECT

2.1. Sound

2.1.1. Sound Pressure Level

Sound is a time changing physical quantity related to pressure. The Pascal (Pa) unit is used for sound pressure (Sp). In the area of hearing research, the minimum level of this unit is defined as the absolute threshold of hearing (10^{-5} Pa) and the maximum level of the unit is defined as the threshold of pain (10^{2} Pa). The reference pressure (Sp_{ref}) is accepted as 20 µPa (Zwicker & Fastl, 1999). The formula of the Sound Pressure Level (SPL) is:

$$SPL = 10 \times \log \frac{Sp^2}{Sp_{ref}^2} = 20 \times \log \frac{Sp}{Sp_{ref}} \, dB \qquad \text{(Equation 2.1)}$$

On the SPL scale, the quietest sound that the human ear can hear is 0 dB SPL. 60 dB SPL corresponds to normal human speech and 140 dB SPL is the level where the sound starts to cause pain. Some common sounds and their decibel levels are shown in Table 2.1.

Table 2.1 : Sound levels of common sounds

Sound Source	**SPL (dB)**
Whisper	30
Human speech	60
Heavy traffic	80
Tractor	90
Ambulance siren	120
Jet engine at takeoff	140
Rocket launch	180

2.1.2. Sound Intensity

Sound Intensity (SI) is the rate of energy flow through an area of 1 m^2. The unit of sound intensity is Watts (W/m^2) and reference sound intensity (SI_{ref}) is accepted as 10^{-12} W/m^2 (Gade, 1982). The formula of sound intensity level (L_{SI}) is:

$$L_{SI} = 10 \times \log \frac{SI}{SI_{ref}} \text{ dB} \quad \text{(Equation 2.2)}$$

2.1.3. Loudness

Loudness is accepted as a subjective measure, because sounds at different intensities and frequencies are perceived as being at different loudness levels (Zwicker & Fastl, 1999). In addition to that variation, having hearing loss distorts and modifies the perception of loudness.

Basically, sound intensity, frequency and duration are the main parameters affecting loudness. Frequency becomes more important especially when hearing impairment occurs. Also, duration is an important factor because of temporal integration carried out by the human ear (in 200 ms time frame). It means that perceived loudness is an average value of the intensity during that time. Thus, for better loudness, longer sounds are needed.

The sensitivity to different frequencies is defined as equal loudness and it is plotted as curves (Figure 2.1). This figure is adapted from Fletcher and Munson (1933). In the 1920's Barkhausen defined the measure of Loudness Level (Zwicker, 1961). It characterizes the loudness sensation of any sound. The unit of perceived loudness is phon and the decibel hearing level is used as a measurement of loudness perception. As seen from the figure, the maximum sensitivity region is between 3-4 kHz and the minimum sensitivity is for low frequencies, especially while going towards the softer sounds. The dashed curve shows the threshold of hearing. That shows the needed sound intensity for different frequencies of hearing. In these curves, at 1000 Hz, the sound intensity level matches the loudness level in dB (Zwicker & Fastl, 1999).

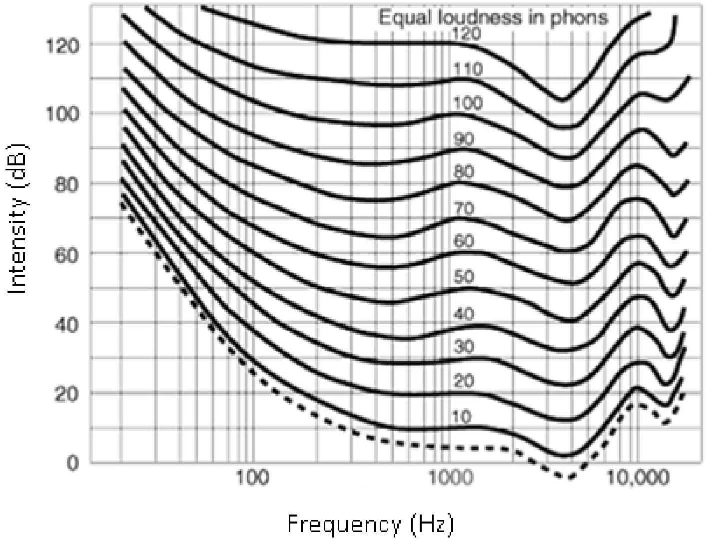


Figure 2.1: Equal-loudness contours

2.2. Human Hearing

2.2.1. Anatomy of the Ear

The human auditory system is comprised of the ears and their connections to and within the central nervous system. It can be divided into the outer, middle, and inner ears, the auditory nerve, and the central auditory pathways.

Hearing starts in the outer ear and it works as a collector for directing the external sounds to the ear canal. The shape of the outer ear is very important for obtaining directional information. The ear canal is like a tube with a length of 2.6 cm and diameter of 0.6cm. On the other end of the canal, a membrane called the ear drum closes the tube.

In the middle ear, by resonance of the ear drum (tympanic membrane), the incoming signal is converted to mechanical energy and transmitted to the inner ear through another membrane called the oval window. Three small bones -the hammer, the anvil, and the stirrup- are responsible for this transportation in the middle ear.

The incoming signal to the oval window goes through the inner ear. The inner ear has two main parts. The first part is the sensory organ of hearing, the cochlea, and the second part is the balance system, the vestibular system. The cochlea is like a tube with a length of 3-5 cm and diameter of 2 mm. However, the cochlea's size narrows towards the end of the tube. There are two membranes in the cochlea, Reissner's membrane and the basilar membrane. Those membranes divide the cochlea in two parts along its length.

The effects of the sounds construct the transversal motion in the basilar membrane and those motions are captured by the hair cells on top of the basilar membrane. Hair cells have two different types (inner hair cells (IHCs) and outer hair cells (OHCs)) and their mission is to transmit the incoming motions to the brain. There are approximately 3500 IHCs and 12000 OHCs in the cochlea (Gelfand, 1998).

2.2.2. Perception of the Sound

When the sound reaches the ear, sound propagates through the auditory canal and vibrates the tympanic membrane. The tympanic membrane transmits the sound to the middle ear and, then to the oval window at the base of the cochlea.

In the inner ear, the basilar membrane works with the place principle which is valid throughout the auditory pathway into the brain. The basilar membrane has different flexibility from the oval window at the other end and behaves like a frequency spectrum analyzer. While the oval window part (place of high frequencies) is not flexible, the end of the basilar membrane (place of low frequencies) is the most flexible part. Thus, specific nerves respond to specific frequencies in the basilar membrane (characteristic frequency).

Another working principle of the human hearing is the volley principle, which is known as an information encoding scheme. The basic transmitting method in the nerve cells is done by action potentials (electrical pulses). Nerve cells can encode audio information by action potentials. On the other hand, there is a limitation of 500 action potentials per second for the neurons. For a 1 to 500 hertz sound signal, a neuron produces 1 to 500 action potentials per second, respectively. Above 500 hertz, several nerve cells work together to perform the task. Thus, five nerve cells performing at 400 times per second work for a 2000 hertz sound signal.

Mechanical energy is thus converted into electrical energy. Then, the neurotransmitter is transmitted across the space between the hair cell and the afferent nerve. The signal is carried by that nerve through the central auditory system to the auditory cortex in the brain.

2.3. Hearing Loss

2.3.1. Types of Hearing Loss

While giving the definition of hearing loss, three fundamental properties (placement, degree and configuration) of hearing loss are used.

Placement Categorization: Placement shows where the auditory system is damaged for hearing loss.

In this categorization, there are three types of hearing loss:

1. Conductive Hearing Loss: Conductive hearing loss occurs when there is a problem in transportation of the sound from the outer ear canal to the tiny bones of the middle ear. In this kind of hearing loss, a reduction in sound level occurs, which causes a problem in hearing sounds that have low loudness levels. For this kind of hearing loss, there are medical and surgical solutions.

2. Sensorineural Hearing Loss: The problems of sensorineural hearing loss originate from the inner ear or the nerve pathways to the brain. Generally, for this kind of hearing loss, medical or surgical methods are not enough for effective correction. For subjects with sensorineural hearing loss, there is a dominant reduction in sound level, some problems in speech understanding and diminished clearness of

hearing are observed. Major reasons for sensorineural hearing loss are head trauma, birth injury, tumors, diseases and aging.

In sensorineural hearing loss, if there is an outer hair cells problem, because of the diminished active mechanism in the cochlea, the auditory filters become broader and this results in poor speech recognition in noise (Stelmachowicz, Johnson, Larson and Brookhauser, 1985). On the other hand, if there is a problem in the inner hair cells or in the auditory nerve, because of reduction in the transmission efficiency to the auditory pathway, there is usually poor speech recognition, even in the quiet (Pauler, Schuknecht and Thornton, 1986).

3. Mixed Hearing Loss: This type of hearing loss occurs when both a conductive hearing loss and a sensorineural hearing loss are present at the same time. Thus, mixed hearing loss shows the problems in all parts of the ear. All disabilities related to the ear are observed and all reasons of both types are valid for mixed hearing loss.

Degree Categorization: In this categorization, the severity of the loss is the main factor. There are six different hearing loss levels which show the subject's thresholds for perceived softest intensity in daily usage:

- Normal range or no impairment = 0 dB to 20 dB
- Mild loss = 20 dB to 40 dB
- Moderate loss = 40 dB to 55 dB
- Moderate to Severe loss = 55 dB to 70 dB
- Severe loss = 70 dB to 90 dB
- Profound loss = 90 dB or more

Configuration Categorization: This categorization refers to the hearing loss levels according to each frequency or frequency region in the spectrum. Thus, for that category, there are mainly three different types: low frequency hearing loss, high frequency hearing loss and flat hearing loss.

2.4. Measurement Techniques

2.4.1. Audiometry

An audiogram shows the general losses of hearing. It includes the recordings of the results of the hearing test. The hearing loss information is given by frequency (Hz) versus intensity (dB) lines. There are seven points for the fundamental frequencies in the range of 125 Hz and 8000 Hz. The softness of a sound changes by moving from top to bottom (Figure 2.2).

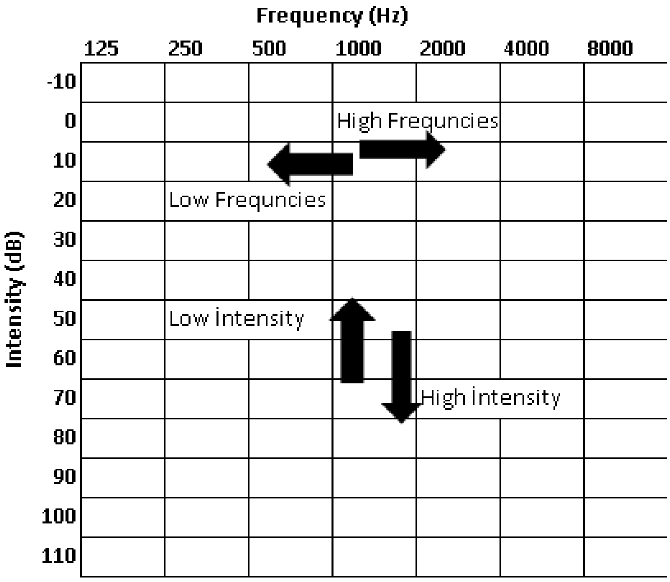


Figure 2.2: Frequency and intensity representation on the audiogram

For adults, the normal thresholds are considered in the range of 0-20 dB. Different degrees of hearing loss are indicated by the audiogram below (Figure 2.3)

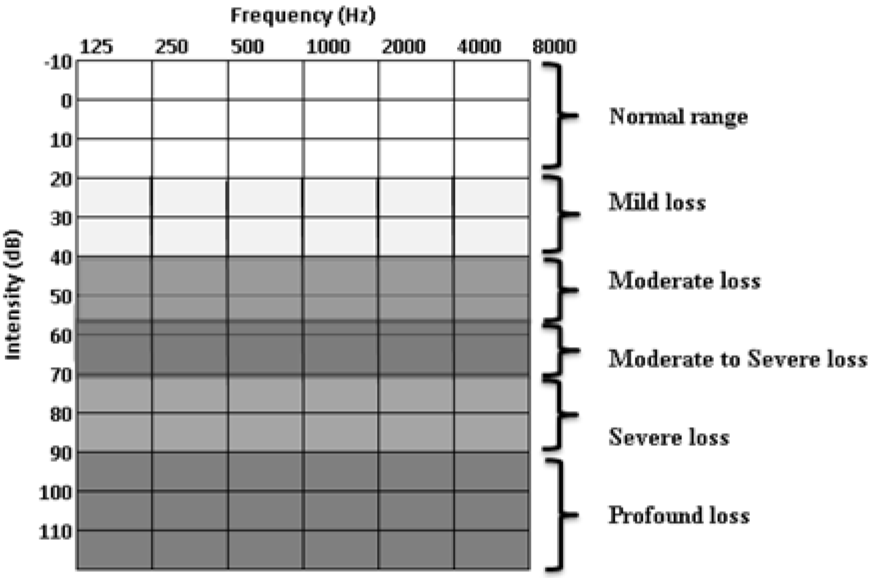


Figure 2.3: Representation of different degrees of hearing loss on the audiogram

2.4.2. Other Measurement Methods

In general, formal audiometric measurement is used but because of its expense or access it may not always be possible. There are different methods with different techniques for different aims in hearing testing like tuning fork tests, measurement of auditory brainstem response, measurement of otoacoustic emissions and tympanometry. In this section, some brief descriptions of these alternative techniques are given.

Tuning Fork Tests: There is another screening procedure with the name of "bedside testing". In this testing, tuning forks are used in order to test at determined frequencies. Rinne, Schwabach, Bing, and Weber are the different test methods that use tuning forks (Kazemi, 1999). Among these tests, the Rinne test is the most frequent office test and it was described by Adolf Rinne in 1855.

Auditory Brainstem Response (ABR): ABR was described by Jewett and Williston in 1971. ABR includes a presentation of a sound like a click to get a signal aroused from the brainstem in order to monitor for hearing loss or deafness. The patients of this test are usually newborn infants. The functions of the ears and various brain functions of the auditory system can be assessed by this method before describing a possible hearing problem with the child.

Otoacoustic Emissions (OAE): Otoacustic emissions were described by Kemp (1978). Generation of otoacustic emissions occurs in the cochlear outer hair cells (Bolay et al., 2008). Generally, the inaudible sounds from the cochlea after the stimulation are named as otoacoustic emissions. When the outer hair cells of the cochlea vibrate, an inaudible sound echoing back in the middle ear occurs. A small probe placed into the ear canal can measure this sound. An emission occurs with a normal hearing person. However, the persons who have hearing loss greater than 25-30 dB do not produce any emissions. These emissions can show some problems in the ear.

Tympanometry: In general usage, measuring the inflexibility of the eardrum and evaluating the middle ear function is done by tympanometry (Lidén, Peterson and Björkman, 1969).

CHAPTER 3

HEARING LOSS SIMULATION STUDIES

3.1. Introduction

The first studies on HLS date back to 1974 (Villchur, 1974), where the first simulation was done for loudness recruitment by reducing the span between hearing thresholds and equal loudness contours. Nowadays, the research is still ongoing. In the study of Desloge et al., 2011, the general picture of the HLS studies was depicted. According to that study, there are mainly two approaches in the literature. In the first approach, the additive masking noise method (Milner et al., 1984; Zurek and Delhorne, 1987; Florentine et al., 1993) and multiband amplitude expansion methods (Villchur, 1973, 1974; Moore and Glasberg, 1993; Duchnowski and Zurek, 1995) were used for simulating the aspects of audibility. In the second approach, reproduction of different suprathreshold effects (reduced audibility, reduced frequency selectivity and loudness recruitment) of hearing loss was studied by using specific effects alone (Baer and Moore, 1993) or in combination with previous effects (Moore et al., 1995; Nejime and Moore, 1997). In this study, the second approach was adopted and combination of the effects has been used for implementing the HLS.

Many researchers have attempted to specify the rationale behind the hearing loss in order to simulate it. The main reasons of having difficulty in understanding speech (and similar problems for other types of sounds) are due to reduced audibility, reduced frequency selectivity, loudness recruitment and the dead region, which is the frequency spectrum part with completely inactive IHCs. Therefore, by simulating these phenomena, the estimated response of the hearing impaired ear can be achieved.

There are different methods for simulating different suprathreshold effects. Reduced audibility can be simulated by threshold elevation according to the subject's audiogram; the spectral smearing algorithm can be applied to simulate reduced frequency selectivity; and loudness recruitment can be achieved by the loudness recruitment algorithm (Moore, 2003).

Reduced audibility is the fundamental effect of hearing loss that occurs at different levels for each frequency. It can be measured by audiometry and recorded in an audiogram. This effect can be simulated by decreasing the dB amount of the specific frequency band of the input signal according to the related hearing threshold level.

Frequency selectivity is the ability of the ear to resolve the spectral components of the input sound as a band pass filter. In hearing impaired subjects, these filters are broader than normal (Glasberg and Moore, 1986). Thus, the ability to select out specific frequencies is reduced. To achieve a similar effect with a hearing impaired ear, changing the shape of the spectral contents of the input signal has been used by both analogue and digital signal processing methods.

Villchur (1977), Summers and A1-Dabbagh (1982) and Summers (1991) were some of the studies that used analogue signal processing for spectral smearing. The main idea in these studies is to split both signal and noise into bands and to multiply the related signal and noise bands. However, when this method is used, instable amplitudes not correlated with the speech signal can occur because of multiplication. On the other hand, Celmer and Bienvenue (1987), Howard-Jones and Summers (1992), ter Keurs et al. (1992), Moore et al. (1992a) and Baer and Moore (1993) used digital signal processing in the spectral smearing studies. The processing in all these studies were done in the frequency domain with fast Fourier transform (FFT). The processed signal was then transformed into the time domain with the inverse FFT with overlap-add method (Allen, 1977). In the studies of Celmer and Bienvenue (1987), Howard-Jones and Summers (1992) and ter Keurs et al. (1992), signal and noise were processed separately for spectral smearing. However, in the studies of Moore et al. (1992a) and Baer and Moore (1993), the mixture of signal and noise was processed to get more realistic results. Also, intelligibility of the signals was measured in both quiet and noisy environments in these studies. As expected, the results showed that intelligibility of speech was inversely proportional to the level of spectral smearing in both quiet and noisy environments.

Another common effect is loudness recruitment. The first definition of loudness recruitment was made by Fowler (1936). In this definition, `loudness` shows the perceptual strength of the sound pressure and `recruitment` specifies the increment of the sound. If the sound level is increased, after a specific level, the rate of growth of the loudness level occurs more rapidly in hearing impaired subjects than in normal hearing subjects. At high levels, such as 90-100 dB, loudness becomes equal to its own value as with normal hearing subjects.

In the literature, different techniques were used for refinement of the loudness recruitment. These techniques were: linear amplification, which tried to keep the amplification level as high as possible above the hearing threshold (Lippman et al., 1981); amplitude compression, which provided better refinement, especially for subjects having significant dynamic range loss (Bustamante and Braida, 1987); parametric compression, which provided flexible time and frequency components for better refinement (Rutledge and Clements, 1991); wavelet based compression, which used the wavelet coefficients for refinement (Drake et al., 1993); and multi band compression which supplied the outer hearing cells’ compressors (Allen, 1998).

The first attempt for simulating the loudness recruitment was done by Villchur (1974). The general logic of all mentioned methods was to acquire the inverse calculation of the model of Villchur which was a combination of an expander and an attenuator.

Two fundamental approaches were mainly used to simulate the loudness recruitment. In the first approach, background noise was used, not to simulate loudness recruitment, but its effect (Fabry and van Tasell, 1986; Humes et al., 1987; Zurek and Delhorne, 1987; Dubno and Schaefer, 1992; Duchnowski and Zurek, 1995). However, this method did not give satisfactory results for some hearing impaired subjects (Phillips, 1987, Stevens and Guirao, 1967). In the second approach, the signal was split into several frequency bands and then combined back after applying dynamic range expansion on each of the bands (Villchur, 1977; Duchnowski, 1989; Zurek and Delhorne, 1987; Moore and Glasberg, 1993, Moore et al., 1995). In these studies, different numbers of band systems (16-band for Villchur, 1977; 14-band for Duchnowski, 1989; 13-band for Moore and Glasberg, 1993) were implemented. Subjects with severe hearing loss were investigated and the results of both hearing impaired and normal hearing subjects were compared.

In the study of Nejime and Moore (1997), all three mentioned suprathreshold effects were combined in the same algorithm to simulate the hearing loss. The methodology of the study was the same as the study of Moore and Glasberg (1993). Only normal subjects were used and different hearing loss conditions were simulated for the calculations about hearing impaired subjects. According to the results of the study, spectral smearing was found as an additive property to the other suprathreshold effects and usability of all effects was shown. In the study of Moore et al. (1997), the comparison of combined methods with or without the spectral smearing effect and the effect of the dead regions were investigated. According to the results of the study, the importance of spectral smearing in HLS was shown. On the other hand, simulation of dead regions had no substantial effect.

3.2. Evaluation of Hearing Loss Simulation

3.2.1. Subjective Measures

The first study about the rhyme test was done by Fairbanks (1958) and, with the inspiration of this study, MRT was designed by House et al. in 1965. In general, a list of fifty or twenty-five word groups with six rhyming words in each group are used in the MRT. In rhyming tests, the subjects try to choose the correct spoken word among the group of written words that rhyme with it. Words in the groups are generally designed to have the same first character or same last character. There are MRTs in different languages constructed by considering the phonetic characteristics of that language (House et al., 1965 for English; Li et al., 2000 for Chinese; Tihelka and Matoušek, 2004 for Czech). However, there was not any MRT study for Turkish.

Diagnostic Rhyme Test (DRT) was developed by Voiers (1977) and is based on only a pair of rhyming words. DRT has a simpler training session than MRT for the subjects. For evaluating the intelligibility of Turkish language, there are some DRT studies in the literature (Palaz et al., 2005; Haşim et al., 2006).

Mean Opinion Score (MOS) is slightly different from the rhyme tests and is used for speech coding algorithms and synthesized speech. It measures the speech intelligibility in the means of speech quality with a questionnaire. Some questions about the overall impression, voice pleasantness, pronunciation, speaking rate, acceptance, and articulation are asked in the MOS tests (ITU-T P.85, 1994; Salza et al., 1996).

3.2.2. Objective Measures

There are several challenges in carrying out subjective speech intelligibility tests, such as the long test duration, costs for test arrangements and difficulty of finding suitable subjects. Therefore, some alternative objective measurement methods have also been developed for evaluating speech intelligibility.

Studies on objective measurement methods for speech intelligibility commenced in Bell Laboratories in 1940. In 1969, the American National Standards Institute (ANSI) developed the articulation index (AI) (ANSI-S3.5, 1969). When calculating this index, the spectrum is divided into one-octave or one-third octave bands. Then, the signal to noise ratio (SNR) values are calculated for each band and weighting factors are applied to the SNR values according to the importance of a frequency band. After normalization, the articulation index gives a value between zero and one; zero indicating completely unintelligible speech and one indicating completely intelligible speech.

Another objective measure, the speech transmission index (STI), was proposed by Steeneken and Houtgast (1980). Calculation of STI is based on the preserved spectral differences of the phonemes. To obtain this index, an artificial input signal is constructed instead of a speech signal. For construction and analysis of this artificial signal, a modulation transfer function is used. This transfer function is determined according to both the one octave bands of noise (125 Hz – 8 kHz) and number of modulation frequencies (63 Hz-12.5 kHz). The analysis is based on specifying the significant SNR values of the octave bands of the artificial signal. The general usage areas of STI are for evaluations of reverberation, non linear distortions, noise, and echoes (IEC 60268-16, 1998).

The third objective measure, the speech intelligibility index (SII) was defined by the ANSI in 1997 (ANSI-S3.5, 1997). It has the same principle as the articulation index but a number of corrections and a different weighting function for each frequency band were added to the SII calculations.

The definition of SII in the ANSI standard is "Product of band importance function and band audibility function, summed over the total number of frequency bands in the computational method" (ANSI-S3.5, 1997). The details of the computational method are explained in the standard.

In SII calculations, there are four basic parameters; equivalent speech spectrum level, equivalent noise spectrum level, equivalent hearing threshold level and band importance function. The SII gives non linear results between 0 (unintelligible) and 1 (excellent intelligible), like the AI (Sherbecoe and Studebaker, 2002).

The details of the parameters of SII as described in the ANSI standard (ANSI-S3.5, 1997) and their usage in this work are provided below:

- "*The equivalent speech spectrum level* is the speech spectrum level at the center of the listener's head. *The equivalent noise spectrum level* is the noise spectrum level at the center of the listener's head." Both parameters are calculated by taking the logarithms of root mean squares of each frequency band. The results are time-averaged values for input speech. The units are decibel (dB).

- The audiogram values of the subjects specify the *equivalent hearing threshold level* for the SII. If the number of frequency bands of the equivalent hearing threshold level are higher than those available with the audiogram of the subject, interpolation may be required. In this study, audiograms of the subjects were linearly interpolated to obtain eighteen centre frequencies of the one-third octave band SII procedure.

- The *band importance function* is a kind of weighting function that shows the relative importance of a specific band on the overall speech intelligibility. There are different band importance functions for four SII procedures (Critical band, equally contributing critical band, one-third octave band and octave band). These procedures have different numbers of critical bands and different center frequencies. The proper procedure is selected according to the speech material. The sum of band importance factors always gives “1” for all procedures.

There are seven band importance functions that are considered for seven different types of speech materials (Table 3.1). There are 18 factors for each one of the one-third octave band with the center frequencies: 160, 200, 250, 315, 400, 500, 630, 800, 1000, 1250, 1600, 2000, 2500, 3150, 4000, 5000, 6300, and 8000.

Table 3.1: Band importance factors of one-third octave band procedure for seven different speech materials

	Average speech	**Various nonsense syllable tests**	**CID-22 – Phonetically Balanced Words**	**NU6 – Mono syllables**	**Diagnostic rhyme test**	**Passages of easy reading material**	**SPIN-Mono syllables in Noise**
1	0.0083	0	0.0365	0.0168	0	0.0114	0
2	0.0095	0	0.0279	0.013	0.024	0.0153	0.0255
3	0.015	0.0153	0.0405	0.0211	0.033	0.0179	0.0256
4	0.0289	0.0284	0.05	0.0344	0.039	0.0558	0.036
5	0.044	0.0363	0.053	0.0517	0.0571	0.0898	0.0362
6	0.0578	0.0422	0.0518	0.0737	0.0691	0.0944	0.0514
7	0.0653	0.0509	0.0514	0.0658	0.0781	0.0709	0.0616
8	0.0711	0.0584	0.0575	0.0644	0.0751	0.066	0.077
9	0.0818	0.0667	0.0717	0.0664	0.0781	0.0628	0.0718
10	0.0844	0.0774	0.0873	0.0802	0.0811	0.0672	0.0718
11	0.0882	0.0893	0.0902	0.0987	0.0961	0.0747	0.1075
12	0.0898	0.1104	0.0938	0.1171	0.0901	0.0755	0.0921
13	0.0868	0.112	0.0928	0.0932	0.0781	0.082	0.1026
14	0.0844	0.0981	0.0678	0.0783	0.0691	0.0808	0.0922
15	0.0771	0.0867	0.0498	0.0562	0.048	0.0483	0.0719
16	0.0527	0.0728	0.0312	0.0337	0.033	0.0453	0.0461
17	0.0364	0.0551	0.0215	0.0177	0.027	0.0274	0.0306
18	0.0185	0	0.0253	0.0176	0.024	0.0145	0

CHAPTER 4

FREQUENCY LOWERING METHODS

4.1. Introduction

From the early years of the 1900s, several methods were tried to find a solution to the high frequency hearing loss. Most of the studies in the literature mainly focused on the methods of slow playback, channel vocoding, frequency compression, frequency shifting and frequency transposition. The term, frequency lowering, is used as an umbrella term to indicate all of the mentioned methods.

Comprehensive literature reviews about frequency lowering methods (FLMs) are given in several studies (Braida, Durlach, Lippmann, Hicks, Rabinowitz, Reed (1979), Turner and Hurtig (1999) and Simpson (2009)).

In principle, it is possible to increase the audibility by increasing the amount of linear gain applied. However, loudness recruitment, which is one of the suprathreshold effects of the ear, limits the amplification to a specific range for subjects with high frequency hearing loss (Hood, 1972).

Although the necessity of using amplification for hearing impaired subjects was identified by earlier studies, it was also understood that the usage of amplification alone is not enough for restoring hearing (Ching, Dillon & Byrne, 1998; Hogan & Turner, 1998; Murray & Byrne, 1986).

There are two main problems with the use of amplification. The first problem occurs because of the reduction in the auditory area in the high frequency hearing loss. This problem causes a reduction in frequency selectivity and abnormal sound distortions. As a result, the problem becomes independent of the amplification.

The second problem with amplification is that subjects with high frequency hearing loss are typically required to listen to sounds at dangerously high levels. In that case, generally, loudness should be in the 90-100 dB range for hearing impaired subjects (Fowler, 1936). Hearing impaired subjects have a narrower range of both audible and comfortable sound levels than normal hearing subjects. Thus, extra gain application with the amplification is not a solution.

In recent years, many researchers have shown dead regions as the reason for the impracticality of high-frequency amplification (Baer, Moore & Kluk, 2002; Moore & Glasberg, 1997; Vickers, Baer & Moore, 2001).

In the following sections, the details and advances of the most widely used FLMs are given. These methods are slow playback technique, channel vocoders, frequency compression and frequency shifting/transposition.

4.2 Slow Playback

4.2.1. The Methodology

In the slow playback method (Beasley, Mosher & Orchik, 1976; Bennett & Byers, 1967), segments of the incoming signal are recorded and played back with a slower rate. As a result, the output signal is lengthened in time and lowered in frequency. This shows the impracticality of the slow-playback method for hearing aids, which work in real time. Otherwise, synchronization problems occur in the usage of hearing aids. To overcome the synchronization problem, deletion of the segments may be applied. However, this is undesirable as it causes distortion.

4.2.2. Early Studies

In the slow-playback method, investigation of the intelligibility of speech for normal subjects focused on vowels, nonsense monosyllables, and phonetically balanced words (Fletcher, 1929; Kurtzrock, 1956; Tiffany and Bennett, 1961; Daniloff, Shriner,and Zemlin, 1968).

Bennett and Byers (1967) evaluated slow-playback speech with 15 subjects having high-frequency sensorineural hearing losses. For the speech intelligibility measurements, the rhyme test (Fairbanks, 1958) was used without training. The majority of impaired listeners indicated that the slow-played speech generally sounded like male speech. Bandwidth reduction of up to 20% resulted in small performance increment (8%) in scores. On the other hand, bandwidth reductions could not provide speech intelligibility improvement with the slow-playback method.

4.3 Channel Vocoding

4.3.1. The Methodology

The channel vocoding technique depends on the division of the signal into frequency bands with bandpass analysis filters. These bands are modified, added together, and presented again to the listener by extraction of the signal envelope from each filter (Ling, 1968; Ling and Maretic, 1971).

There are three main steps in this technique: estimation of envelopes of high frequency signals, usage of the amplitudes of the signal generators for modulation, and frequency lowering by using a set of synthesis filters. The last step involves combining the processed part with unprocessed low frequency signals.

In the channel vocoder, aspects of the spectral shape are preserved during the processing. Many of the studies in the literature have failed to demonstrate an improvement in speech perception. The processing typically did not distinguish between voiced and unvoiced sounds, which may have sounded very different to natural speech and therefore difficult to recognize and interpret. Thus, no commercial device implements channel vocoding as a method for frequency lowering (Simpson, 2009).

4.3.2. Early Studies

Channel vocoders, first introduced by Dudley (1939), are used for bandwidth reduction in certain voice communication systems.

On the other hand, there is no evidence for vocoders to be more effective in providing additional speech cues and to have performance increments in speech discrimination ability than the conventional hearing aids (Ling, 1968, Ling and Druz, 1967, Ling & Maretic, 1971).

4.3.3. Recent Advances

Posen, Reed & Braida (1993) developed a channel vocoding scheme that only became active when the signal was dominated by high-frequency information. Preliminary testing with this scheme was carried out with two normal hearing subjects. Both participants were trained and tested in listening to frequency-lowered and low-pass filtered speech. In general, 9% performance increment was achieved for the two individuals when compared with the low-pass filtered condition.

A more recent study (Baskent and Shannon, 2006) was done by using noise band vocoder for increasing the speech transmission for high frequency hearing impaired subjects with dead regions. In the study, dropping carrier bands for the vocoder were used instead of dead regions and results of the speech recognition were obtained according to the size and location of the dead region. However, the results of the study showed no significant performance increment in speech recognition. This unexpected result was explained by the spectral distortions, which occurred while mapping the acoustic information on to the remaining bands.

4.4 Frequency Compression

4.4.1. The Methodology

Frequency compression has been used for frequency lowering by reducing the bandwidth of the input signal. It can be linear (known as a frequency shifting) or nonlinear. Linear frequency compression or frequency shifting lowers all frequency components downward by a constant factor and has the advantage of preserving spectral information as the ratios among the frequency components (McDermott and Dean, 2000; Turner and Hurtig, 1999). By this way, constant ratios between the frequencies of the formant peaks, which are important for the vowel recognition, are preserved (Neary, 1989). On the other hand, the pitch of the speech signal is lowered, and the speech may become unnatural. For example, a female voice may sound more like a male voice. After frequency shifting, overlapped lower parts are extracted from the output signal, which decreases the quality of the output signal. Therefore, there is no hearing device yet, that applies linear frequency compression or frequency shifting (Simpson, 2009).

In the nonlinear frequency compression technique, higher compression ratios are applied progressively to the higher frequency parts for reducing the bandwidth of the speech signal (Sekimoto & Saito, 1980). High frequencies above the cutoff, which is determined by each subject's audiogram, are compressed nonlinearly for shifting to lower frequencies. Signals below the cutoff frequency are amplified with no frequency compression.

In the literature, the frequency at which frequency compression begins is variable, and often the low frequencies are unchanged by the processing. The frequency compression can preserve the proportional frequency relations of normal speech and the normal temporal envelopes of speech. These properties appear to offer opportunities to tackle sensorineural hearing loss.

4.4.2. Early Studies

To obtain the compressed signal, some deletions were applied to the input signal in the early studies. There were different approaches for deletions; deleting segments periodically in time (Fairbanks, Everitt and Jaeger, 1954), deleting successive pitch periods of voiced sounds (David and McDonald, 1956; Scott and Gerber, 1972), and deleting segments in adherence to phonological rules (Toong, 1974).

Nagafuchi (1976) compressed the frequencies of monosyllables containing both consonants and vowels by various proportionality factors. In that study, he showed that to achive the desired performance, the bandwidth of the signal should be compressed up to the maximum of 70% of its initial size.

4.4.3. Recent Advances

Both linear and nonlinear frequency compression methods were investigated by Reed, Hicks, Braida and Durlach (1983). Six normal hearing subjects were added in a preliminary study, but no performance increment was obtained in the discrimination of the consonant stimuli. Despite these unwanted results, the best scored method was tested on three subjects with hearing impairments, in the second study (Reed et al. 1985). However, frequency compression scores were lower than linear amplification scores for all participants.

In the study for comparison of linear frequency compression and amplification (Turner and Hurtig, 1999), frequency compression provided significant benefit for approximately 45% and 20% of the speech materials spoken by a female and male talker, respectively.

In the study of Simpson, Hersbach and McDermott (2005), nonlinear frequency compression was tested with 17 subjects with moderate to profound sensorineural hearing loss. The frequency compression method was implemented in a body-worn device which participants used daily for 4 to 5 weeks. Monosyllabic word test scores obtained with a conventional hearing device (implemented with amplification method) were compared with the scores obtained with the frequency compression device. As a result, eight hearing impaired subjects (47%) showed significant phoneme score increment with the frequency compression scheme over the conventional hearing device. All hearing impaired subjects showed significant mean performance increment of 6% for phoneme scores.

In another study (Gifford et al. 2007), a similar comparison was made between a conventional hearing aid that applies amplification and a frequency compression device was carried out. 6 adult participants with steeply sloping hearing losses participated in the study. Speech performance measures included monosyllabic words and sentences in both quiet and noisy environments. Participants were required to wear the Nano Xp, which implements frequency compression, during a 5-week take home period. Two participants (33%) showed an average performance increment of 17% when compared to the conventional devices that implement amplification.

Scollie, Parsa, Glista, Bagatto, Wirtzfeld, and Seewald (2009) investigated a method for selection of the cutoff frequency and compression ratio for the nonlinear frequency compression. The method was implemented into a prototype hearing aid, and testing was carried out in 24 hearing impaired subjects (11 children and 13 adults) for longer than 4 weeks. All the children, and 8 of the 13 adult subjects, showed statistically significant improvement in speech perception when compared to conventional amplification. 69% of adult users and 91% of child users obtained benefit when using the frequency compression device.

4.5 Frequency Transposition

4.5.1. The Methodology

Frequency transposition is another method for frequency lowering. Frequency transposition shifts high-frequency sounds to lower frequencies and adds the transposed signal to an unprocessed lower frequency signal. The main aim is to provide audibility of problematic high frequency signals at the expense of lowering of natural high frequencies. There were many studies with different approaches for frequency transposition method in the literature. Although the first attempts for frequency transposition started from the 1940s (French and Steinberg, 1947; Pollack, 1948), the first implementation of frequency transposition was made in the 1960s (Johansson, 1961).

As low frequency information is usually not affected by transposition schemes, higher sound quality can be achieved by frequency transposition. In addition, the ratio between high frequencies in the transposed band is usually preserved. The main disadvantage of frequency transposition is the overlap of transposed and low-frequency parts. This can be detrimental as the added high-frequency information can mask useful low-frequency information as well as transposing unwanted high-frequency background noise.

4.5.2. Early Studies

Among the frequency transposition methods, the first implementation was made with Oticon TP 72 (Johansson, 1961). This device consisted of two channels. Frequencies of 150 Hz to 3 kHz were amplified, while higher frequencies (4-8 kHz) were passed through a nonlinear modulator and converted into low-frequencies below 1.5 kHz. It did not preserve the important details of the input signal’s spectral shape and no satisfactory results were obtained.

Johansson and Sjogren (1965) compared transposition with compression and amplification for both normal hearing subjects with simulated losses and hearing-impaired children. For 12 normal hearing subjects, high-frequency hearing loss was simulated by a combination of 1000-Hz low-pass filtering and masking noise. As a result, after training for one week, larger performance increments in speech identification (from 18% to 70% correct) were observed for the use of transposition than the use of both compression and amplification.

Another comparison study was done by Ling (1968) among transposition, vocoder and linear amplification. Eight children with residual hearing only at low frequencies were trained for 40 minutes each day over 10 days and tested in a counterbalanced order. In the study, no difference was found among the three methods for speech identification.

Velmans (1971, 1974) designed a patented transposer which shifts the frequencies from 4-8 kHz to the 0-4 kHz region. The resulting output was obtained by mixing the shifted and low passed frequencies. The results indicated that transposition improves imitation performance for sounds which contain significant high-frequency components. Also, subjects who heard the transposed signals achieved significantly better imitation of both manner and place of articulation than those who heard only low-frequency components.

4.5.3. Recent Advances

The study of MacArdle et al. (2001) documented the performance of a group of profoundly deaf children fitted with the TranSonic FT 40 real time hearing system. The processing unit analyzes the incoming speech signal and categorizes it as either high or low frequency, depending on whether its energy peak is above or below 2.5 kHz, like in the study of McDermott & Knight (2001). Speech sounds with energy peaks below 2.5 kHz are categorized as “vowels” and divided by possible shifting factors from 1 to 1.4. Speech sounds with energy peaks above 2.5 kHz are categorized as “consonants” and divided by possible shifting factors from 1 to 6. The TranSonic FT 40 device was used over 48 months with 36 children with profound hearing loss. Improved aided thresholds were compared with their conventional devices. Among the subjects, only four children (11%) showed significant performance increment with TranSonic FT 40 device.

In the study of Robinson et al. (2007), a frequency band within the participant's dead region was transposed into a lower frequency band. An edge frequency (f_e) was determined for the dead region. Frequencies below the edge frequency were amplified but not transposed. A band from f_e to 1.7 f_e was selected as the destination band for the frequency transposition. A source band within the dead region was selected as 2 f_e to 2.7 f_e and the source band was transposed into the destination band. Eight subjects with dead regions were evaluated in the quiet. Significant performance increment was obtained only for two subjects (25%).

One of the recently developed frequency transposition hearing device is called Widex Inteo's audibility extender (AE) (Kuk, 2007; Kuk et al., 2006; Kuk et al. 2007). The audiogram was used to determine the starting frequency for the transposition. Frequencies below the starting frequency are amplified but not transposed. Higher frequencies up to two octaves above the starting frequency are analyzed by the hearing device. As the first step of the algorithm, a source octave part of the spectrum was selected with the highest intensity property. A narrow range of frequencies with the highest intensity levels within this range were selected, transposed by one octave, and overlapped with the lower frequency signal below the starting frequency. For the final output, the original signal part below the start frequency was mixed with the processed part.

In testing, all subjects listened to 12 bird songs, 12 musical passages, and 12 speech passages . According to the results, small performance increment (from 8% to 17%) was obtained for consonant scores after the training. . Also, the complexity of the stimuli affected the performances of word scores. Thus, while the performance in word scores was over 60% for bird songs, it decreased to 33% for speech passages.

CHAPTER 5

IMPLEMENTATION OF HEARING LOSS SIMULATION

5.1. Experiment I: Offline Testing with SII for Determining the Parameters of HLS

5.1.1. Objectives

- To investigate the effects of audiogram type, gender of the speaker, and speech level on the HLS.
- To determine the most effective method combination for the HLS.
- To determine the significant values of the parameters of the determined method combination for HLS.

In order to achieve the above-mentioned objectives, six different audiograms, five different speech levels and two sound files for different genders of the speakers were used. Five different HLS methods that were obtained by different combinations of three suprathreshold effects were implemented. For finding the significant values of the parameters of the determined method combinations, SII values were used for all methods. After the statistical analysis of the results, one method and its parameters were selected for the HLS.

5.1.2. Audiograms

In this experiment, six different audiograms with standard hearing threshold levels were used as shown in Table 5.1. These values are the average values of commonly used hearing threshold levels in the audiogram classifications (Carhart, 1945; Clark, 1981; Margolis and Saly, 2007).

Table 5.1: Audiogram values for six different hearing loss levels

	Audiogram	**125**	**250**	**500**	**1000**	**2000**	**4000**	**6000**	**8000**
1	Normal	0	0	0	0	0	0	0	0
2	Mild	15	20	20	25	25	30	35	37
3	Moderate	20	20	25	25	30	40	45	50
4	Moderate to severe	35	35	40	45	50	60	65	68
5	Severe	35	45	50	65	75	80	85	85
6	Profound	55	55	75	85	90	95	97	100

5.1.3. Stimuli

Two wave files containing 3-second long male and female speech, recorded with a 16 bit, 44100 Hz sampling rate were used for this study. Both files were downloaded from the internet site (www.freesounds.com). The intelligibility scores were controlled before the study. The content of the female speech was “Someone left you a message.” and the content of the male speech was “This is the district line train to nowhere.” Figure 5.1 shows the spectrograms of the sounds.

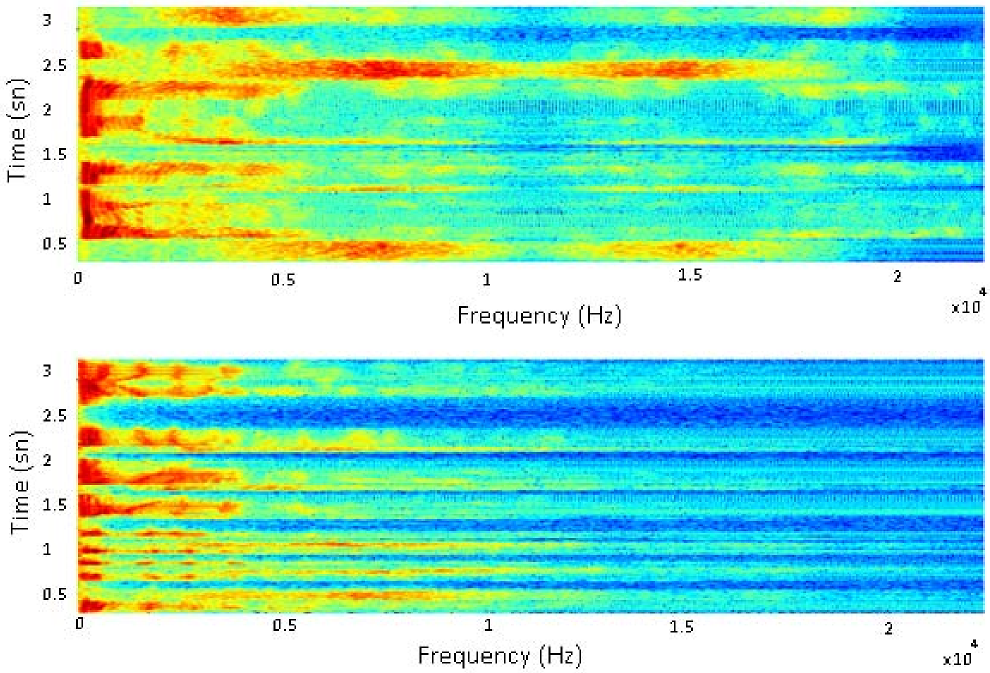


Figure 5.1: Spectrograms of the input files (Top: Female speech; Bottom: Male speech)

5.1.4. Experiment Design

For the pre-study, the experiment was designed by the following parameters and values:

- Gender: Male speaker, Female speaker
- Audiogram: Normal, Mild, Moderate, Moderate to Severe, Severe, Profound
- Speech Level: 55, 60, 65, 70, 75 dB
- Loudness Recruitment parameters
  - Low constant: 1, 1.5, 2
  - High constant: 2, 2.5, 3, 3.5, 4
- Spectral Smearing parameters:
  - Smearing Factor: 3, 6
  - Hamming Window Size: 128, 256, 512, 1024
- Methods:
  1. Original Sound (Unprocessed Sound)
  2. Threshold Elevation Processed Sound
  3. Threshold Elevation + Loudness Recruitment Processed Sound

4. Threshold Elevation + Spectral Smearing Processed Sound
5. Threshold Elevation + Loudness Recruitment + Spectral Smearing Processed Sound

In SII calculation, first, each sound was divided into 18 octave bands. Then, the root mean square (RMS) energies of the signals at each band were calculated. The normalized decibel values of the energies at these 18 bands constructed the equivalent speech spectrum level. The standard “no noise” position (-50 dB for 18 frequency bands) was applied as an equivalent noise spectrum level for all methods. For methods 2, 3, 4 and 5, a normal audiogram was applied as the equivalent hearing threshold level because normal hearing subjects listened to these simulated sounds . However, for method 1, all audiogram types except the normal were applied as the equivalent hearing threshold level because hearing impaired subjects listened to these original sounds . The Diagnostic Rhyme test choice was selected for all calculations as the band importance function because this choice has the most similar content to MRT. The SII algorithm was downloaded and adapted from the SII web site (http://www.sii.to/index.html).

5.1.5. Implementation

Spectral Smearing

The smearing function is based on human auditory filters and requires only the smearing factor, which determines the width of the filters. The general behavior of the smearing function is recalculating each power spectrum component by summing the surrounding components with a specified weight. The spectral smearing applied in this work follows the processing steps described in Baer and Moore (1993).

Auditory filters are characterized by an intensity weighting function which determines the filter shape (Patterson et al., 1982). This function includes the sharpness of the filter and the deviation amount from the filter’s center frequency. By changing the sharpness of the filter, the effect of the smearing can be changed. For normal hearing subjects, sharpness values of both sides are approximately equal.

Mainly, the smearing function was calculated by using normal auditory filters and hearing impaired (widened) auditory filters. There are a few steps for calculating the smearing function:

- First, normal hearing and widened auditory filters were calculated with intensity weighting function and equivalent rectangular bandwidth (Glasberg and Moore, 1990).
- Then, for the widened auditory filter, the sharpness parameter was determined by the ratio of the normal hearing sharpness parameter to the smearing factor (Different smearing factors (3 and 6) were tested to get the effect of the smearing on the speech intelligibility).
- Finally, the smearing function matrix was obtained by dividing the normal auditory filters by the widened auditory filters.
- This smearing function matrix was used for calculating the smeared components of the power spectrum.

For calculating the smeared components of the power spectrum, first a Hamming window with possible window sizes was applied to the input. Then, by Fast Fourier Transform (FFT), the input was converted into the frequency domain. The smearing function was multiplied with the power component of the input. After recombination with the phase angle, the inverse FFT was applied and the final smeared result was obtained. For the whole process, overlap and add method has been implemented in MATLAB. The schematic diagram of these steps can be found in Figure 5.2.

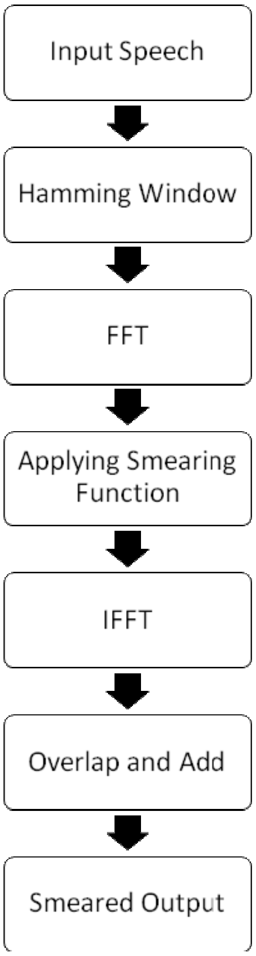


Figure 5.2: Diagram of workflow of “spectral smearing effect” sequences

Loudness Recruitment and Threshold Elevation

The suprathreshold effects of reduced audibility and loudness recruitment were simulated together with a single processing block, as applied by Moore and Glasberg (1993). While simulating the loudness recruitment, the hearing threshold levels of each subject are taken into account for calculating the parameters of loudness recruitment. Thus, there was no need for an extra step to simulate the reduced audibility.

There are mainly six steps for simulating the loudness recruitment as shown by Moore and Glasberg (1993):

- In the first step, the input signal is filtered according to the thirteen center frequencies (100, 190, 306, 452, 640, 879, 1184, 1579, 2067, 2698, 3503, 4529, and 5837 Hz).
- An auditory filter is applied to provide the similarity with moderate to severe cochlear hearing loss.
- In the second step, time alignment is applied to all outputs of the filter for determining the compatible peaks. Then, the Hilbert transform of the input signal is extracted from the input signal for obtaining the analytical signal.
- In the third step, the input signal is decomposed into an envelope and a fine structure by using the input signal and the Hilbert transform of the input signal(Fine structure is equal to the ratio of the input signal to the envelope).
- The decomposition and the processing only with the envelopes of the input signal prevent the distortion of the spectral components. In the fourth step (main processing step), the outputs of the filter are normalized so that the unity peak corresponds to 100 dB SPL (Complete loudness recruitment level).
- There is a slope (a constant factor, $N > 1$) between the levels of a normal ear and a hearing impaired ear. Thus, loudness growth can be simulated by processing the envelope with the power N (The value of N was determined for each of the 13 frequency bands according to the hearing threshold of each hearing impaired subject according to the complete loudness recruitment level. For example, for the 50 dB hearing loss threshold, N will be 2 (100/(100-50)) and for 67 dB hearing loss threshold, N will be 3 (100/(100-67))). To obtain the final output for each channel, the processed envelope is multiplied with its fine structure, as the fifth step.
- The final sixth step combines all the channels to obtain the output sound (Moore and Glasberg, 1993).

A schematic diagram of these steps can be found in Figure 5.3.

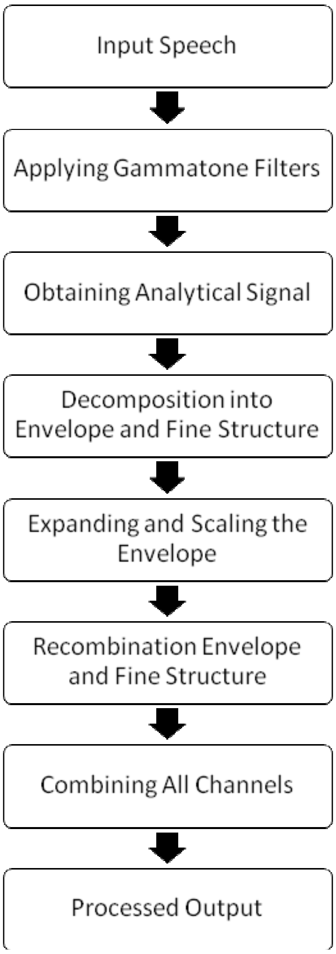


Figure 5.3: Diagram of workflow of "loudness recruitment and threshold elevation effects" sequences

In our implementation, an additional process for attenuation was applied to the loudness recruitment algorithm. For a hearing loss threshold above 75 dB, there is almost certainly loss of function of inner hair cells, and this deficiency behaves like a simple attenuation (Gelfand, 1998). Thus, above 75 dB hearing loss (N=4), the same power N is used and an extra attenuation was applied for the difference from 75 dB. The implemented loudness recruitment constant factors are shown in Table 5.2 as an example. All calculations and implementations were done using MATLAB.

Table 5.2: Example table for power factor, N, of loudness recruitment and applied extra attenuation according to the thirteen center frequencies

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
Hearing Thresholds (dB)	45	45	48	51	55	57	60	62	69	85	85	85	85
N, power factor	1.82	1.82	1.96	2.08	2.27	2.38	2.56	2.7	3.33	4	4	4	4
Extra Attenuation Amount (dB)	0	0	0	0	0	0	0	0	0	10	10	10	10

5.1.6. Results & Discussion of Experiment I

The statistical analyses were done separately for each method. For the gender of the speaker, the T-test was applied and the results of group statistics and independent samples test were shown. For other parameters, the ANOVA test was applied and graphical representations according to SII mean values with respect to gender were shown. The results and graphs were shown only for significant parameters.

For all methods, the results of the test of between-subjects effect (which had the highest value of r^2) were shown for all parameters to specify the significant ones. All significance values were calculated according to the 95% confidence interval (significance level of 0.05).

Statistics for the Method 1:

Method 1: Original (Unprocessed) sounds for hearing impaired subjects
Parameters: Gender, Audiogram, Speech Level

Table 5.3: T-test result for the gender of speaker for method 1

		t-test for Equality of Means			
		t	df	Sig. (2-tailed)	Mean Difference
SII	Equal variances assumed	2,923	48	,005	,18978288
	Equal variances not assumed	2,923	47,996	,005	,18978288

Table 5.4: Result of between subjects effects for the method 1

Dependent Variable: SII

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	2,459[a]	24	,102	4,917	,000
Intercept	16,182	1	16,182	776,505	,000
Audiogram	2,408	4	,602	28,892	,000
SpeechLevel	,013	4	,003	,156	,958
Audiogram * SpeechLevel	,038	16	,002	,113	1,000
Error	,521	25	,021		
Total	19,163	50			
Corrected Total	2,980	49			

a. R Squared = ,825 (Adjusted R Squared = ,657)

<u>Graph of significant parameter versus SII:</u>

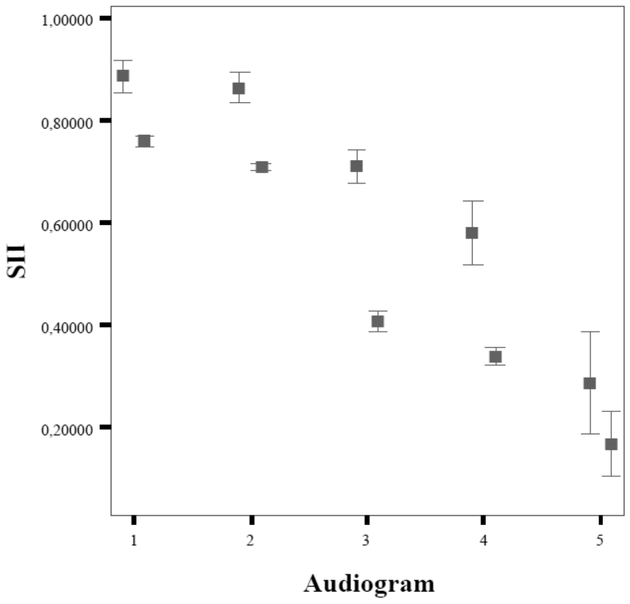


Figure 5.4: Audiogram versus SII graph for Method 1 (The first line stands for man and second line stands for woman for each audiogram.)

Significant parameters for Method 1 are the gender of speaker and audiogram type (Table 5.4). SII values for gender of speaker are higher for male speech (mean value of 0.66) than for female speech (mean value of 0.47) and significant for Method 1 (Table 5.3). SII values for audiogram types are decreasing while the level of the hearing loss is increasing as expected. Also, male speech has higher SII than female speech for all audiogram types (Figure 5.4).

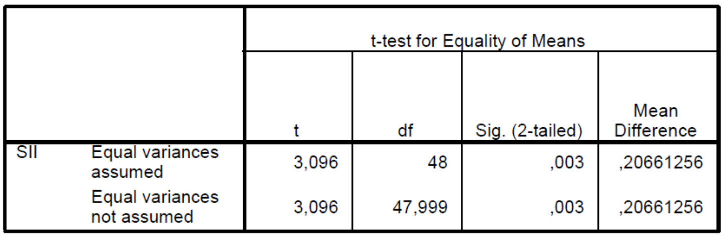
Statistics for the Method 2:

Method 2: Threshold Elevation

Parameters: Gender, Audiogram, Speech Level

Gender Parameter:

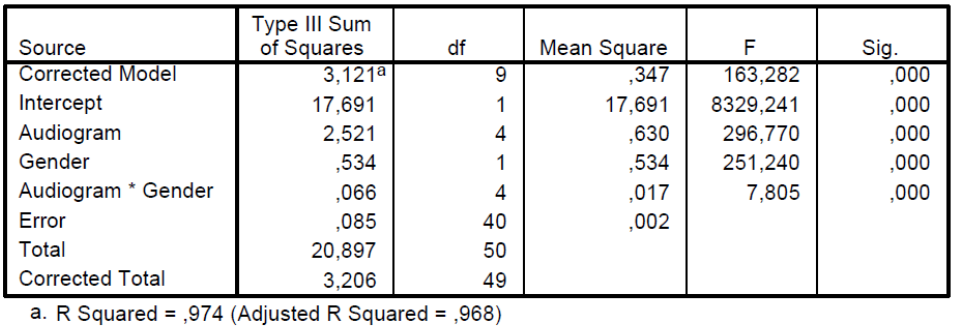
Table 5.5: T-test result for the gender of speaker for method 2



		t-test for Equality of Means			
		t	df	Sig. (2-tailed)	Mean Difference
SII	Equal variances assumed	3,096	48	,003	,20661256
	Equal variances not assumed	3,096	47,999	,003	,20661256

Result of between subjects effects:

Table 5.6: Result of between subjects effects of audiogram and gender for the method 2



Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	3,121[a]	9	,347	163,282	,000
Intercept	17,691	1	17,691	8329,241	,000
Audiogram	2,521	4	,630	296,770	,000
Gender	,534	1	,534	251,240	,000
Audiogram * Gender	,066	4	,017	7,805	,000
Error	,085	40	,002		
Total	20,897	50			
Corrected Total	3,206	49			

a. R Squared = ,974 (Adjusted R Squared = ,968)

Graph of significant parameter versus SII:

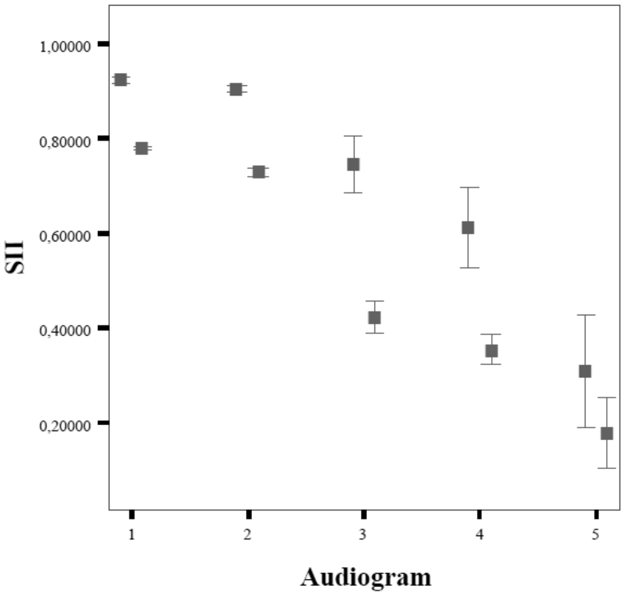


Figure 5.5: Audiogram versus SII graph for Method 2 (The first line stands for man and second line stands for woman for each audiogram.)

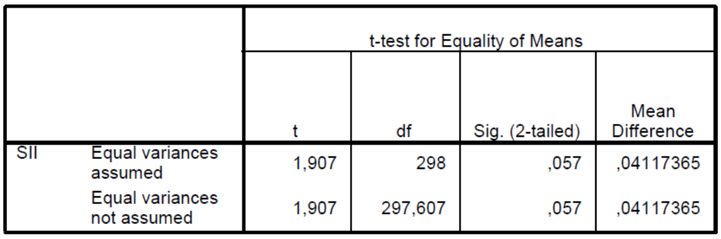
Significant parameters for Method 2 are the gender of speaker, audiogram type and combined effect of audiogram*gender of speaker (Table 5.6). SII values for the gender of the speaker are higher for male speech (mean value of 0.69) than for female speech (mean value of 0.49) and significant for Method 2 (Table 5.5). SII values for audiogram types are decreasing while the level of the hearing loss is increasing as expected. Also, male speech has higher SII than female speech for all audiogram types (Figure 5.5).

Statistics for the Method 3:

Method 3: Threshold Elevation + Loudness Recruitment

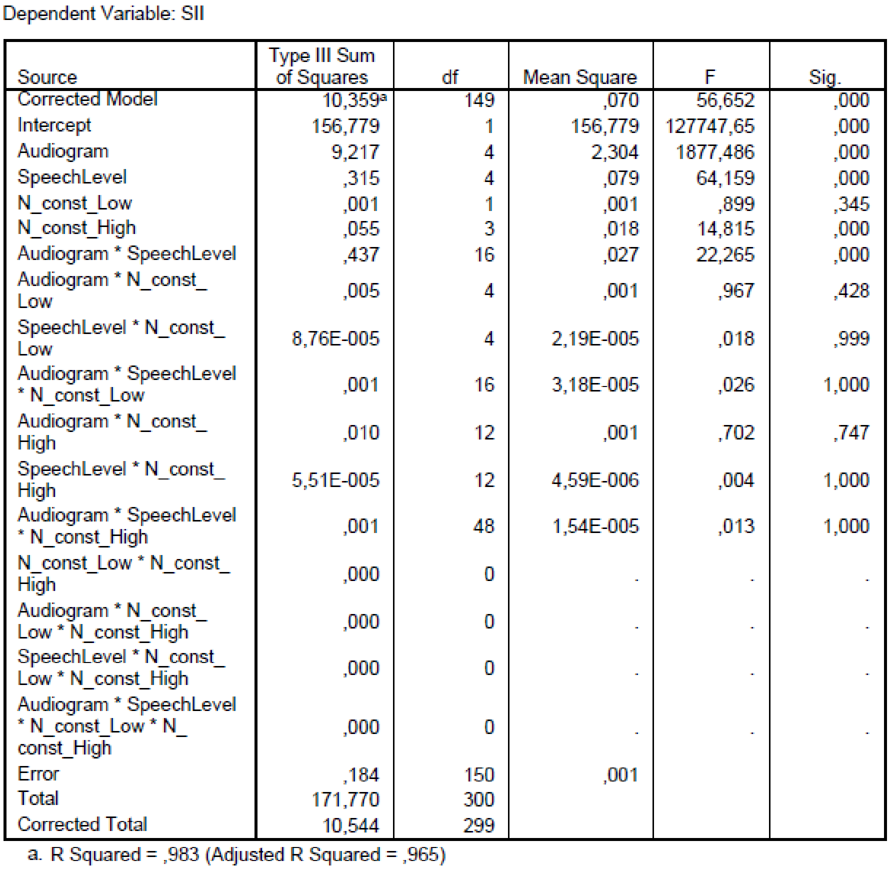
Parameters: Gender, Audiogram, Speech Level, Loudness Recruitment parameters (N_const_Low, constant for lower parts of the spectrum, N_const_High, constant for higher parts of the spectrum)

Table 5.7: T-test result for the gender of speaker for method 3



		t-test for Equality of Means			
		t	df	Sig. (2-tailed)	Mean Difference
SII	Equal variances assumed	1,907	298	,057	,04117365
	Equal variances not assumed	1,907	297,607	,057	,04117365

Table 5.8: Result of between subjects effects for the method 3



Dependent Variable: SII

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	10,359^a	149	,070	56,652	,000
Intercept	156,779	1	156,779	127747,65	,000
Audiogram	9,217	4	2,304	1877,486	,000
SpeechLevel	,315	4	,079	64,159	,000
N_const_Low	,001	1	,001	,899	,345
N_const_High	,055	3	,018	14,815	,000
Audiogram * SpeechLevel	,437	16	,027	22,265	,000
Audiogram * N_const_Low	,005	4	,001	,967	,428
SpeechLevel * N_const_Low	8,76E-005	4	2,19E-005	,018	,999
Audiogram * SpeechLevel * N_const_Low	,001	16	3,18E-005	,026	1,000
Audiogram * N_const_High	,010	12	,001	,702	,747
SpeechLevel * N_const_High	5,51E-005	12	4,59E-006	,004	1,000
Audiogram * SpeechLevel * N_const_High	,001	48	1,54E-005	,013	1,000
N_const_Low * N_const_High	,000	0	.	.	.
Audiogram * N_const_Low * N_const_High	,000	0	.	.	.
SpeechLevel * N_const_Low * N_const_High	,000	0	.	.	.
Audiogram * SpeechLevel * N_const_Low * N_const_High	,000	0	.	.	.
Error	,184	150	,001		
Total	171,770	300			
Corrected Total	10,544	299			

a. R Squared = ,983 (Adjusted R Squared = ,965)

Graphs of significant parameters versus SII:

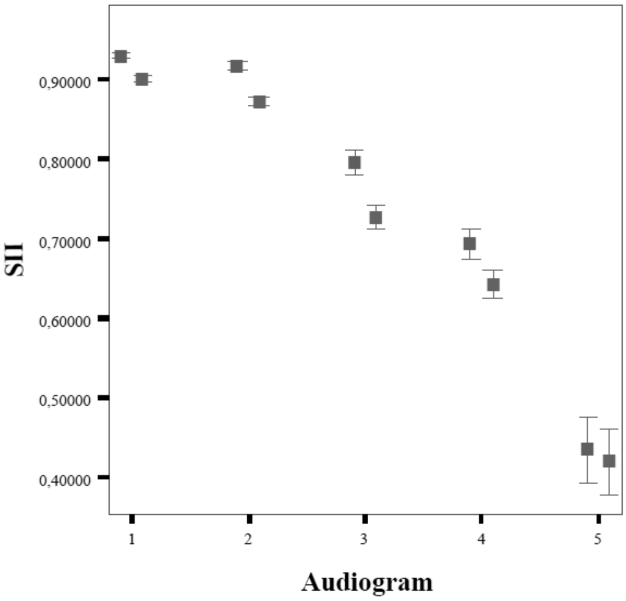


Figure 5.6: Audiogram versus SII graphs for Method 3 (The first line stands for man and second line stands for woman for each audiogram.)

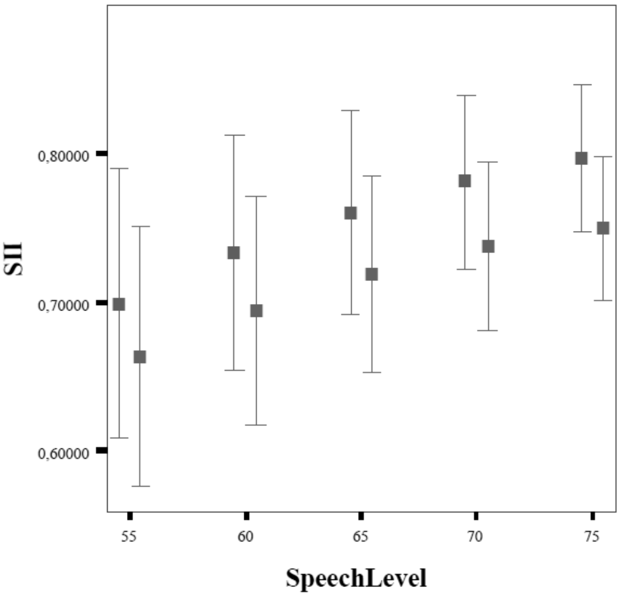


Figure 5.7: Speech level versus SII graphs for Method 3 (The first line stands for man and second line stands for woman for each speech level.)

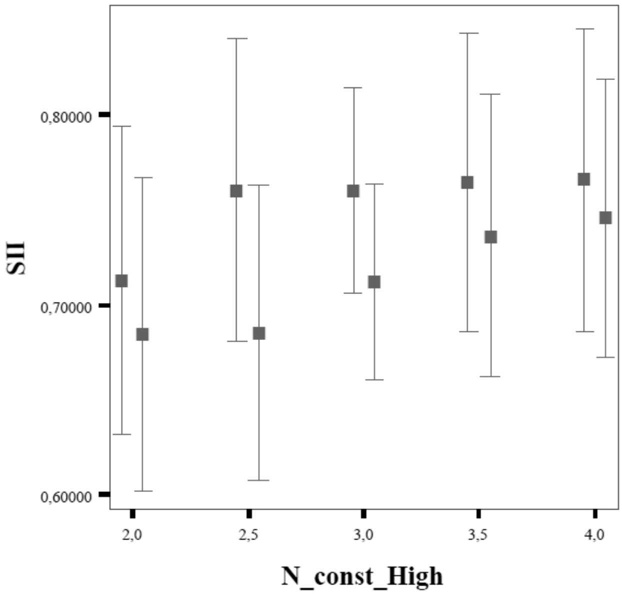


Figure 5.8: N_const_High versus SII graphs for Method 3 (The first line stands for man and second line stands for woman for each N_const_High.)

Significant parameters of the Method 3 are Audiogram, Speech Level, N_const_High and combined effect of Audiogram*Speech Level (Table 5.8). SII values for the gender of the speaker are higher for male speech (mean value of 0.75) than for female speech (mean value of 0.71) and significant for Method 3 (Table 5.7)

SII values for audiogram types are decreasing while the level of the hearing loss is increasing. Also, SII values are higher for male speech than for female speech for all audiogram types (Figure 5.6).

From the speech level graph (Figure 5.7), the significance of the speech level can be observed. While the speech level is increasing, SII value is increasing for both male and female speech at approximately 0.7 level.

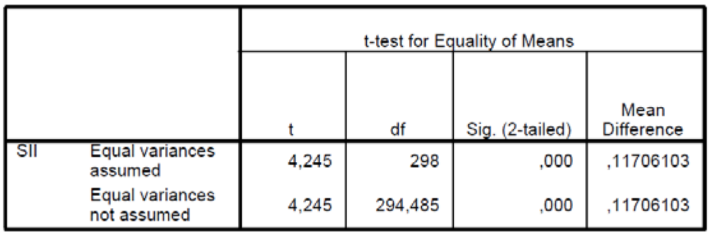
The significant parameter of the loudness recruitment was only N_const_High. In Figure 5.8, significantly different SII values are seen for different values of N_const_High. Again, SII values are higher for male speech than for female speech for all N_const_High values.

Statistics for the Method 4:

Method 4: Threshold Elevation + Spectral Smearing

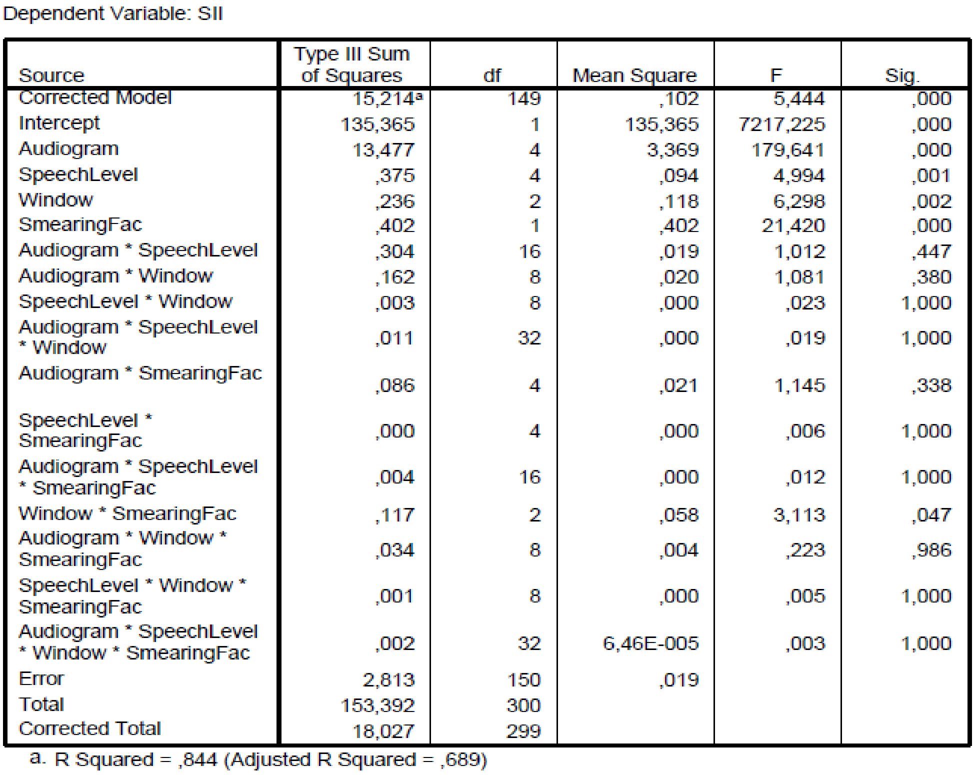
Parameters: Gender, Audiogram, Speech Level, Spectral Smearing Parameters (Window Size, Smearing Factor)

Table 5.9: T-test result for the gender of speaker for method 4



		t-test for Equality of Means			
		t	df	Sig. (2-tailed)	Mean Difference
SII	Equal variances assumed	4,245	298	,000	,11706103
	Equal variances not assumed	4,245	294,485	,000	,11706103

Table 5.10: Result of between subjects effects for the method 4



Dependent Variable: SII

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	15,214[a]	149	,102	5,444	,000
Intercept	135,365	1	135,365	7217,225	,000
Audiogram	13,477	4	3,369	179,641	,000
SpeechLevel	,375	4	,094	4,994	,001
Window	,236	2	,118	6,298	,002
SmearingFac	,402	1	,402	21,420	,000
Audiogram * SpeechLevel	,304	16	,019	1,012	,447
Audiogram * Window	,162	8	,020	1,081	,380
SpeechLevel * Window	,003	8	,000	,023	1,000
Audiogram * SpeechLevel * Window	,011	32	,000	,019	1,000
Audiogram * SmearingFac	,086	4	,021	1,145	,338
SpeechLevel * SmearingFac	,000	4	,000	,006	1,000
Audiogram * SpeechLevel * SmearingFac	,004	16	,000	,012	1,000
Window * SmearingFac	,117	2	,058	3,113	,047
Audiogram * Window * SmearingFac	,034	8	,004	,223	,986
SpeechLevel * Window * SmearingFac	,001	8	,000	,005	1,000
Audiogram * SpeechLevel * Window * SmearingFac	,002	32	6,46E-005	,003	1,000
Error	2,813	150	,019		
Total	153,392	300			
Corrected Total	18,027	299			

a. R Squared = ,844 (Adjusted R Squared = ,689)

Graphs of significant parameters versus SII:

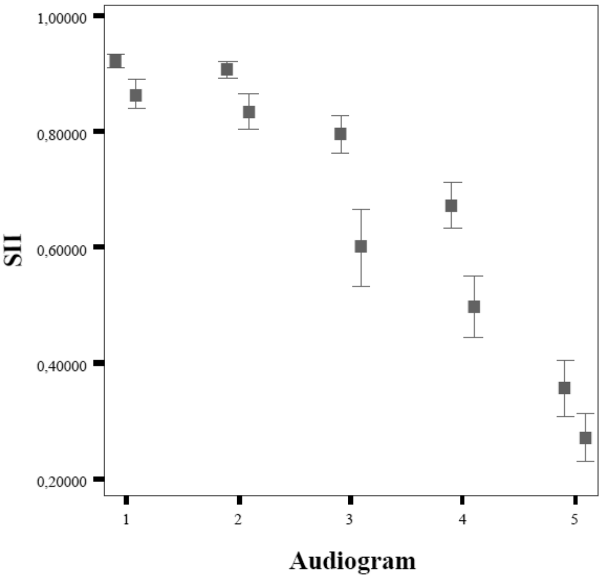


Figure 5.9: Audiogram versus SII graphs for Method 4 (The first line stands for man and second line stands for woman for each audiogram.)

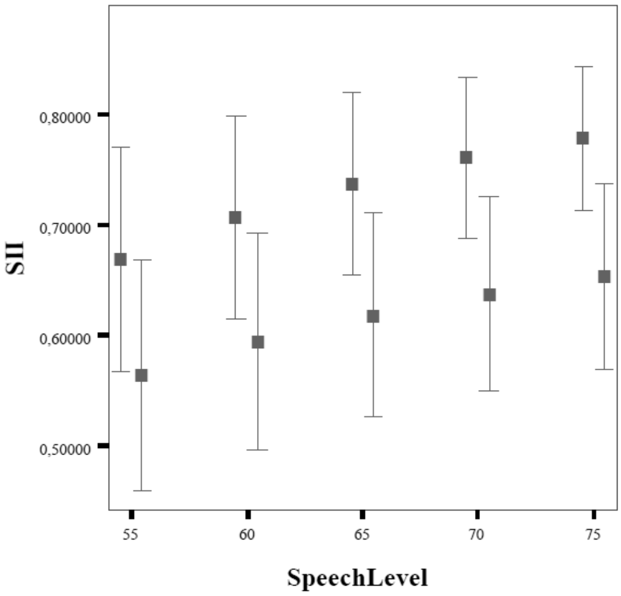


Figure 5.10: Speech level versus SII graphs for Method 4 (The first line stands for man and second line stands for woman for each speech level.)

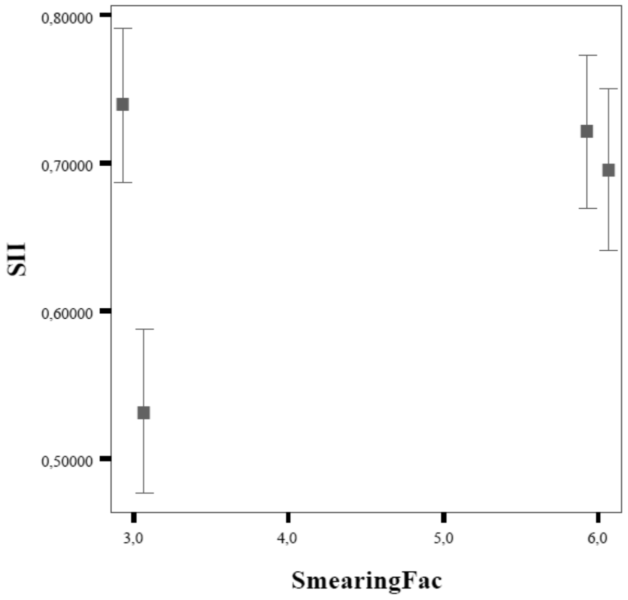


Figure 5.11: Smearing factor versus SII graphs for Method 4 (The first line stands for man and second line stands for woman for each smearing factor.)

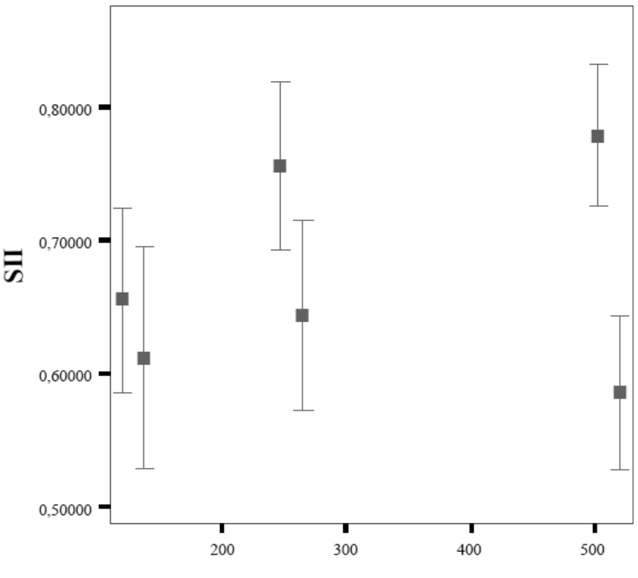


Figure 5.12: Window size versus SII graphs for Method 4 (The first line stands for man and second line stands for woman for each window. Error bars show 95% Cl of mean.)

Significant parameters of the Method 4 are audiogram, speech level, window size, smearing factor and combined effect of window size*smearing factor (Table 5.10). SII values for the gender of the speaker are higher for male speech (mean value of 0.73) than for female speech (mean value of 0.61) and significant for Method 4 (Table 5.9)

SII values for the audiogram parameter are decreasing while the level of the hearing loss is increasing. Also SII values are higher for male speech than for female speech for all audiogram types (Figure 5.9).

As seen from the Figure 5.10, SII values for different speech levels can be seen. Also SII values are higher for male speech than for female speech for all speech level values. However, the increment is in the level of 0.7.

For the smearing factor, different SII values are seen for different factor values. Especially, for the smearing factor of 3, the SII values of male speech and female speech are very different from each other (Figure 5.11).

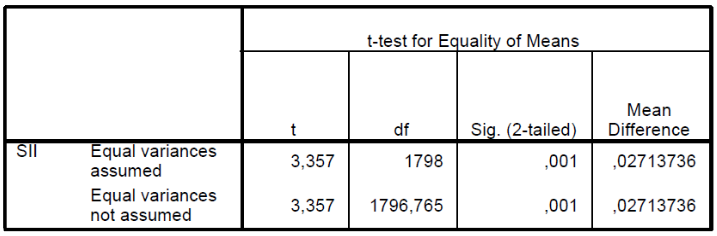
For the window size, different SII values are seen for different factor values. Especially, for the window size of 512, the SII values of male speech and female speech are very different from each other and have small standard deviations (Figure 5.12).

Statistics for the Method 5:

Method 5: Threshold Elevation + Loudness Recruitment + Spectral Smearing

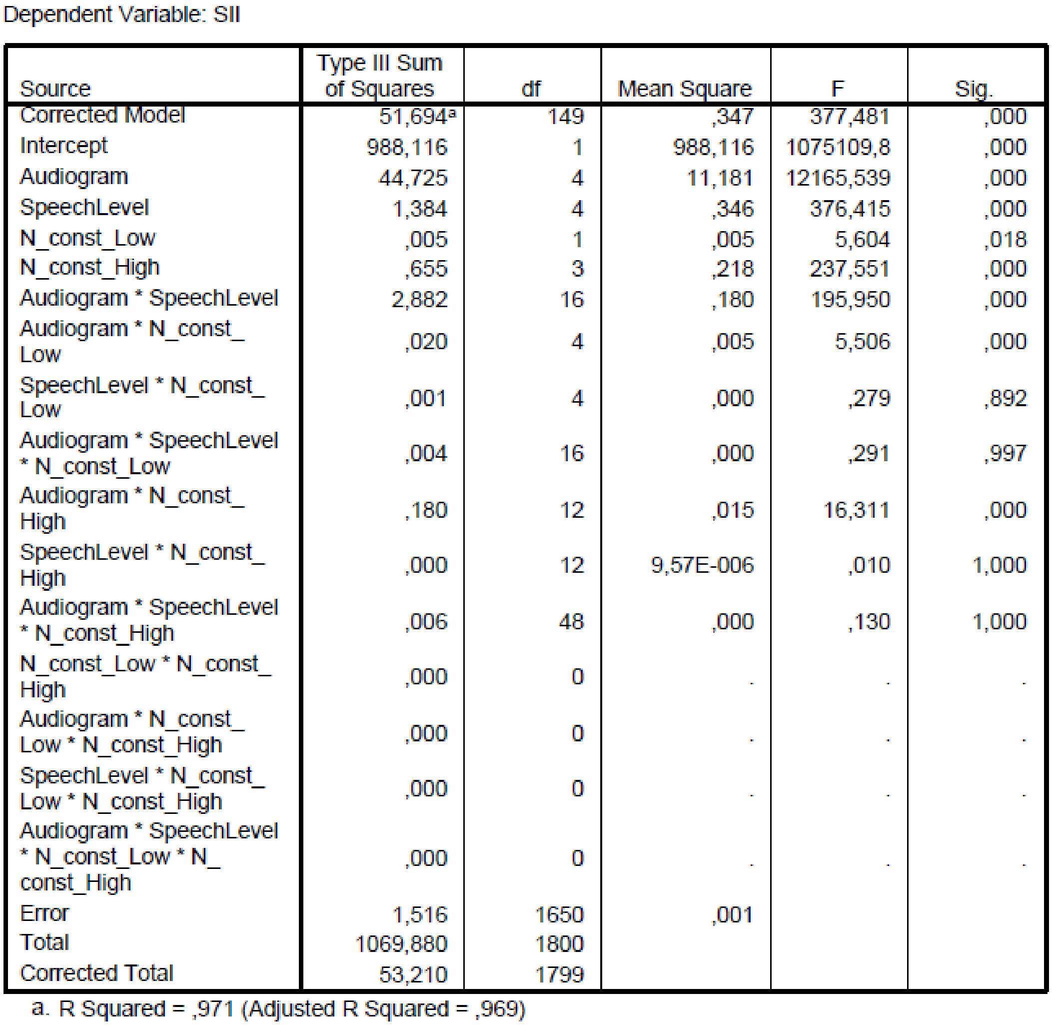
Parameters: Gender, Audiogram, Speech Level, Spectral Smearing Parameters (Window Size, Smearing Factor), Loudness Recruitment Parameters (N_const_Low, constant for lower parts of the spectrum , N_const_High, constant for higher parts of the spectrum)

Table 5.11: T-test result for the audiogram parameter for Method 5



		t-test for Equality of Means			
		t	df	Sig. (2-tailed)	Mean Difference
SII	Equal variances assumed	3,357	1798	,001	,02713736
	Equal variances not assumed	3,357	1796,765	,001	,02713736

Table 5.12: Result of between subjects effects for the Method 5



Dependent Variable: SII

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	51,694[a]	149	,347	377,481	,000
Intercept	988,116	1	988,116	1075109,8	,000
Audiogram	44,725	4	11,181	12165,539	,000
SpeechLevel	1,384	4	,346	376,415	,000
N_const_Low	,005	1	,005	5,604	,018
N_const_High	,655	3	,218	237,551	,000
Audiogram * SpeechLevel	2,882	16	,180	195,950	,000
Audiogram * N_const_Low	,020	4	,005	5,506	,000
SpeechLevel * N_const_Low	,001	4	,000	,279	,892
Audiogram * SpeechLevel * N_const_Low	,004	16	,000	,291	,997
Audiogram * N_const_High	,180	12	,015	16,311	,000
SpeechLevel * N_const_High	,000	12	9,57E-006	,010	1,000
Audiogram * SpeechLevel * N_const_High	,006	48	,000	,130	1,000
N_const_Low * N_const_High	,000	0	.	.	.
Audiogram * N_const_Low * N_const_High	,000	0	.	.	.
SpeechLevel * N_const_Low * N_const_High	,000	0	.	.	.
Audiogram * SpeechLevel * N_const_Low * N_const_High	,000	0	.	.	.
Error	1,516	1650	,001		
Total	1069,880	1800			
Corrected Total	53,210	1799			

a. R Squared = ,971 (Adjusted R Squared = ,969)

Graphs of significant parameters versus SII:

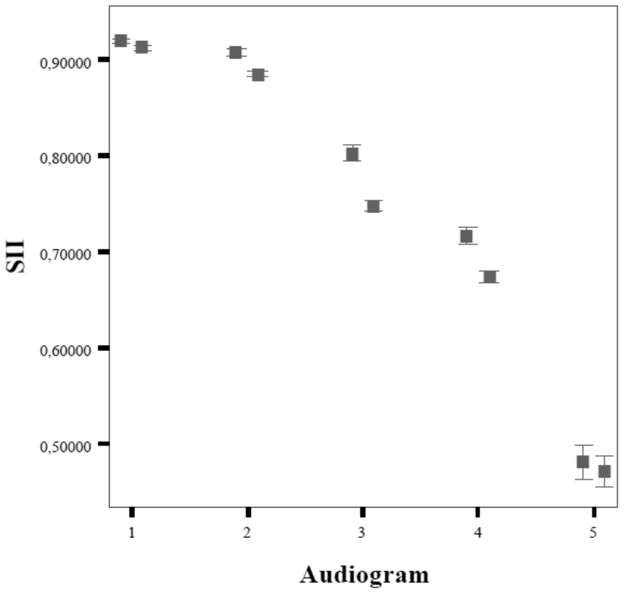


Figure 5.13: Audiogram versus SII graphs for Method 5 (The first line stands for man and second line stands for woman for each audiogram.)

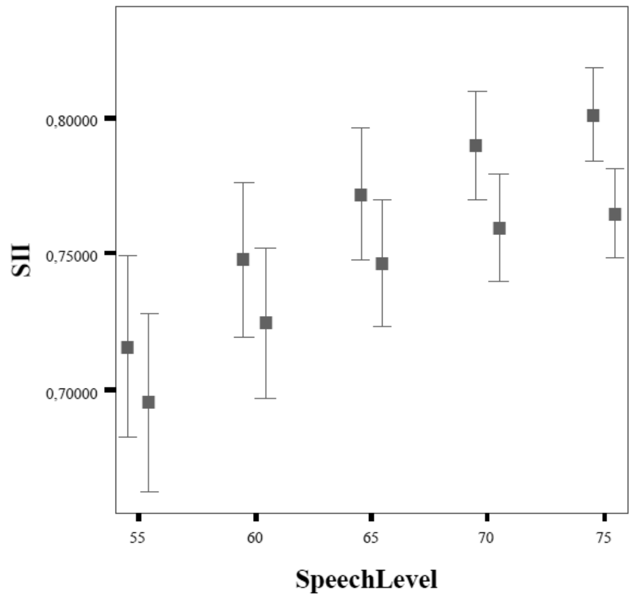


Figure 5.14: Speech level versus SII graphs for Method 5 (The first line stands for man and second line stands for woman for each speech level.)

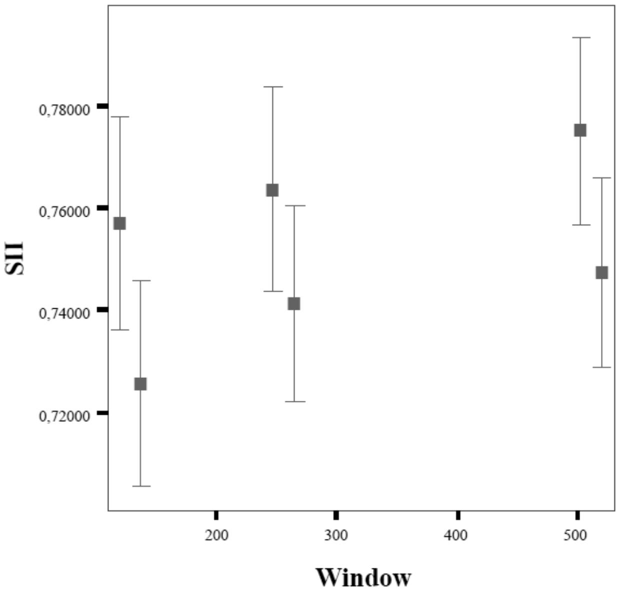


Figure 5.15: Window size versus SII graphs for Method 5 (The first line stands for man and second line stands for woman for each window.)

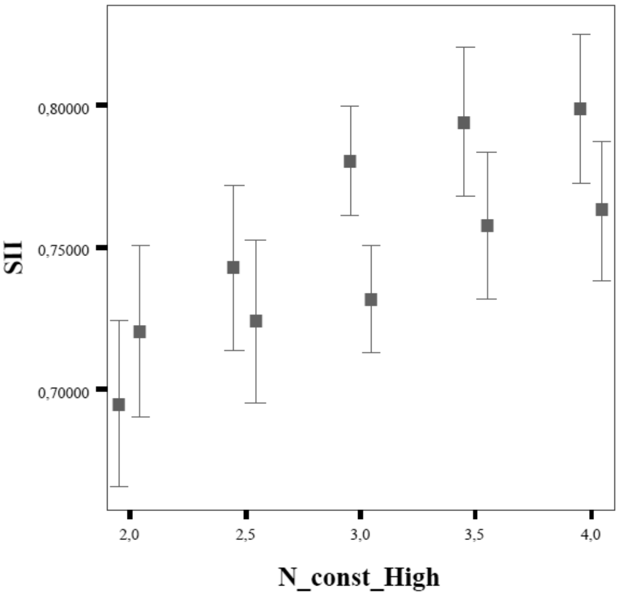


Figure 5.16: N_const_High versus SII graphs for Method 5 (The first line stands for man and second line stands for woman for each N_const_High.)

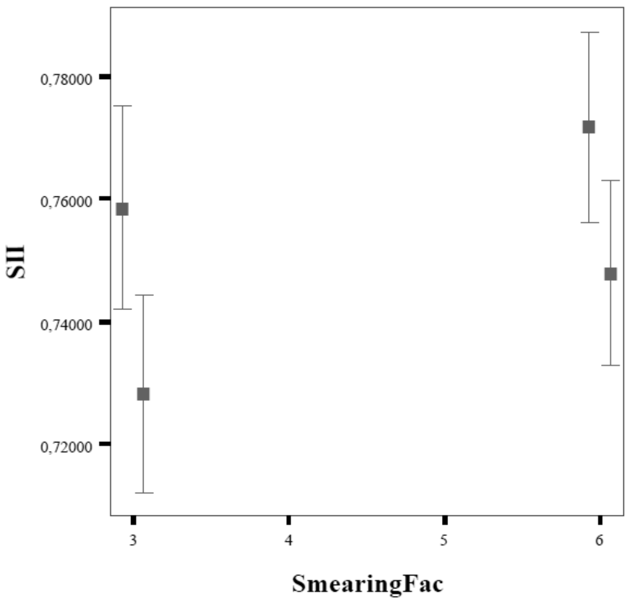


Figure 5.17: Smearing factor versus SII graphs for method 5 (The first line stands for man and second line stands for woman for each smearing factor)

Significant parameters of Method 5 are gender, audiogram, speech level, n_const_high, window size and smearing factor (Table 5.12). SII values for the gender of the speaker are higher for male speech (mean value of 0.76) than for female speech (mean value of 0.73) and significant for Method 5 (Table 5.11)

SII values for the audiogram parameter are decreasing while the level of hearing loss is increasing. Also SII values are higher for male speech than for female speech for all audiogram types (Figure 5.13).

From the speech level graph (Figure 5.14), the significance of the speech level can be observed. While the speech level is increasing, SII value is increasing for both male and female speech. Also SII values are higher for male speech than for female speech for all speech level values. However, the increment is in the level of 0.7, the same as other methods.

The window size graph (Figure 5.15) shows the very small range of the SII values for all values. Only for the window size of 512, there is much more difference between the SII values of male and female speech.

The smearing factor graph (Figure 5.16) shows the very small range of the SII values for all values. It is only for the smearing factor of 3 that there is much more difference between the SII values of male and female speech.

From the graph of N_const_Low (Figure 5.17), the same SII values are seen for both male and female speech. For the other parameter, N_const_High, significantly different SII values are seen for different values.

Selecting the Method for HLS

The general picture for significant parameters was shown in the Table 5.13.

Table 5.13: Significant parameters for all methods (S: significant; NS: not significant)

No	Method	Gender	Audiogram	Speech Level
1	Unprocessed	S	S	NS
2	Threshold Elevation	S	S	NS
3	Threshold Elevation + Loudness Recruitment	NS	S	S
4	Threshold Elevation + Spectral Smearing	NS	S	S
5	Threshold Elevation + Loudness Recruitment + Spectral Smearing	S	S	S

In the methods 1, 2 and 5, the gender parameter was significant. Also in method 3, it has a p value of 0.057. In all methods, SII values for male speech were greater than for female speech. Thus, the gender factor was included for the HLS.

Another significant parameter for all methods was the audiogram type, as expected. As expected, in all methods, while the hearing loss increased, SII values decreased for both male and female speech. Since each hearing impaired subject is expected to have a different audiogram type, it needs to be included as a parameter for the HLS.

After applying any of the suprathreshold effects, speech level became significant. That shows the computational efficiency on the speech sound of suprathreshold effects. On the other hand, the difference between minimum and maximum values of SII is very small (0.2). In the later MRT experiments with subjects, the sound level was fixed at 80 dB measured at the ear location when sounds were presented by headphones. Fixing this parameter was necessary to decrease the overall testing time and reduced the possibility of subjects' memorizing the test words.

For loudness recruitment, two different parameters were used as also seen in the literature (lower constant factor and higher constant factor). For all methods, while the lower constant factor was not significant, the higher constant factor was significant. However, the higher constant factor was not affecting the general results much (0.1 for male speech, 0.2 for female speech). As a result, the significance of the loudness recruitment was shown with this experiment. The values were determined according to the hearing thresholds of the real hearing impaired subjects.

Similar to loudness recruitment, spectral smearing has two parameters for simulation (smearing factor and window size). The results of the SII values for spectral smearing were consistent with the results in the literature. Thus, 3 and 512 were selected as parameters for smearing factor and window size, respectively, because they have smaller standard deviations and higher differences between the genders of speakers.

In conclusion, Method 5 (Threshold Elevation + Loudness Recruitment + Spectral Smearing) with the specified parameters of the suprathreshold effects was selected for implementation of the HLS.

5.2. Experiment II: Rhyme Testing with Hearing Impaired and Normal Hearing Subjects with Simulated Hearing Loss

5.2.1. Objectives

- To investigate the effect of HLS on both hearing impaired and normal subjects.
- To show the reliability of HLS with combined suprathreshold effects by subjective measure.
- To develop MRT for the Turkish language
- To specify the relationship between the MRT and the SII for different noise contents.

- To determine the significant factors (gender of speaker, noise, MRT list type) on MRT and SII for both unsimulated and simulated sounds.

In order to achieve the above-mentioned objectives, first, MRT for Turkish language was prepared with three different subset lists as a subjective measure. The unsimulated sounds were constructed with 2 different genders of speaker, 3 different noise contents and 3 different MRT lists. Twelve hearing impaired subjects listened to those sounds . Then, all sounds were processed with the determined HLS method and its parameters. Thirty-six normal hearing subjects listened to simulated sounds . The SII values for both unsimulated and simulated sounds were calculated as an objective measure.

5.2.2. Subjects

Twelve hearing impaired subjects (ten male and two female), and thirty-six normal hearing subjects (twenty-five male and eleven female) participated in the study. Three normal hearing subjects listened to sounds simulating the hearing loss of each hearing impaired subject. The average value of three normal hearing subjects was compared with one hearing impaired subject.

Normal hearing subjects were recruited after measuring their hearing threshold levels. The main selection criteria were to have a maximum of 20 dB hearing loss for any of the standard frequencies (250, 500, 1000, 2000, 4000, 6000 and 8000 Hz).

Hearing impaired subjects were selected to provide different demographics and audiological varieties. Audiogram values and properties of the hearing impaired subjects used in the tests can be seen from the Table 5.14 and Table 5.15. Subjects were asked to remove their hearing aids during the tests, if they had them.

The general criteria for the hearing impaired subjects were:

- Not very old, to prevent other age-related problems affecting the hearing (mean age for all hearing-impaired subjects was 53)
- No known health problem that would affect the hearing (health problems were asked)

- Having similar hearing losses for both ears so as not to be affected by the other ear.
- Having sufficient education and cultural level for identifying and selecting the words easily (more than half of the subjects had university degrees; only Subject 5 and Subject 6 had preliminary education degrees. Subject 9 had a musical education background and was familiar with musical tones.)

Table 5.14: Audiometric measurements of both ears of the hearing impaired subjects for standard frequencies (Hz) and showing tested ear (L: left ear; R: right ear)

	250	**500**	**1000**	**2000**	**4000**	**6000**	**8000**	**Ear Tested**
Subject 1 L	55	55	55	50	55	70	85	
Subject 1 R	45	50	55	60	65	85	85	■
Subject 2 L	10	10	10	35	60	70	80	■
Subject 2 R	10	15	15	30	55	65	80	
Subject 3 L	30	30	25	55	80	87	95	■
Subject 3 R	40	40	35	55	70	75	80	
Subject 4 L	15	10	10	10	30	45	55	■
Subject 4 R	15	10	10	10	30	45	55	
Subject 5 L	45	70	75	85	90	95	100	■
Subject 5 R	25	25	20	40	70	75	85	
Subject 6 L	25	20	20	30	55	57	60	
Subject 6 R	70	80	90	100	100	100	100	■
Subject 7 L	40	50	70	75	70	65	70	■
Subject 7 R	45	55	70	75	65	75	80	
Subject 8 L	25	40	50	50	80	85	100	■
Subject 8 R	20	30	35	50	80	85	100	
Subject 9 L	30	45	55	50	50	40	50	
Subject 9 R	30	45	60	45	45	35	55	■
Subject 10 L	20	30	30	45	55	50	65	
Subject 10 R	55	55	50	55	50	70	60	■
Subject 11 L	40	40	40	45	45	50	50	■
Subject 11 R	40	40	45	45	50	50	50	
Subject 12 L	20	20	30	85	110	110	110	■
Subject 12 R	20	15	20	70	110	110	110	

Table 5.15: Information about the hearing impaired subjects

				Hearing Loss			
	Gender	**Age**	**Education Level**	**Ear**	**Cause**	**Duration**	**Hearing Aid**
Subject 1	M	30	University	Both	Unknown	20 years	Yes
Subject 2	M	70	University	Both	High Noise	5 years	Yes
Subject 3	M	53	University	Both	Unknown	4 months	No
Subject 4	M	48	High School	Both	Unknown	5 years	No
Subject 5	M	52	Preliminary School	Both	Inflammation	1 year	No
Subject 6	W	55	Preliminary School	Both	Inflammation	50 years	No
Subject 7	W	37	High School	Both	Measles	30 years	Yes
Subject 8	M	56	University	Both	High Pressure	8 years	Yes
Subject 9	M	66	University	Both	High Noise	8 years	Yes
Subject 10	M	70	University	Both	Unknown	6 years	Yes
Subject 11	M	53	High School	Both	High Noise	10 years	No
Subject 12	M	48	University	Both	Noise	25 years	No

For the study, ethics approval was obtained from the Ethics Committee of the Middle East Technical University. At the beginning of the experiment, each participant took written instructions and their questions were answered by the experimenter, if they had any. Afterwards, each participant signed an informed consent form before participating in the study. One of the samples of the ethical forms for subjects can be found in APPENDIX G. All subjects were trained until they got used to the MRT procedures. MRT was started with a no noise case for all subjects.

Hearing impaired subjects listened to the stimuli using headphones in a noise-free environment. The stimuli were only provided to the selected ear of each hearing impaired subject.

5.2.3. Stimuli

Words in MRT lists were spoken by a male and a female native Turkish speaker and recorded in an acoustically treated studio at the Electrical and Electronics Engineering department of the Middle East Technical University. For each word group, the speakers repeated the sentence “Aşağıdakilerden <Word> kelimesini seçer misiniz?” which can be translated into English as “Could you choose the word <Word>?”

The sounds were recorded at 48000 Hz sampling frequency with 16 bit resolution using a Sennheiser M64 pre-polarized condenser microphone and EDIROL UA-1000 Audio Capture device. Speakers were told to maintain a constant level of speech throughout the recording. Noisy sounds were constructed afterwards by adding restaurant noise for all sounds.

5.2.4. Experiment Design

The basic steps and applied statistical analysis of Experiment II are depicted in the Figure 5.19. In this experiment, first, hearing impaired subjects listened to unsimulated sounds in MRT (pre-simulation case). Then, normal hearing subjects listened to the simulated sounds according to the hearing thresholds of hearing impaired subjects in MRT (post-simulation case). The intelligibility indexes of both unsimulated and simulated sounds were calculated by SII. The results of SII and MRT were analyzed by correlation analysis. At the end, the performance matching was done between the results of pre-simulation and post-simulation cases.

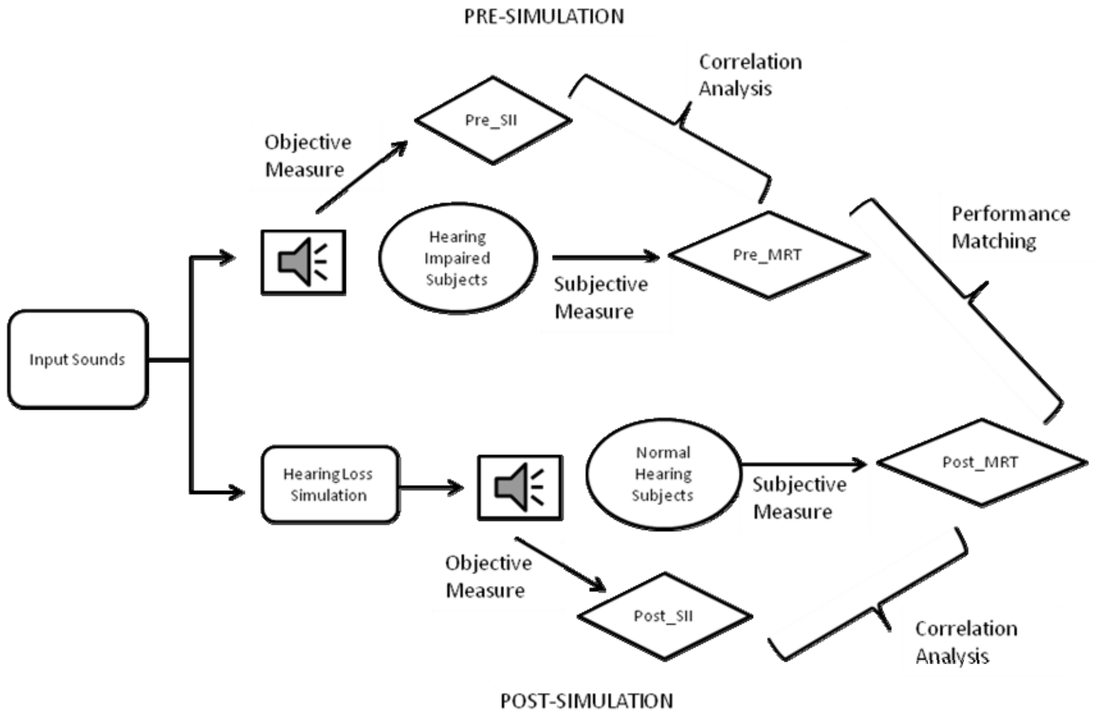
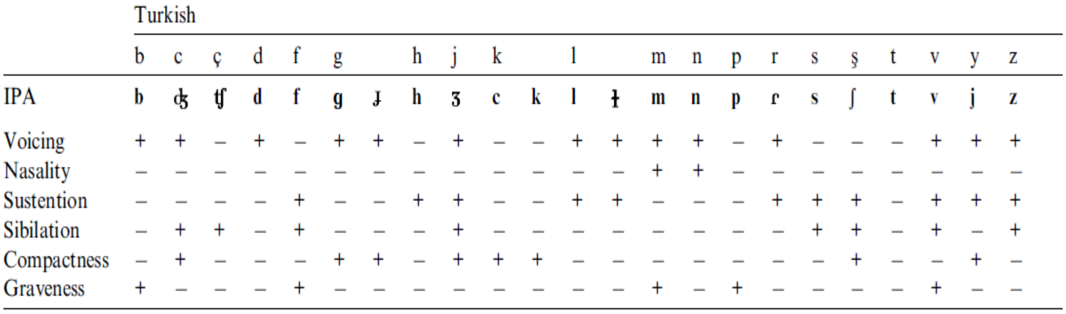


Figure 5.18: Schematic diagram of workflow for Experiment II

In designing the MRT lists, only well known and commonly used words were used. For MRT, two 25-word grouped lists and one 50-word grouped list were prepared.

One of the 25-word grouped lists has the word groups started with the same character and the other 25-word grouped list has the word groups ended with the same character. These lists were created to observe the effect of word structure on their intelligibility when combined with the effect of hearing impairments.

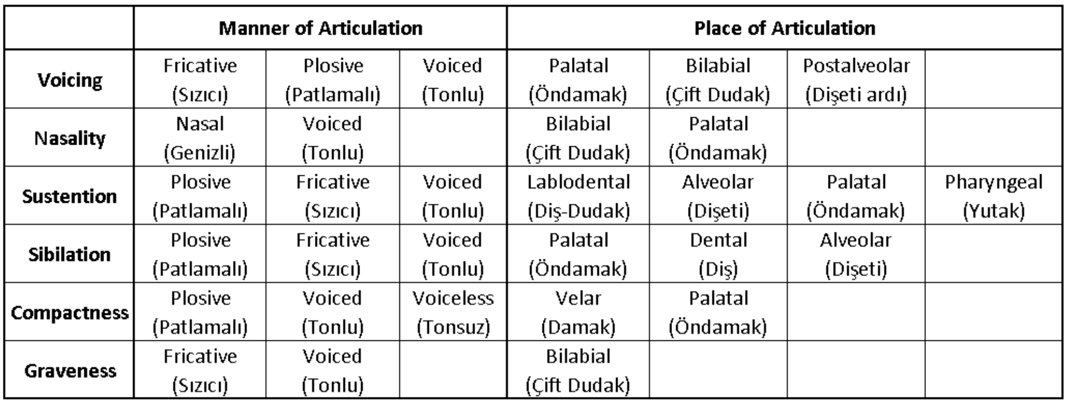
The 50-word grouped list was designed according to the Turkish phonetic characteristics. This list consisted of a number of sub-tests where each sub-test measures the subject's ability to use acoustic information mainly along different dimensions like nasality, sustention, sibilation, compactness and graveness effects for better modeling of Turkish according to the phonetic characteristics (Figure 5.19) (Palaz et al., 2005).



Turkish	b	c	ç	d	f	g		h	j	k		l		m	n	p	r	s	ş	t	v	y	z
IPA	b	ʤ	ʧ	d	f	g	ɟ	h	ʒ	c	k	l	ɫ	m	n	p	ɾ	s	ʃ	t	v	j	z
Voicing	+	+	–	+	–	+	+	–	+	–	–	+	+	+	+	–	+	–	–	–	+	+	+
Nasality	–	–	–	–	–	–	–	–	–	–	–	–	–	+	+	–	–	–	–	–	–	–	–
Sustention	–	–	–	–	+	–	–	+	+	–	–	+	+	–	–	–	+	+	+	–	+	+	+
Sibilation	–	+	+	–	+	–	–	–	+	–	–	–	–	–	–	–	–	+	+	–	+	–	+
Compactness	–	+	–	–	–	+	+	–	+	+	+	–	–	–	–	–	–	–	+	–	–	+	–
Graveness	+	–	–	–	+	–	–	–	–	–	–	–	–	+	–	+	–	–	–	–	+	–	–

Figure 5.19: Phonetic characteristics of the Turkish language

There are two classifications for articulation of consonants by phoneticians. One of them is the place of articulation showing the place of consonants, which starts from the lips and goes to the glottal region in the vocal tract. The other classification is the manner of the articulation, which includes several factors about the sound articulation like degree of narrowing of vocal tract, raised or lowered position of velum and being voiced/voiceless. Used phonetic characteristics for Turkish and their classification properties are shown in the Figure 5.20 (International Phonetic Association (IPA), 1999).



	Manner of Articulation			**Place of Articulation**			
Voicing	Fricative (Sızıcı)	Plosive (Patlamalı)	Voiced (Tonlu)	Palatal (Öndamak)	Bilabial (Çift Dudak)	Postalveolar (Dişeti ardı)	
Nasality	Nasal (Genizli)	Voiced (Tonlu)		Bilabial (Çift Dudak)	Palatal (Öndamak)		
Sustention	Plosive (Patlamalı)	Fricative (Sızıcı)	Voiced (Tonlu)	Lablodental (Diş-Dudak)	Alveolar (Dişeti)	Palatal (Öndamak)	Pharyngeal (Yutak)
Sibilation	Plosive (Patlamalı)	Fricative (Sızıcı)	Voiced (Tonlu)	Palatal (Öndamak)	Dental (Diş)	Alveolar (Dişeti)	
Compactness	Plosive (Patlamalı)	Voiced (Tonlu)	Voiceless (Tonsuz)	Velar (Damak)	Palatal (Öndamak)		
Graveness	Fricative (Sızıcı)	Voiced (Tonlu)		Bilabial (Çift Dudak)			

Figure 5.20: Properties of phonetic characteristics of the Turkish language according to the manner and place of articulation of sounds

Although there are six phonetic characteristics, five of them (except voicing) were selected for constructing the 50-word grouped list to obtain meaningful statistics (10 words form 5 phonetics). Voicing is selected because of the hardness of constructing rhyme test.

All subjects listened to different subsets of the testing material to reduce the testing time. Selected tests were arranged to get the same number of listened cases. Each case was tested seven times by different subjects so that meaningful comparisons and statistical analysis could be carried out.

There were three different factors: gender of the speaker (male/female), SNR (no noise, 0 dB, -3 dB) and word lists (same first consonant, same last consonant and list according to Turkish phonetics). According to those combinations, 18 different cases were constructed for MRT.

All lists for each different word lists are shown in Table 5.16, Table 5.17 and Table 5.18. To prevent memorizing the words, the order of words both in the list and within the word groups were randomly mixed. Generally, all subjects listened to words from 8 to 12 lists in the tests and it took 40-45 minutes per subject.

Table 5.16: MRT list of 25 word groups with same first character

No	1. Word	2. Word	3. Word	4. Word	5. Word	6. Word
1	yat	yaz	yay	yan	yar	yas
2	fan	fas	far	fay	fal	faz
3	hap	hak	hat	haz	hal	han
4	kın	kıl	kıt	kın	kız	kış
5	bar	baz	bam	bal	bay	bas
6	güç	gül	gün	gür	güz	güm
7	kek	ker	kem	kel	kez	keş
8	sos	sol	son	sop	soy	sor
9	hal	hak	har	hap	hat	haz
10	baş	bas	bay	bal	baz	bam
11	yar	yan	yas	yat	yay	yaz
12	kez	kel	kem	kek	keş	ket
13	sor	sol	som	sos	soy	son
14	taç	tam	tav	tay	tan	tas
15	hak	ham	haz	hat	hal	hac
16	keş	kek	kem	kel	kez	ker
17	sop	soy	sol	som	son	sos
18	tay	tam	tak	tan	taç	tat
19	hal	hat	has	ham	har	hak
20	kıl	kız	kıt	kış	kın	kın
21	tak	tam	taç	tas	tan	tat
22	ham	hak	har	han	hap	hat
23	sap	saç	sac	sam	saz	san
24	şad	şal	şak	şam	şan	şap
25	kam	kaç	kaş	kan	kap	kat

Table 5.17: MRT list of 25 word groups with same last character

No	**1. Word**	**2. Word**	**3. Word**	**4. Word**	**5. Word**	**6. Word**
1	şen	sen	ben	ten	gen	yen
2	mal	dal	hal	fal	lal	şal
3	yay	vay	fay	hay	tay	çay
4	gaz	haz	baz	kaz	naz	yaz
5	tak	hak	kak	şak	pak	yak
6	sal	bal	dal	mal	şal	fal
7	dar	bar	kar	zar	far	nar
8	bor	mor	kor	zor	lor	hor
9	sur	dur	kur	nur	tur	vur
10	tat	hat	kat	yat	zat	mat
11	tam	cam	dam	gam	nam	ham
12	kil	çil	dil	fil	mil	pil
13	doz	boz	yoz	koz	poz	toz
14	pin	bin	din	kin	hin	tin
15	pim	çim	kim	mim	sim	tim
16	çan	şan	fan	han	san	zan
17	dar	bar	gar	far	var	zar
18	zan	çan	fan	han	tan	yan
19	fit	bit	çit	kit	hit	sit
20	sol	bol	hol	rol	yol	dol
21	kel	bel	jel	gel	tel	yel
22	hat	zat	kat	mat	tat	yat
23	ten	ben	gen	men	fen	yen
24	rol	bol	gol	hol	mol	sol
25	bor	zor	hor	kor	lor	mor

Table 5.18: MRT list of 50 words groups according to their Turkish phonetic features (Words with phonetic feature were placed in the first order.)

No	**1. Word**	**2. Word**	**3. Word**	**4. Word**	**5. Word**	**6. Word**	**Feature**
1	**ben**	sen	şen	ten	gen	yen	graveness
2	**fal**	dal	hal	mal	lal	şal	graveness
3	**mol**	gol	sol	hol	rol	kol	graveness
4	**put**	tut	dut	kut	şut	gut	graveness
5	**vay**	çay	fay	hay	tay	yay	graveness
6	**baz**	haz	gaz	kaz	naz	yaz	graveness
7	**pak**	hak	kak	şak	tak	yak	graveness
8	**ver**	ger	ker	şer	ter	yer	graveness
9	**kem**	ker	keş	kel	kek	kez	graveness
10	**sop**	son	sol	sor	sos	soy	graveness
11	**mal**	bal	dal	sal	şal	fal	nasality
12	**mil**	kil	pil	zil	dil	fil	nasality
13	**nar**	bar	kar	zar	far	dar	nasality
14	**mor**	kor	bor	zor	lor	hor	nasality
15	**naz**	kaz	faz	yaz	baz	saz	nasality
16	**nem**	dem	gem	yem	kem	hem	nasality
17	**nur**	dur	kur	sur	tur	vur	nasality
18	**mat**	hat	kat	yat	zat	tat	nasality
19	**kem**	kez	kel	kek	ket	keş	nasality
20	**son**	som	sol	sor	sos	soy	nasality
21	**ham**	cam	dam	gam	nam	tam	sustention
22	**fil**	çil	dil	kil	mil	pil	sustention
23	**fas**	pas	kas	yas	tas	bas	sustention
24	**far**	bar	çar	kar	nar	dar	sustention
25	**yoz**	boz	doz	koz	poz	toz	sustention

Table 5.24 (cont.): MRT list of 50 words groups according to their Turkish phonetic features (Words with phonetic feature were placed in the first order.)

26	**sek**	bek	dek	kek	pek	tek	sustention
27	**hin**	bin	din	kin	pin	tin	sustention
28	**jul**	bul	çul	dul	kul	pul	sustention
29	**sim**	çim	kim	mim	pim	tim	sustention
30	**şal**	şak	şam	şad	şan	şap	sustention
31	**şan**	çan	fan	han	san	zan	compactness
32	**gar**	bar	dar	far	var	zar	compactness
33	**şark**	fark	bark	park	sark	çark	compactness
34	**gen**	ben	fen	men	sen	ten	compactness
35	**yan**	çan	fan	han	tan	zan	compactness
36	**kit**	bit	çit	fit	hit	sit	compactness
37	**yol**	bol	hol	rol	sol	dol	compactness
38	**kim**	çim	mim	pim	sim	tim	compactness
39	**bay**	bam	bas	baz	bal	bar	compactness
40	**hak**	hat	han	haz	hap	hal	compactness
41	**kez**	kem	kek	kel	ker	keş	sibilation
42	**kız**	kıt	kıl	kın	kış	kır	sibilation
43	**jel**	bel	kel	gel	tel	yel	sibilation
44	**zam**	bam	dam	ham	nam	tam	sibilation
45	**zat**	hat	kat	mat	tat	yat	sibilation
46	**fen**	ben	gen	men	ten	yen	sibilation
47	**var**	bar	dar	yar	gar	kar	sibilation
48	**sol**	bol	gol	hol	mol	rol	sibilation
49	**çin**	bin	din	hin	kin	pin	sibilation
50	**zor**	bor	hor	kor	lor	mor	sibilation

5.2.5. Implementation

In this study, the combined method for all suprathreshold effects (Method 5) was used for HLS. For evaluating the effect of smearing, the smearing factor and the hamming window size were selected as 3 and 512, respectively based on the results of the offline simulation study. The parameters of loudness recruitment were calculated according to each subject's audiogram values.

For spectral smearing, loudness recruitment and threshold elevation, the same implementation steps were carried out as in the Experiment I by using MATLAB.

5.2.6. Results & Discussion of Experiment II

Comparison of Measures' Distributions

In this analysis, a 95% confidence interval of the difference was applied to all subjects for both pre-simulation and post-simulation. While the results of MRT showed normal distribution, SII did not show such a distribution. Thus, for comparing the significance of the mean distributions of MRT, paired samples test and Pearson coefficients for correlation were used. The paired samples test gives the differences between values of the two variables and tests whether the average is different from zero. Results of SII did not have a normal distribution. Thus, the Wilcoxon Signed Ranks Test and Spearman's rho were calculated for SII (Table 5.20). The Wilcoxon signed-rank test can give information about the differences between the pairs and Spearman's rho is used for not normally distributed variables in the correlation analyses.

For the results of MRT, as seen from the Table 5.19, similar mean values, 58.40 and 57.37 were obtained for pre-simulation and post-simulation, respectively. According to the p values of the paired samples test, similar results were obtained between pre-simulation and post-simulation for all subjects, except for three subjects (Subject 1, Subject 5, and Subject 9). Subject 1 performed much better in the MRT test than was expected considering his high level of hearing loss. This unexpected result can be explained by the developed coping mechanism of this subject as a result of the long duration of hearing loss (30 years of age with 20 years of hearing loss history). For Subject 5, the level of education could have resulted in lower MRT scores than expected. Subject 9 is a musician, which could have contributed to higher MRT percentages than expected. According to the Pearson coefficients, on average, there is a 58% correlation between pre-simulation and post-simulation values. The smallest Pearson coefficient is obtained for Subject 9.

For the results of SII, an opposite situation to the MRT was observed. Except for three subjects (Subject 2, Subject 5, Subject 10), the p values of the paired samples test gave statistically significant values. On the other hand, the same mean value, 0.23, was obtained for both pre-simulation and post-simulation. Also, except Subject 3 and Subject 6, all subjects have correlation values greater than 69% and the mean value for all subjects is 74%.

These results show that MRT is a more reliable measure than SII for the simulation studies. All results for both MRT and SII are given in APPENDIX A.

Table 5.19: Mean values of both MRT and SII for each subject

Mean Value	**MRT Results**		**SII Results**	
	Pre Simulation	Post Simulation	Pre Simulation	Post Simulation
Subject 1	73.50	48.92	0.24	0.31
Subject 2	59.50	55.89	0.29	0.29
Subject 3	45.40	53.97	0.16	0.29
Subject 4	64.00	67.33	0.25	0.14
Subject 5	36.17	51.22	0.2	0.23
Subject 6	49.17	56.61	0.1	0.24
Subject 7	59.80	54.27	0.24	0.31
Subject 8	66.40	62.47	0.32	0.2
Subject 9	75.00	58.07	0.19	0.12
Subject 10	54.80	61.40	0.22	0.2
Subject 11	69.33	62.22	0.3	0.19
Subject 12	50.50	60.75	0.22	0.16
Grand Mean	**58.40**	**57.37**	**0.23**	**0.23**

Table 5.20: Significance and correlation analysis of both MRT and SII for each subject (Correlation is significant at the 0.05 level for Pearson coefficients and 0.01 level for Spearman's rho; bold values show the statistically significant ones)

Mean Value	**MRT Results**		**SII Results**	
	Paired samples test (p value)	Correlation (Pearson coefficients)	Wilcoxon Signed Ranks Test (p value)	Correlation (Spearman's rho)
Subject 1	**0**	0.63	**0.02**	0.77
Subject 2	0.23	0.85	0.5	0.74
Subject 3	0.1	0.49	**0.005**	0.52
Subject 4	0.47	0.55	**0.008**	0.83
Subject 5	**0**	0.73	0.29	0.7
Subject 6	0.08	0.71	0.15	0.58
Subject 7	0.22	0.5	**0.02**	0.73
Subject 8	0.23	0.67	**0.04**	0.78
Subject 9	**0.001**	0.39	**0.01**	0.69
Subject 10	0.15	0.55	0.12	0.79
Subject 11	0.12	0.5	**0.01**	0.94
Subject 12	0.17	0.42	**0.01**	0.86
Grand Mean		**0.58**		**0.74**

Subject Analysis

Hearing impaired subjects were ordered according to their hearing loss from the highest to lowest based on their high frequency pure tone averages (HF-PTA) and MRT results. High frequency pure tone average is the average value of hearing losses at 2 kHz, 4 kHz and 8 kHz.

According to the HF-PTAs, there are subjects with all audiogram types in this study:

- Mild hearing loss : Subject 4
- Moderate hearing loss: Subject 9 and Subject 11
- Moderate to severe hearing loss: Subject 1, Subject 2 and Subject 10
- Severe hearing loss: Subject 3, Subject 7 and Subject 8
- Profound hearing loss: Subject 5, Subject 6 and Subject 12

Half of the subjects using hearing aids in their everyday lives (Subject 1, Subject 2, Subject 7, Subject 8, Subject 9, Subject 10) had higher average values from the MRT than the total average of all subjects. The highest average values were obtained for Subject 1 and Subject 7 who had an experience for using hearing aids for a long time. However there was not any difference between the subjects having long hearing loss duration (Subject 1, Subject 6, Subject 7, Subject 12) or being older (Subject 2, Subject 10) or younger (Subject 1, Subject 7).

Interaction Analyses between MRT and SII According to the Noise Amount

In this section, there are four different analyses for investigating the relationship of MRT and SII (pre_MRT vs. pre_SII, post_MRT vs. post_SII, pre_MRT vs. post_MRT, pre_SII vs. post_SII). The analyses were done according to the noise amounts.

Pre_MRT vs. Pre_SII

In this analysis, the results of MRT and SII were investigated for pre-simulation. Distinct regions for each noise case can be seen on Figure 5.21:

- For the no noise case, there is a similar distribution among the results of MRT and SII.
- For noisy cases, more dense groups have occurred.
- The size of the groups was larger for MRT than for SII for noisy cases.
- SII results for noisy cases were denser than the results of the MRT, because SII is more sensitive to noise than MRT.
- However, the expected decaying behavior was observed from both SII and MRT as the noise was increasing.
- According to these results, the simulation gave more reliable and consistent results between MRT and SII especially for no noise case.

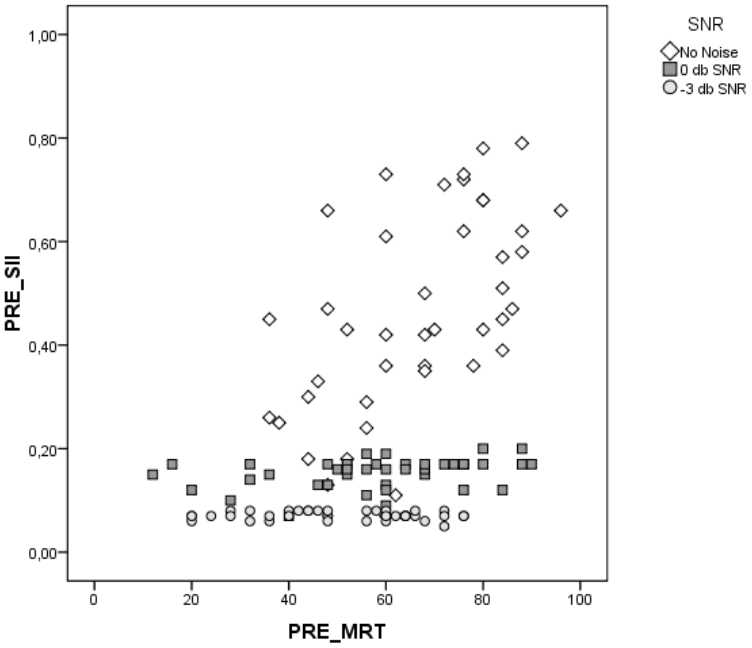


Figure 5.21: Scatter plot of pre_MRT and pre_SII according to noisy cases.

Post_MRT/Post_SII

In this analysis the results of MRT and SII were investigated for post-simulation. Here, similar comments to the pre-simulation can be made. Distinct regions between noisy cases and the no noise case can be seen in Figure 5.22:

- For the no noise case, there is a similar distribution among the results of MRT and SII.
- But for noisy cases, denser groups occur.
- The size of the group for the results of MRT was larger than the size of the group for the SII for noisy cases.
- The compactness of the SII had decreased. This shows the effect of the simulation on the noisy sounds for the SII calculations.
- SII values became similar and the difference between 0 dB SNR and -3 dB SNR cases diminished.
- Both SII and MRT results display the expected decaying behavior as the noise increases.

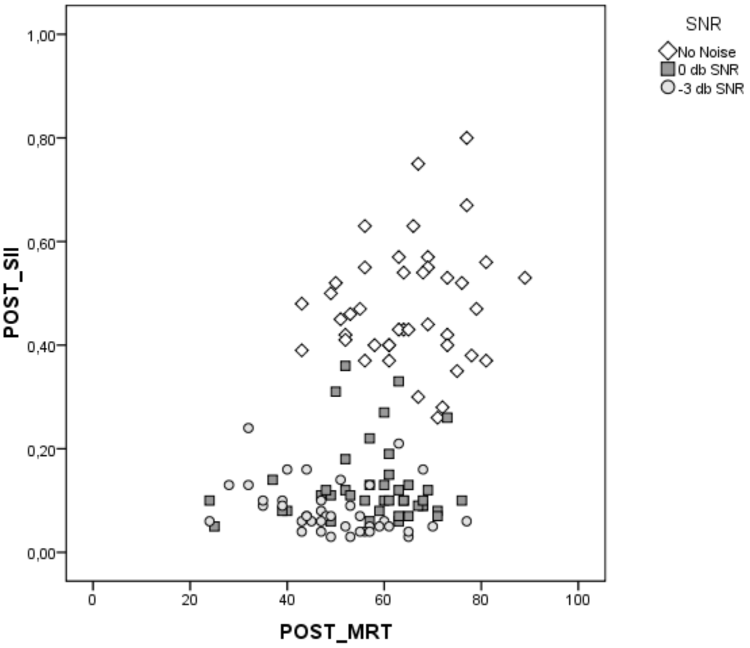


Figure 5.22: Scatter plot of post_MRT and post_SII according to noisy cases

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Pre_MRT/Post_MRT

In this analysis, the results of MRT were investigated for both pre-simulation and post-simulation. The general picture of noisy sounds for MRT can be seen in Figure 5.23:

- As expected, while the amount of the noise increases, the correct percentages decrease for both pre_MRT and post_MRT results.
- The difference between no noise and 0 dB SNR cases is lower than the difference between 0 dB SNR and -3 dB SNR cases. The results of “No noise” and “0 dB SNR” cases are in the same region and have higher values than “-3 dB SNR” case (Being closer to the 45^{o} line from both sides for all MRT results shows the consistency between pre-simulation and post-simulation for MRT).

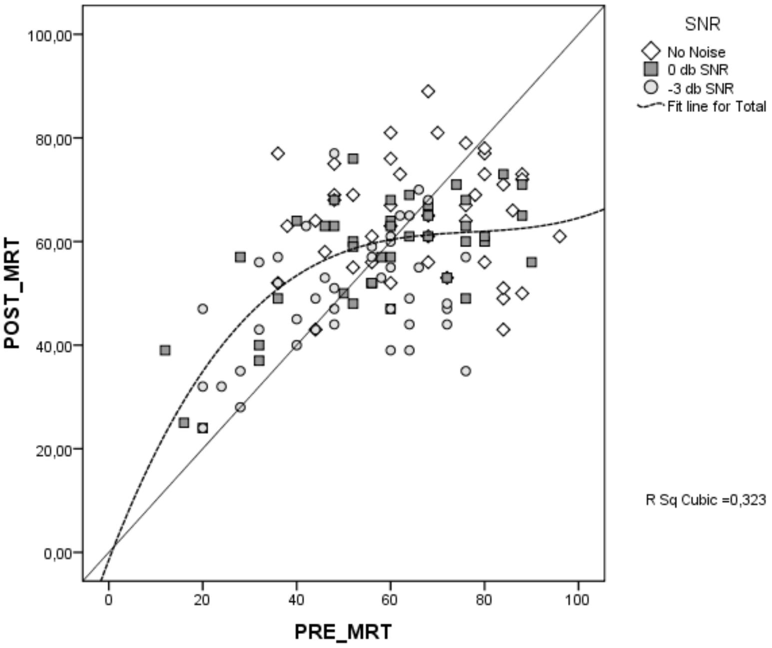


Figure 5.23: Scatter plot and curve fitting plot (R2: 0,323) of pre_MRT and post_MRT according to noisy cases (45^{o} line stands for guidance).

Pre_SII/Post_SII

In this analysis, the results of SII were investigated for both pre-simulation and post-simulation. Distinct regions for each noise case can be seen in Figure 5.24:

- For no noise cases, there is a similar distribution for pre_SII and post_SII.
- For noisy cases, denser groups occur.
- The size of the group for post_SII is larger than for pre_SII for noisy cases. These dense groups show that SII is very sensitive to noise, resulting in non linearity for noisy cases.
- As expected, while the amount of noise in the sounds increases, the correct percentages decrease for both pre_SII and post_SII.

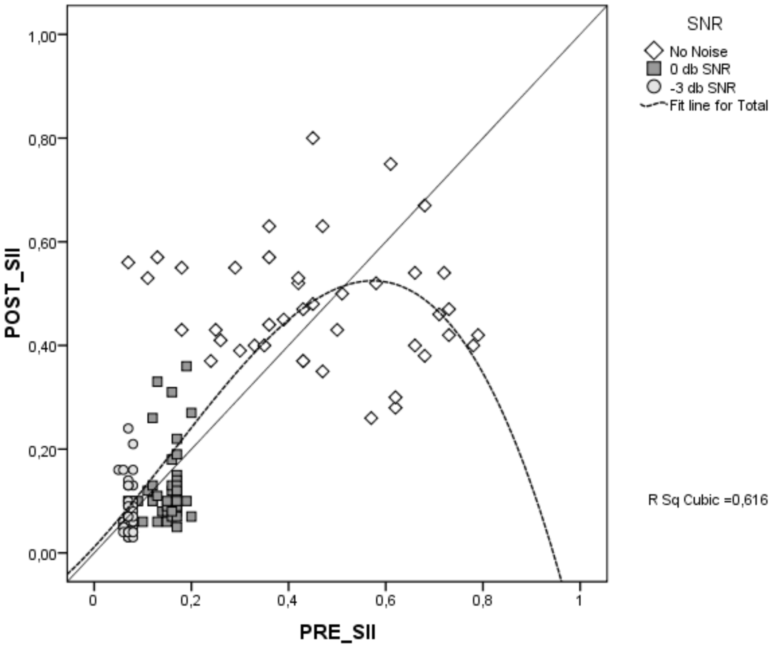


Figure 5.24: Scatter plot and curve fitting plot (R2: 0, 616) of SII for pre_SII and post_SII according to noisy cases (45^o line stands for guidance).

Univariate Analysis

In this section, univariate analysis of HLS is presented. Mean values for each factor are shown in Table 5.21.

Grand mean values for pre_MRT and post_MRT (58.4 and 57.37, respectively) are very close to each other. While significant factors for pre_MRT are noise and the combined effect of the noise and test list, all factors are significant for post_MRT.

The mean values for noise cases decreases in parallel with the noise amount and there is approximately equal decrement between the noise cases for both measures. Thus, noise is statistically significant for all measures for both pre-simulation and post-simulation.

Grand mean values for pre_SII and post_SII are the same (0.23). The only significant factor for pre_SII is noise. After the simulation, the gender factor becomes significant besides the noise.

The performance of the HLS was also shown by both MRT and SII via the univariate analyses. HLS gave consistent results for grand means. In the literature, noise is identified as the main significant factor. In this study, HLS reflected reliable results according to the noise content. There are similar decrements among the results of noisy cases. Also, HLS gave more distinguishable results for gender and test list according to the MRT and gave more distinguishable results for gender according to the SII.

A general decrease according to the noise amount was not observed for the 25-word grouped list with same first consonant for both genders for pre-simulation. This may show that noise is not effective for discriminating Turkish words starting with the same consonant. In general, results obtained for female speech were higher than for male speech for all processed sounds.

Table 5.21: General values, significant factors and parameters' mean values of MRT and SII for both pre-simulation and post-simulation (FC: List with the same first character; LC: List with the same last character; TP: List according to Turkish Phonetics; "*" specifies the statistically significant factors).

	Pre_MRT	**Pre_SII**	**Post_MRT**	**Post_SII**
Grand Means	58.40	0.23	57.37	0.23
Significant Factors				
Gender			*	*
Test			*	
Noise	*	*	*	*
Noise*Test	*			
Mean Values				
Gender - Female	59.02	0.21	61.89	0.25
Gender -Male	57.78	0.24	52.86	0.21
No Noise	66.38	0.46	64.91	0.48
0 dB SNR	57.95	0.15	57.31	0.13
-3 dB SNR	50.86	0.07	49.90	0.08
Test List - FC	57.52	0.20	60.00	0.24
Test List - LC	54.76	0.25	50.52	0.22
Test List - TP	62.91	0.23	61.60	0.23

Analysis for Significant Factors to the HLS Difference

The different values between pre-simulation and post-simulation for both measures were calculated as a percentage change for each factor.

Because of having a non-linear output of SII, the difference percentages do not give meaningful and comparable results. Thus, difference analyses were investigated only for MRT values.

MRT Difference

The percentage values of differences between pre-simulation and post-simulation results are investigated according to the test factors and their interactions. The results of this analysis are shown in Table 5.22. The values on the diagonal of the Table 5.22 are for a single factor. Other values are for interactions of two factors.

Considering the single factors, the maximum change occurred in the positive direction for “female” voice (6.2%) and minimum change occurred in the negative direction for the “no noise” case (-0.2%).

Considering the interaction of factors, the changes of percentage values were in the range of -0.2 and 15.7.

Table 5.22: Percentage values of MRT differences for all simulation factors. Bold values show the highest changes (if change was higher than ten for both ways) and gray filled values show the lowest changes (if change was lower than two for both ways. Negative values show the decrement and positive values show the increment for post-simulation).

		Gender		**Noise**			**Test List**		
		Female	**Male**	**No Noise**	**0 dB SNR**	**-3 dB SNR**	**FC**	**LC**	**TP**
Gender	**Female**	6.2							
	Male		-4.0						
Noise	**No Noise**	4.1	-4.6	-0.2					
	0 dB SNR	6.1	-1.2		2.4				
	- 3 dB SNR	8.4	-6.0			1.0			
Test List	**FC**	**15.7**	-6.5	**13.5**	6.3	-7.6	4.3		
	LC	-1.5	0.2	**-15.2**	0.8	**12.4**		-0.6	
	TP	4.7	-5.5	0.9	0.3	-2.4			-0.4

The percentage values of differences of each test factor for each subject are shown in Table 5.23. The grand mean difference values for each subject are shown in the last column. Subjects with the highest changes (Subject 1, Subject 5 and Subject 9) had difference in the same way for all factors. These results show that the simulation did not work well in accordance for those subjects (25%) in MRT. These results are consistent with the results of MRT in Table 5.20. The results of subjects (Subject 2, Subject 4, Subject 7 and Subject 8) with the lowest change show that the simulation worked well for those subjects (33%) in MRT. For the rest of the subjects (42%), the simulation worked moderately. As a conclusion, HLS gave consistent results for 75% of the subjects.

As expected, HLS gave the most consistent results for the “no noise” case for MRT. Also for other noise cases, the changes were below 2.5%. The highest change occurred for the “female” voice (6.2%), which may also explain the gender being a significant factor for post-simulation cases.

Table 5.23: Percentage values of MRT differences of three simulation factors for each subject. Bold values show the highest changes (if change was higher than twelve for both ways) and gray filled values show the lowest changes (if change was lower than seven for both ways). Negative values show the decrement and positive values show the increment for post-simulation.

		Gender		**Noise**			**Test List**			
		Female	**Male**	**No Noise**	**0 dB SNR**	**3 dB SNR**	**FC**	**LC**	**TP**	**Grand Mean**
Subjects	**1**	-19.7	-43.5	-34.8	-13.0	-32.0	-38.8	-24.8	-31.3	**-31.6**
	2	-2.3	-4.7	-5.8	-24.0	4.8	-2.8	-7.2	-0.5	-3.5
	3	23.5	3.2	53.0	0.7	32.3	23.0	13.0	11.0	15.4
	4	5.5	5.5	-12.5	5.5	14.5	25.0	-2.8	-3.0	5.5
	5	32.5	27.3	21.5	38.3	.	33.3	28.0	28.5	**29.9**
	6	15.8	10.2	24.3	1.8	24.0	22.0	11.0	6.0	13.0
	7	0.6	-13.8	-8.7	.	-3.5	-10.7	-8.3	-2.2	-6.6
	8	4.6	-15.2	-5.6	5.0	-7.5	-6.0	-8.3	-2.5	-5.3
	9	-11.3	-28.7	-26.0	-23.0	-17.7	-12.8	-29.0	-26.3	**-21.7**
	10	16.0	5.2	26.5	10.5	-10.5	-3.8	18.3	18.3	9.5
	11	-8.0	-9.8	-11.7	-14.7	-0.7	-10.5	-17.7	-1.7	-9.0
	12	9.5	28.5	6.7	11.0	30.3	38.7	12.7	-1.0	19.0

Phonetic Analysis

For phonetic analysis, a few steps were realized:

- First, each MRT word was selected from the whole speech (Section 5.2.4.).
- Then, words with same phonetic characteristics were grouped (For the 50 word group list, five different groups with ten MRT words were constructed).
- SII values of each group were calculated.
- Equivalent speech spectrum levels of both genders were calculated for each phonetics.
- Audiograms were recalculated for 18 octaves band for all subjects.

- For comparison, only the MRT results of 50 word groups were taken into account and the percentages of correct MRT responses for each phonetics were calculated for each subject.

All results for percentages of correct MRT responses and the SII values are listed in the APPENDIX B. For statistical analysis, one-way ANOVA was applied to both MRT and SII results; equivalent speech spectrum graphs were shown and the MRT percentages of each phonetics for each subject were illustrated for each phonetic.

One-way ANOVA Analysis

As seen from the Table 5.24 and Table 5.25, the only significant parameter for both MRT and SII is the SNR.

Table 5.24: The ANOVA analysis for the results of MRT for the phonetic analysis

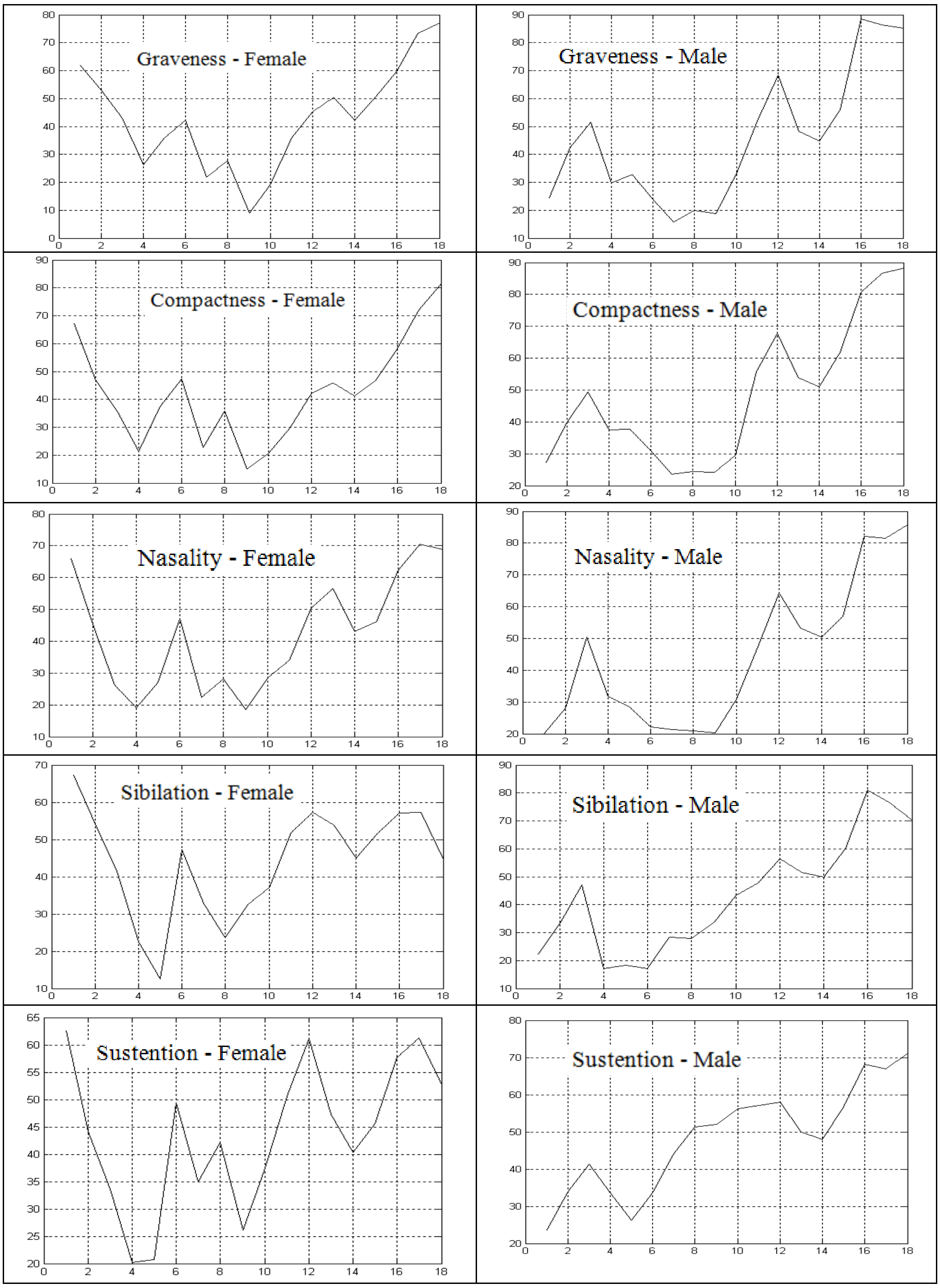
		Sum of Squares	df	Mean Square	F	Sig.
GENDER	Between Groups	1,745	9	,194	,764	,650
	Within Groups	50,755	200	,254		
	Total	52,500	209			
SNR	Between Groups	12,193	9	1,355	2,120	,029
	Within Groups	127,807	200	,639		
	Total	140,000	209			
SUBJECT	Between Groups	116,022	9	12,891	1,150	,329
	Within Groups	2242,074	200	11,210		
	Total	2358,095	209			
PHONETIC	Between Groups	12,494	9	1,388	,681	,725
	Within Groups	407,506	200	2,038		
	Total	420,000	209			

Table 5.25: The ANOVA analysis for the results of SII for the phonetic analysis

		Sum of Squares	df	Mean Square	F	Sig.
GENDER	Between Groups	21,760	71	,306	1,376	,056
	Within Groups	30,740	138	,223		
	Total	52,500	209			
SNR	Between Groups	84,169	71	1,185	2,930	,000
	Within Groups	55,831	138	,405		
	Total	140,000	209			
SUBJECT	Between Groups	864,331	71	12,174	1,125	,277
	Within Groups	1493,764	138	10,824		
	Total	2358,095	209			
PHONETIC	Between Groups	149,210	71	2,102	1,071	,361
	Within Groups	270,790	138	1,962		
	Total	420,000	209			

Equivalent Speech Spectrum Levels (ESSLs)

The ESSLs for each phonetic word were calculated for the standard 18 octave bands (Figure 5.25). For getting a comparison with the subjects' hearing threshold levels, audiograms were recalculated for 18 octaves bands for all subjects (Table 5.26).


Graveness - Female

Graveness - Male

Compactness - Female

Compactness - Male

Nasality - Female

Nasality - Male

Sibilation - Female

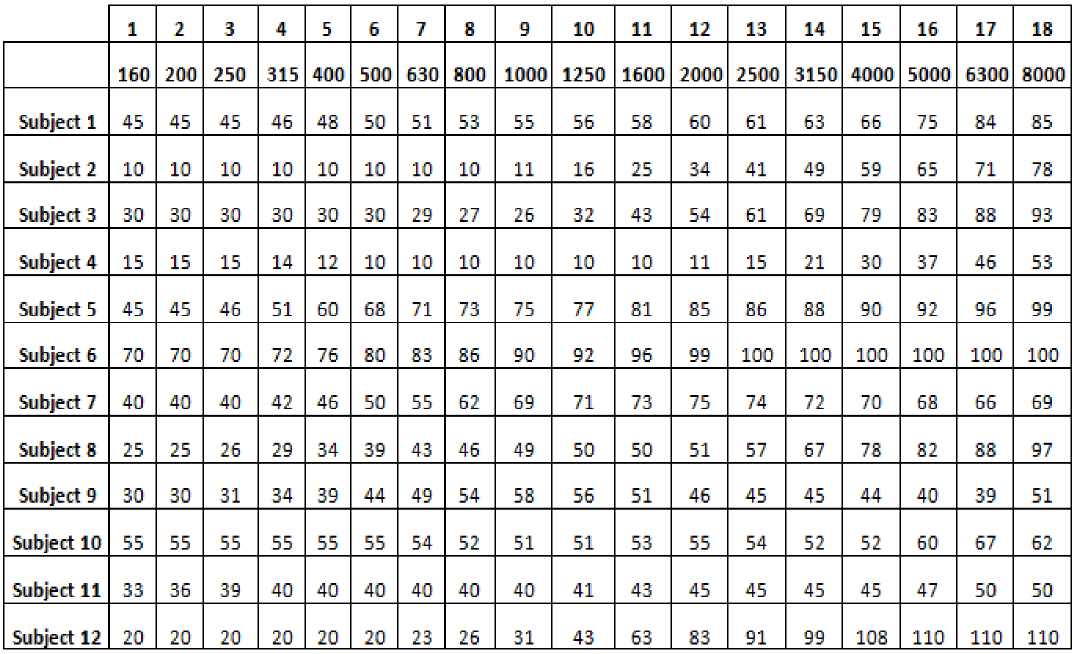
Sibilation - Male

Sustention - Female

Sustention - Male

Figure 5.25: Equivalent speech spectrum levels of each phonetics

Table 5.26: Hearing threshold levels for 18 octave band for all subjects



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	6300	8000
Subject 1	45	45	45	46	48	50	51	53	55	56	58	60	61	63	66	75	84	85
Subject 2	10	10	10	10	10	10	10	10	11	16	25	34	41	49	59	65	71	78
Subject 3	30	30	30	30	30	30	29	27	26	32	43	54	61	69	79	83	88	93
Subject 4	15	15	15	14	12	10	10	10	10	10	10	11	15	21	30	37	46	53
Subject 5	45	45	46	51	60	68	71	73	75	77	81	85	86	88	90	92	96	99
Subject 6	70	70	70	72	76	80	83	86	90	92	96	99	100	100	100	100	100	100
Subject 7	40	40	40	42	46	50	55	62	69	71	73	75	74	72	70	68	66	69
Subject 8	25	25	26	29	34	39	43	46	49	50	50	51	57	67	78	82	88	97
Subject 9	30	30	31	34	39	44	49	54	58	56	51	46	45	45	44	40	39	51
Subject 10	55	55	55	55	55	55	54	52	51	51	53	55	54	52	52	60	67	62
Subject 11	33	36	39	40	40	40	40	40	40	41	43	45	45	45	45	47	50	50
Subject 12	20	20	20	20	20	20	23	26	31	43	63	83	91	99	108	110	110	110

MRT Percentages of Each Phonetic

The box plots of each subject were illustrated for each phonetic (Figure 5.26 and Figure 5.27). According to plots, the percentages of the MRT were different for each subject. The general comparison criterion was being above or below the MRT percentage of 50% for all phonetics. The results for Subject 1, Subject 4, Subject 9 and Subject 11 are above the percentage of 50%; the results for Subject 3 and Subject 7 are equal to the percentage of 50%; the results for Subject 5 are below the percentage of 50% and the results for other subjects (Subject 2, Subject 6, Subject 8, Subject 10, Subject 12) are changing in percentage.

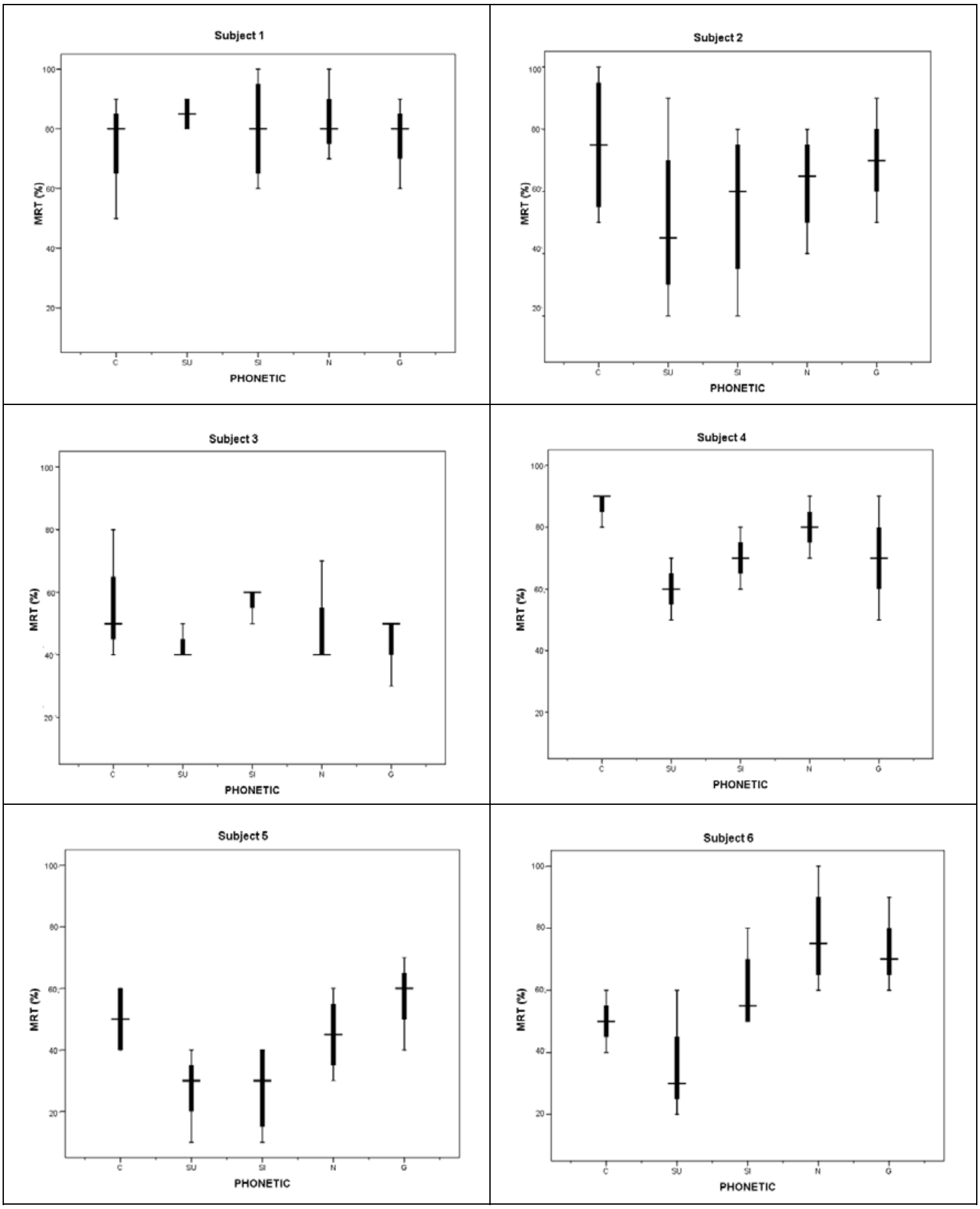


Figure 5.26: Box-plot of percentages of the results of MRT of each phonetics for the Subject 1 to Subject 6 (C: Compactness, SU: Sustention, SI: Sibilation, N: Nasality, G: Graveness)

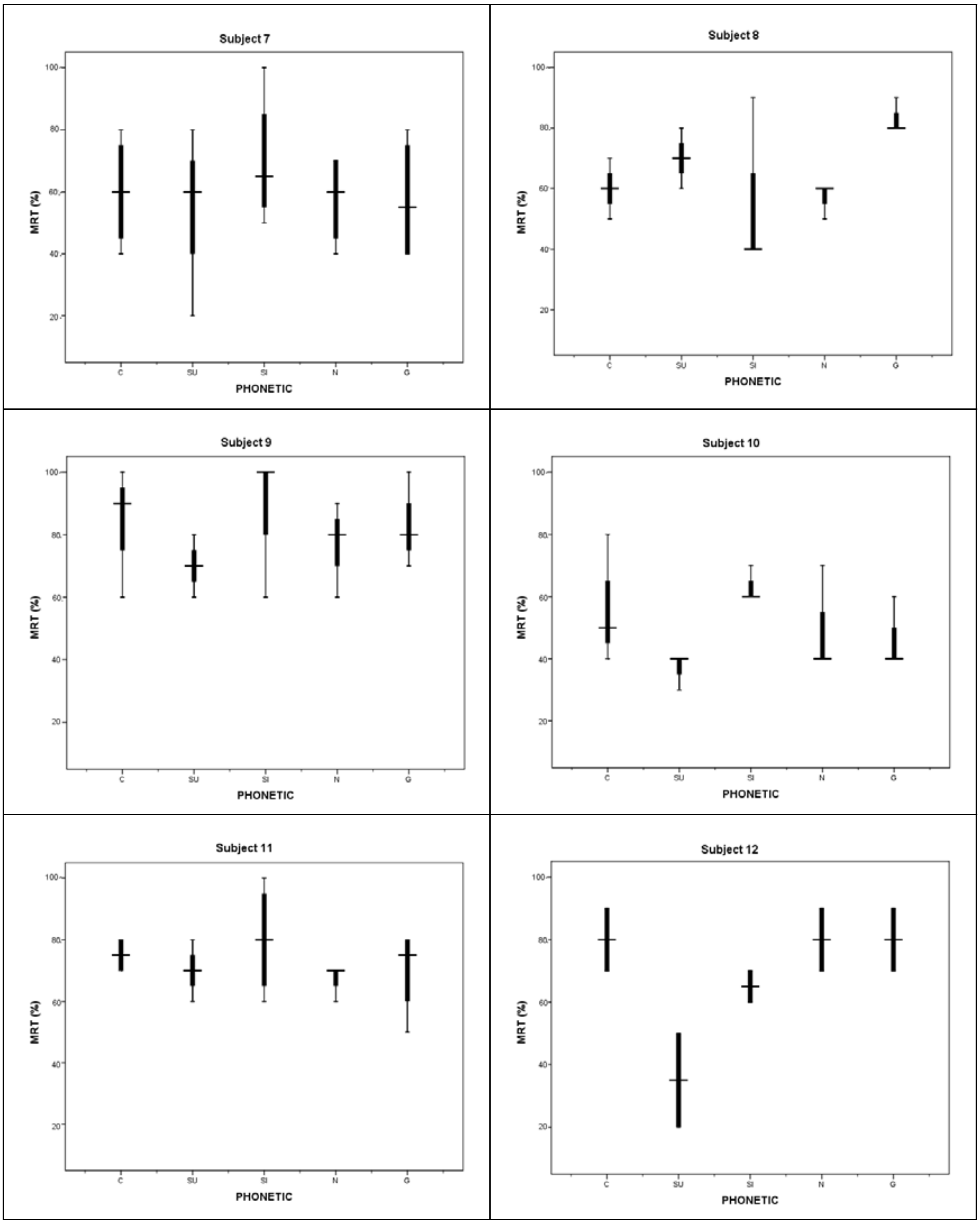


Figure 5.27: Box-plot of percentages of the results of MRT of each phonetics for the Subject 7 to Subject 12 (C: Compactness, SU: Sustention, SI: Sibilation, N: Nasality, G: Graveness)

The noise amount was found as the only significant factor on the words of different phonetics of Turkish Language for both MRT and SII. This result is consistent with the results of significant factors of pre-simulation (Table 5.21). The effect of common articulation properties of the phonetics (Figure 5.20) was observed with the ESSL graphs, too. Although there are some differences between the levels of the gender of the speaker, there are not big differences between the phonetics in the same gender of the speaker. When the audiograms of 18 octave band and the ESSL levels of the phonetics were taken into account together, SII gave consistent results for all subjects (APPENDIX B). Also, MRT results are consistent with the subjects' hearing threshold levels. Considering all phonetics, except for Subject 8, the sibilation property has the lowest MRT percentage. Thus, subjects with higher frequency hearing loss showed the lowest performance for this phonetic.

General View of the Results

As a result of Experiment II, the results of HLS were investigated by two measures. Both measures gave consistent results with the mean values for all subjects. On the other hand, the results of MRT were more consistent than the results of SII. The results of SII were highly affected by the noise. The reliability of HLS was shown with the scatter plots results for pre-simulation and post-simulation using both measures. Also for each factor, HLS gave similar results according to univariate analysis. Difference analysis showed the detailes of changes after the simulation and gave consistent results with the correlation analysis. Because there were not meaningful differences among the phonetics, the detailed analysis and comparisons could not be done for each subject for different phonetics.

CHAPTER 6

IMPLEMENTATION OF FREQUENCY LOWERING METHODS

6.1. Experiment III: Offline Testing with SII for Determining the Parameters of FLM

6.1.1. Objectives

- To develop novel methods with the combination of most frequently used FLMs.
- To use the HLS for simulating the hearing impaired subjects of Experiment II.
- To calculate the SII values of simulated sounds for all methods and five different noisy environments.
- To determine the FLM and values of its parameters which provide the highest performance increment for different noisy environments for each hearing impaired subject.

In order to achieve the above-mentioned objectives, the audiograms of twelve hearing impaired subjects of the second experiment were used for simulating sounds with HLS. The same female and male speech sounds of Experiment I were used for this offline study. For investigating the speech intelligibility for different noisy environments, one noiseless and four noisy sounds were constructed. From four FLMs used in the literature, different novel combinations were developed with their parameters. All significant values were selected according to the SII. According to results of the ANOVA analysis, subject-specific methods and their parameters were selected to obtain the highest speech intelligibility performance increment.

6.1.2. Audiograms

The same audiograms of the hearing impaired subjects of Experiment II were used in this study to obtain meaningful comparisons. All audiograms were simulated by HLS.

6.1.3. Stimuli

The same female and male speech sounds of Experiment I were used for providing consistency between offline experiments.

For determining methods and their parameters for each subject and environment, four noisy sounds were constructed afterwards by adding different noises with the same decibel level of speech sound (0 dB SNR). These were selected by taking into account the common environments in daily life such as high frequency noise, traffic noise, restaurant noise and music noise. The spectrograms of these noises can be seen from Figure 6.1.

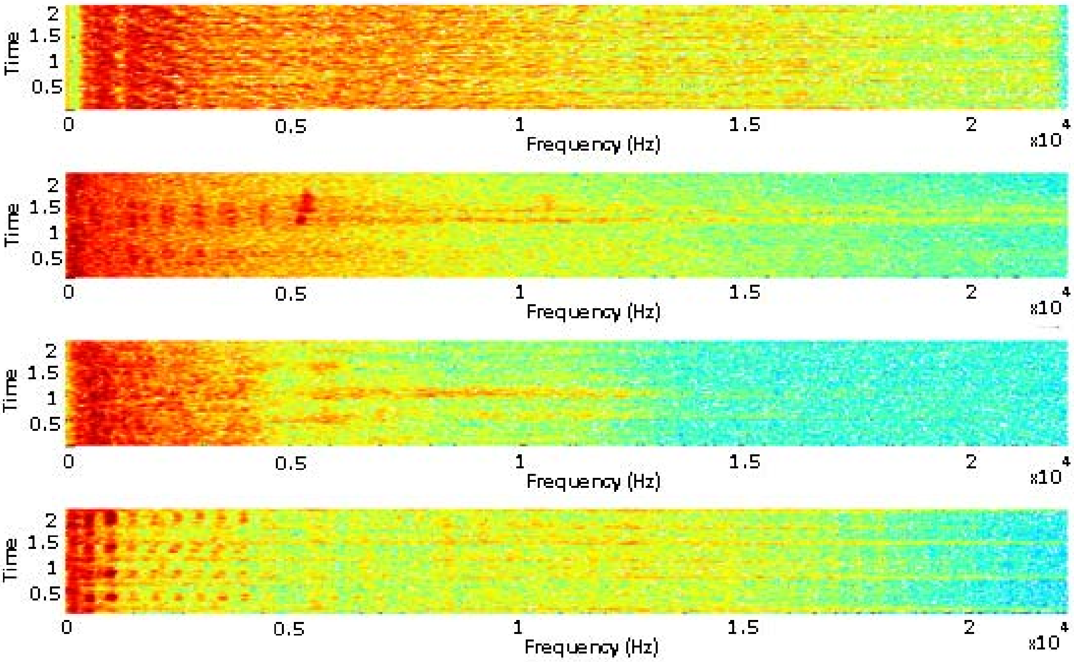


Figure 6.1: Spectrograms of the noise sounds (From top to bottom: High frequency noise, Traffic noise, Restaurant noise, Music noise)

6.1.4. Experiment Design and Implementation

For the offline simulation study, 2 genders of speaker (female, male), 12 simulated audiograms, 9 methods (amplification + 8 FLMs) and 5 different noisy environments (no noise, restaurant, high frequency, music and traffic) were considered as parameters of the FLMs study (Total 1080 cases).

The intelligibility increments were calculated by taking the difference of SII values of unprocessed and processed sounds. (Intelligibility increments for all subjects are listed in APPENDIX C). The selection of the subject-specific methods was done according to these intelligibility increments. On the other hand, the selection of the subject-specific FLMs was done in comparison with the intelligibility increment of the amplification method for the same noise environments. The reason for selecting the amplification method as a comparison method is because it is the most commonly applied method in today's commercial hearing aids. When more than one value of the same parameter resulted in maximum intelligibility increment, one of them was selected for the MRT (Parameters that gave the maximum intelligibility increments are listed in the APPENDIX D for all subjects).

In all calculations, first, FLMs were applied; then, simulation was done to obtain the desired output as in hearing aids. The algorithms of all methods were implemented in MATLAB. The explanations of the parameters of methods are given below:

For the amplification,

- There is only one parameter, hearing loss amount, for determining the gain applied according to the subject's audiogram.
- In FLMs, amplification was applied only for the [0-1 kHz] band as applied in the literature.

For the frequency shifting and frequency transposition,

Tthe "starting frequency" determines the lowest frequency of the shifted band

- The "shifting amount" determines the amount of lowering.
- The only difference between them is that while shifted frequencies are added together in the case of overlapping with the lower frequencies in frequency transposition, the shifted frequencies are replaced in the case of overlapping with the lower frequencies without addition in frequency shifting.

For non-linear compression,

- The compression factor determines the dynamic range of compressed spectrum. By increasing the compression factor, the spectrum is compressed into a smaller frequency range.
- The warping factor determines the compression's linearity (Hicks, Braida and Durlach, 1981). By increasing the warping factor, high frequencies are lowered more than low frequencies (Table 6.1).

Table 6.1: Parameters and technical details of the nine methods used to obtain the highest speech intelligibility increment

No	Method	Different Values of The Parameters	Technical Procedures
1	Amplification (A)	Gain: Hearing loss amount in the related band	• Amplifies the whole band according to the subject's audiogram
2	Amplification with Frequency Shifting (A_FS)	Gain: Hearing loss amount in the related band	• Amplifies [0 - 1 kHz] band according to the subject's audiogram. • Shifts the [SF – 8 kHz] band with the specified SA towards the lower part of the spectrum. • At last, amplified and shifted parts are added together.
		Starting Frequency (SF): 4, 5, 6 kHz	
		Shifting Amount (SA): 2, 3, 4, 5 kHz	
3	Amplification with Frequency Transposition (A_FT)	Gain: Hearing loss amount in the related band	• Amplifies [0 - 1 kHz] band according to the subject's audiogram. • Shifts the [SF – 8 kHz] band with the specified SA towards the lower part of the spectrum. • After shifting, overlapping frequencies with lower parts are added together. • At last, amplified and shifted parts are added together.
		Starting Frequency (SF): 4, 5, 6 kHz	
		Shifting Amount (SA): 2, 3, 4, 5 kHz	
4	Amplification with Non-Linear Frequency Compression (A_ NLC)	Gain: Hearing loss amount in related band	• Amplifies [0 - 1 kHz] band according to the subject's audiogram. • Compresses the [SF – 8 kHz] band with the specified CF and WF. • At last, amplified and compressed parts are added together.
		Starting Frequency (SF): 1, 2, 3 kHz	
		Compression Factor (CF): 4, 5, 6, 7	
		Warping Factor (WF): 0.3, 0.5, 0.7	

Table 6.1 (cont.): Parameters and technical details of the all nine methods used to obtain the highest speech intelligibility increment

5	Amplification with Non-Linear Frequency Compression and Frequency Transposition (A_NLC_FT)	Gain: Hearing loss amount in related band Ending Frequency (EF): 4, 5, 6 kHz Compression Factor (CF): 4, 5, 6, 7 Warping Factor (WF): 0.3, 0.5, 0.7	• Amplifies [0 - 1 kHz] band according to the subject's audiogram. • Compresses the [1 – EF kHz] band with the specified CF and WF. • Shifts the [EF – 8 kHz] band till to the last frequency of the compressed part for not having any gap between the processed parts. • At last, amplified, compressed and shifted parts are added together.
6	Frequency Shifting (FS)	Starting Frequency (SF): 4, 5, 6 kHz Shifting Amount (SA): 2, 3, 3.85, 4, 4.85, 5, 5.85 kHz	• Shifts the [SF – 8 kHz] band with the specified SA towards the lower part of the spectrum. • At last, lower parts and shifted parts are added together.
7	Frequency Transposition (FT)	Starting Frequency (SF): 4, 5, 6 kHz Shifting Amount (SA): 2, 3, 3.85, 4, 4.85, 5, 5.85 kHz	• Shifts the [SF – 8 kHz] band with the specified SA towards the lower part of the spectrum. • After shifting, overlapping frequencies with lower parts are added together. • At last, unprocessed and shifted parts are added together.

Table 6.1 (cont.): Parameters and technical details of the all nine methods used to obtain the highest speech intelligibility increment

8	Non-Linear Frequency Compression (NLC)	Compression Factor (CF): 4, 5, 6, 7	• Compresses the [0 – 8 kHz] band with the specified CF and WF.
		Warping Factor (WF): 0.3, 0.5, 0.7	
9	Non-Linear Frequency Compression and Frequency Transposition (NLC_FT)	Ending Frequency (EF): 2, 3, 4, 5 kHz	• Compresses the [0 – EF kHz] band with the specified CF and WF. • Shifts the [EF – 8 kHz] band till to the last frequency of the compressed part for not having any gap between the processed parts. • At last, compressed and shifted parts are added together.
		Compression Factor (CF): 4, 5, 6, 7	
		Warping Factor (WF): 0.3, 0.5, 0.7	

6.1.5. Results & Discussion of Experiment III

In this part, first, ANOVA analysis was done for all parameters (subject, method, noise type and gender of speaker). Then, methods and their parameters were investigated for each subject.

According to the ANOVA analysis and multiple comparisons between means, "Subject" parameter was statistically significant for the frequency lowering methods (Table 6.2). As expected, the lowest intelligibility increment was obtained for Subject 4 because this subject had the lowest hearing loss levels. The highest intelligibility increment was obtained for subjects with moderate, moderate to severe and severe hearing loss in general. Subjects with profound hearing loss (Subject 5, Subject 6, and Subject 12) got moderate intelligibility increments from the methods.

Table 6.2: Multiple comparisons between means of provided speech intelligibility increment for each subject (N shows the total calculated cases, there are 3 different subsets according to subjects' means)

		Subset for alpha = 0.05 Sig.: 0.00		
SUBJECT	N	1	2	3
4	90	0.025		
2	90		0.084	
6	90		0.088	
3	90		0.115	
11	90		0.118	
12	90		0.122	
5	90		0.123	
8	90			0.1711
10	90			0.176
1	90			0.198
9	90			0.20
7	90			0.202

The "Method" parameter was found as statistically significant (Table 6.3). Thus, different methods should be used to obtain the highest intelligibility increment for each subject. Generally there were 3 subsets among enhancement methods for all subjects. As expected, amplification provided the lowest intelligibility increment. Non linear compression with frequency transposition provided the highest intelligibility increment.

Table 6.3: Multiple comparisons between means of provided speech intelligibility increment for each method (N shows the total calculated cases, there are 3 different subsets according to methods' means)

METHOD	N	Subset for alpha = 0.05 Sig.: 0.00 1	2	3
A	120	0.01		
A_ NLC	120		0.120	
A_FT	120		0.120	
A_NLC_FT	120		0.125	
A_FS	120		0.126	
FT	120		0.126	
FS	120		0.150	
NLC	120			0.209
NLC_FT	120			0.230

The "Noise" parameter was found statistically significant for the MRT study (Table 6.4). Generally there were 3 subsets among noise types for all subjects. Music and traffic noise types got similar intelligibility increments. Restaurant and high frequency noise types got similar intelligibility increments. The "No noise" case got the highest intelligibility increment, as expected.

Table 6.4: Multiple comparisons between means of provided speech intelligibility increment for each noise types (N shows the total calculated cases, there are 3 different subsets according to noise types' means)

NOISE TYPE	N	Subset for alpha = 0.05 Sig.: 0.00 1	2	3
Music Noise	216	0.078		
Traffic Noise	216	0.01		
Restaurant Noise	216		0.132	
High frequency Noise	216		0.147	
No Noise	216			0.22

The “Gender” parameter was not statistically significant for enhancement methods. Thus, there is no need for using different gender speeches in MRT testing. Thus, only a female speaker was used in our study. The gender parameter had been found statistically significant in the Experiment I for the speech intelligibility. However, this was not the case for the speech intelligibility increment in the Experiment III.

Significant Methods and Noise Types for Each Subject

Subject 1:

Table 6.5: Multiple comparisons between means of provided speech intelligibility increments for each method for Subject 1 (N shows the total calculated cases, there are 3 different subsets according to methods’ means)

		Subset for alpha = 0.05 Sig.: 0.00		
METHOD	N	1	2	3
A	10	.075		
A_ NLC	10	.155	.155	
A_ FT	10	.157	.157	
A_NLC_FT	10	.161	.161	.161
A_FS	10	.165	.165	.165
FT	10	.213	.213	.213
FS	10	.234	.234	.234
NLC	10		.295	.295
NLC_FT	10			.326

- The “Method” parameter is statistically significant. Thus, different methods should be used to obtain the highest intelligibility increment for Subject 1.
- Generally there are 3 subsets among enhancement methods for Subject 1.
- The highest three methods can be chosen for MRT.
- Amplification provides the lowest intelligibility increment.
- Non linear compression with frequency transposition provides the highest intelligibility increment.

Table 6.6: Multiple comparisons between means of provided speech intelligibility increments for each noise types for Subject 1 (N shows the total calculated cases, there are 2 different subsets according to noise types' means)

NOISE TYPE	N	Subset for alpha = 0.05 Sig.: 0.00	
		1	2
Restaurant Noise	18	.132	
Music Noise	18	.142	
Traffic Noise	18	.148	
Babble Noise	18	.153	
No Noise	18		.414

- The "Noise" parameter is statistically significant.
- For Subject 1, all noise types get similar intelligibility increments. Thus, one can be used instead of others.

Subject 2:

Table 6.7: Multiple comparisons between means of provided speech intelligibility increments for each method for Subject 2 (N shows the total calculated cases, there are 3 different subsets according to methods' means)

METHOD	N	Subset for alpha = 0.05 Sig.: 0.00		
		1	2	3
A	10	-.056		
FT	10		.038	
FS	10		.059	
A_ NLC	10		.104	.104
A_NLC_FT	10		.106	.106
A_FS	10		.107	.107
A_ FT	10		.110	.110
NLC	10		.118	.118
NLC_FT	10			.167

Means for groups in homogeneous subsets are displayed.

- The "Method" parameter is statistically significant. Thus, different methods should be used to obtain the highest intelligibility increment for Subject 2.

- Generally there are 3 subsets among enhancement methods for Subject 2. However, amplification gets negative intelligibility increment. Thus, the highest two methods can be used for MRT.
- Amplification provides the lowest and negative intelligibility increment.
- Non linear compression with frequency transposition provides the highest intelligibility increment.

Table 6.8: Multiple comparisons between means of provided speech intelligibility increments for each noise types for Subject 2 (N shows the total calculated cases, there are 3 different subsets according to noise types' means)

		Subset for alpha = 0.05 Sig.: 0.00		
NOISE TYPE	N	1	2	3
Music Noise	18	.034		
Restaurant Noise	18	.046	.046	
No Noise	18	.085	.085	.085
Babble Noise	18		.112	.112
Traffic Noise	18			.141

Means for groups in homogeneous subsets are displayed.

- The "Noise" parameter is statistically significant.
- Generally there are 3 subsets among noise types for Subject 2.
- The highest three noise types (subset 3) can be used for MRT.

Subject 3:

Table 6.9: Multiple comparisons between means of provided speech intelligibility increments for each method for Subject 3 (N shows the total calculated cases, there are 4 different subsets according to methods' means)

METHOD	N	Subset for alpha = 0.05 Sig.: 0.00			
		1	2	3	4
A	10	.001			
A_ FT	10	.067	.067		
A_ NLC	10		.081		
A_FS	10		.088		
A_NLC_FT	10		.090		
FT	10		.121		
FS	10		.144	.144	
NLC	10			.204	.204
NLC_FT	10				.24

- The "Method" parameter is statistically significant. Thus, different methods should be used to obtain the highest intelligibility increment for Subject 3.
- Generally there are 4 subsets among enhancement methods for Subject 3.
- The highest two methods (subset 4) can be used for MRT.
- Amplification provides the lowest intelligibility increment.
- Non linear compression with frequency transposition provides the highest intelligibility increment.

Table 6.10: Multiple comparisons between means of provided speech intelligibility increments for each noise types for Subject 3 (N shows the total calculated cases, there are 3 different subsets according to noise types' means)

NOISE TYPE	N	Subset for alpha = 0.05 Sig.: 0.00		
		1	2	3
Music Noise	18	.058		
Traffic Noise	18	.066	.066	
Babble Noise	18		.127	.127
Restaurant Noise	18		.133	.133
No Noise	18			.191

- The "Noise" parameter is statistically significant.
- Generally there are 3 subsets among noise types for Subject 3.
- The highest three noise types (subset 3) can be used for MRT.

Subject 4:

Table 6.11: Multiple comparisons between means of provided speech intelligibility increments for each method for Subject 4 (N shows the total calculated cases, there are 2 different subsets according to methods' means)

		Subset for alpha = 0.05 Sig.: 0.00	
METHOD	N	1	2
A	10	-.090	
FT	10	-.012	-.012
FS	10	.012	.012
A_ FT	10	.028	.028
A_FS	10	.029	.029
A_ NLC	10	.030	.030
A_NLC_FT	10	.034	.034
NLC	10		.066
NLC_FT	10		.125

- The "Method" parameter is statistically significant. Thus, different methods should be used to obtain the highest intelligibility increment for Subject 4.
- Generally there are 2 subsets among enhancement methods for Subject 4.
- The highest two methods can be used for MRT.
- Amplification and frequency shifting provides the lowest and negative intelligibility increment.
- Non linear compression with frequency transposition provides the highest intelligibility increment.

Table 6.12: Multiple comparisons between means of provided speech intelligibility increments for each noise types for Subject 4 (N shows the total calculated cases, there are 3 different subsets according to noise types' means)

NOISE TYPE	N	Subset for alpha = 0.05 Sig.: 0.00		
		1	2	3
No Noise	18	-.078		
Music Noise	18	-.039	-.039	
Traffic Noise	18		.013	
Restaurant Noise	18			.099
Babble Noise	18			.128

- The "Noise" parameter is statistically significant.
- Generally there are 3 subsets among noise types for Subject 4.
- The highest two noise types (subset 3) can be used for MRT.

Subject 5:

Table 6.13: Multiple comparisons between means of provided speech intelligibility increments for each method for Subject 5 (N shows the total calculated cases, there are 4 different subsets according to methods' means)

METHOD	N	Subset for alpha = 0.05 Sig.: 0.00			
		1	2	3	4
A	10	-.032			
A_ NLC	10		.107		
A_ FT	10		.108		
A_NLC_FT	10		.111		
A_FS	10		.118		
FT	10		.135	.135	
FS	10		.148	.148	
NLC_FT	10			.179	.179
NLC	10				.230

- The "Method" parameter is statistically significant. Thus, different methods should be used to obtain the highest intelligibility increment for Subject 5.
- Generally there are 4 subsets among enhancement methods for Subject 5.

- The highest two methods (subset 4) can be used for MRT.
- Amplification provides the lowest and negative intelligibility increment.
- Non linear compression provides the highest intelligibility increment.

Table 6.14: Multiple comparisons between means of provided speech intelligibility increments for each noise types for Subject 5 (N shows the total calculated cases, there are 2 different subsets according to noise types' means)

NOISE TYPE	N	Subset for alpha = 0.05 Sig.: 0.00	
		1	2
Music Noise	18	.071	
Traffic Noise	18	.111	.111
Restaurant Noise	18	.134	.134
Babble Noise	18		.147
No Noise	18		.151

- The "Noise" parameter is statistically significant.
- Generally there are 2 subsets among noise types for Subject 5.
- The highest two noise types can be used for MRT.

Subject 6:

Table 6.15: Multiple comparisons between means of provided speech intelligibility increments for each method for Subject 6 (N shows the total calculated cases, there are 2 different subsets according to methods' means)

METHOD	N	Subset for alpha = 0.05 Sig.: 0.00	
		1	2
A	10	-.036	
FT	10		.070
NLC_FT	10		.094
A_ NLC	10		.106
A_FS	10		.107
A_ FT	10		.107
FS	10		.107
A_NLC_FT	10		.11
NLC	10		.13

- The “Method” parameter is statistically significant. Thus, different methods should be used to obtain the highest intelligibility increment for Subject 6.
- Generally there are 2 subsets among enhancement methods for Subject 6.
- The highest method can be used for MRT, because all methods except amplification constructed only one subset.
- Amplification provides the lowest and negative intelligibility increment.
- Non linear compression provides the highest intelligibility increment.

Table 6.16: Multiple comparisons between means of provided speech intelligibility increments for each noise types for Subject 6 (N shows the total calculated cases, there are 3 different subsets according to noise types’ means)

		Subset for alpha = 0.05 Sig.: 0.00		
NOISE	N	1	2	3
No Noise	18	.024		
Music Noise	18	.062	.062	
Traffic Noise	18		.097	.097
Restaurant Noise	18			.123
Babble Noise	18			.135

- The “Noise” parameter is statistically significant.
- Generally there are 3 subsets among noise types for Subject 6.
- The highest three noise types (subset 3) can be used for MRT.

Subject 7:

Table 6.17: Multiple comparisons between means of provided speech intelligibility increments for each method for Subject 7 (N shows the total calculated cases, there are 3 different subsets according to methods' means)

METHOD	N	Subset for alpha = 0.05 Sig.: 0.00 1	2	3
A	10	.036		
A_FS	10		.186	
A_ NLC	10		.191	.191
A_ FT	10		.194	.194
A_NLC_FT	10		.198	.198
FT	10		.199	.199
FS	10		.224	.224
NLC	10		.290	.290
NLC_FT	10			.296

- The "Method" parameter is statistically significant. Thus, different methods should be used to obtain the highest intelligibility increment for Subject 7.
- Generally there are 3 subsets among enhancement methods for Subject 7.
- The highest three methods can be used for MRT.
- Amplification provides the lowest intelligibility increment.
- Non linear compression with frequency transposition provides the highest intelligibility increment.

Table 6.18: Multiple comparisons between means of provided speech intelligibility increments for each noise types for Subject 7 (N shows the total calculated cases, there are 2 different subsets according to noise types' means)

NOISE TYPE	N	Subset for alpha = 0.05 Sig.: 0.00 1	2
Traffic Noise	18	.166	
Restaurant Noise	18	.167	
Babble Noise	18	.178	
Music Noise	18	.182	
No Noise	18		.315

- The “Noise” parameter is statistically significant.
- Generally there are 2 subsets among noise types for Subject 7.
- The highest two noise types can be used for MRT.

Subject 8:

Table 6.19: Multiple comparisons between means of provided speech intelligibility increments for each method for Subject 8 (N shows the total calculated cases, there are 2 different subsets according to methods’ means)

		Subset for alpha = 0.05 Sig.: 0.00	
METHOD	N	1	2
A	10	.037	
A_ FT	10	.153	.153
A_ NLC	10	.153	.153
FT	10	.159	.159
A_NLC_FT	10	.163	.163
A_FS	10	.169	.169
FS	10		.183
NLC	10		.242
NLC_FT	10		.282

- The “Method” parameter is statistically significant. Thus, different methods should be used to obtain the highest intelligibility increment for Subject 8.
- Generally there are 2 subsets among enhancement methods for Subject 8.
- The highest three methods can be used for MRT.
- Amplification provides the lowest intelligibility increment.
- Non linear compression with frequency transposition provides the highest intelligibility increment.

Table 6.20: Multiple comparisons between means of provided speech intelligibility increments for each noise types for Subject 8 (N shows the total calculated cases, there are 3 different subsets according to noise types' means)

NOISE TYPE	N	Subset for alpha = 0.05 Sig.: 0.00		
		1	2	3
Traffic Noise	18	.089		
Music Noise	18	.115	.115	
Restaurant Noise	18		.155	
Babble Noise	18		.159	
No Noise	18			.338

- The "Noise" parameter is statistically significant.
- Generally there are 3 subsets among noise types for Subject 8.
- The highest two noise types can be used for MRT.

Subject 9:

Table 6.21: Multiple comparisons between means of provided speech intelligibility increments for each method for Subject 9 (N shows the total calculated cases, there are 2 different subsets according to methods' means)

METHOD	N	Subset for alpha = 0.05 Sig.: 0.00	
		1	2
A	10	.077	
FT	10	.177	.177
A_ NLC	10	.190	.190
A_ FT	10	.199	.199
A_NLC_FT	10	.200	.200
FS	10	.202	.202
A_FS	10	.202	.202
NLC	10		.260
NLC_FT	10		.297

- The "Method" parameter is statistically significant. Thus, different methods should be used to obtain the highest intelligibility incrementfor Subject 9.
- Generally there are 2 subsets among enhancement methods for Subject 9.

- The highest two methods can be used for MRT.
- Amplification provides the lowest intelligibility increment.
- Non linear compression with frequency transposition provides the highest intelligibility increment.

Table 6.22: Multiple comparisons between means of provided speech intelligibility increments for each noise types for Subject 9 (N shows the total calculated cases, there are 2 different subsets according to noise types' means)

		Subset for alpha = 0.05 Sig.: 0.00	
NOISE TYPE	N	1	2
Traffic Noise	18	.123	
Music Noise	18	.123	
Restaurant Noise	18	.159	
Babble Noise	18	.168	
No Noise	18		.429

- The "Noise" parameter is statistically significant.
- Generally there are 2 subsets among noise types for Subject 9.
- The highest two noise types can be used for MRT.

Subject 10:

Table 6.23: Multiple comparisons between means of provided speech intelligibility increments for each method for Subject 10 (N shows the total calculated cases, there are 3 different subsets according to methods' means)

		Subset for alpha = 0.05 Sig.: 0.00		
METHOD	N	1	2	3
A	10	.083		
A_ NLC	10	.116	.116	
A_ FT	10	.117	.117	
A_NLC_FT	10	.121	.121	
A_FS	10	.122	.122	
FT	10	.202	.202	.202
FS	10	.223	.223	.223
NLC	10		.28	.28
NLC_FT	10			.317

- The “Method” parameter is statistically significant. Thus, different methods should be used to obtain the highest intelligibility increment for Subject 10.
- Generally there are 3 subsets among enhancement methods for Subject 10.
- The highest four methods (subset 3) can be used for MRT.
- Amplification provides the lowest intelligibility increment.
- Non linear compression with frequency transposition provides the highest intelligibility increment.

Table 6.24: Multiple comparisons between means of provided speech intelligibility increments for each noise types for Subject 10 (N shows the total calculated cases, there are 2 different subsets according to noise types’ means)

NOISE TYPE	N	Subset for alpha = 0.05 Sig.: 0.00	
		1	2
Traffic Noise	18	.084	
Music Noise	18	.103	
Restaurant Noise	18	.147	
Babble Noise	18	.148	
No Noise	18		.396

- The “Noise” parameter is statistically significant.
- Generally there are 2 subsets among noise types for Subject 10.
- The highest two noise types can be used for MRT.

Subject 11:

Table 6.25: Multiple comparisons between means of provided speech intelligibility increments for each method for Subject 11 (N shows the total calculated cases, there are 3 different subsets according to methods' means)

METHOD	N	Subset for alpha = 0.05 Sig.: 0.00		
		1	2	3
A	10	.032		
A_ NLC	10	.073	.073	
A_ FT	10	.079	.079	
A_NLC_FT	10	.081	.081	
A_FS	10	.09	.09	
FT	10	.12	.12	.12
FS	10	.144	.144	.144
NLC	10		.2	.2
NLC_FT	10			.244

- The "Method" parameter is statistically significant. Thus, different methods should be used to obtain the highest intelligibility increment for Subject 11.
- Generally there are 3 subsets among enhancement methods for Subject 11.
- The highest four methods (subset 3) can be used for MRT.
- Amplification provides the lowest intelligibility increment.
- Non linear compression with frequency transposition provides the highest intelligibility increment.

Table 6.26: Multiple comparisons between means of provided speech intelligibility increments for each noise types for Subject 11 (N shows the total calculated cases, there are 3 different subsets according to noise types' means)

NOISE TYPE	N	Subset for alpha = 0.05 Sig.: 0.00		
		1	2	3
Music Noise	18	-.002		
Traffic Noise	18	.043		
Babble Noise	18		.132	
Restaurant Noise	18		.139	
No Noise	18			.279

- The "Noise" parameter is statistically significant.
- Generally there are 3 subsets among noise types for Subject 11.
- The highest three noise types can be used for MRT.

Subject 12:

Table 6.27: Multiple comparisons between means of provided speech intelligibility increments for each method for Subject 12 (N shows the total calculated cases, there are 4 different subsets according to methods' means)

METHOD	N	Subset for alpha = 0.05 Sig.: 0.00			
		1	2	3	4
A	10	-.01			
FT	10		.09		
A_NLC_FT	10		.119		
FS	10		.123	.123	
A_ FT	10		.124	.124	
A_FS	10		.129	.129	
A_ NLC	10		.136	.136	.136
NLC	10			.188	.188
NLC_FT	10				.196

- The "Method" parameter is statistically significant. Thus, different methods should be used to obtain the highest intelligibility increment for Subject 12.
- Generally there are 4 subsets among enhancement methods for Subject 12.
- The highest three (subset 4) methods can be used for MRT.
- Amplification provides the lowest and negative intelligibility increment.
- Non linear compression with frequency transposition provides the highest intelligibility increment.

Table 6.28: Multiple comparisons between means of provided speech intelligibility increments for each noise types for Subject 12 (N shows the total calculated cases, there are 3 different subsets according to noise types' means)

NOISE TYPE	N	Subset for alpha = 0.05 Sig.: 0.00		
		1	2	3
Music Noise	18	.082		
No Noise	18	.098	.098	
Traffic Noise	18	.112	.112	
Restaurant Noise	18		.144	.144
Babble Noise	18			.173

- The "Noise" parameter is statistically significant.
- Generally there are 3 subsets among noise types for Subject 12.
- The highest two (subset 3) noise types can be used for MRT.

Overall view of subject-spefic methods:

According to the ANOVA analysis, the selected methods and noise environments for each subject were shown in Table 6.29. The MRT was designed according to all possible combinations of methods and noise environments for each subject (Number of Methods X Number of Noise Types = Total Cases). In total, 71 cases were present for all subjects. The values of the parameters for selected methods and noise environments for each subject can be seen from the Table 6.30.

Table 6.29: Selected methods and noise types for each subject according to the intelligibility increments in the offline FLMs study (Selected ones are filled, total cases are calculated by the multiplication of the numbers of methods and noise types).

	METHODS					**NOISE TYPES**					
	A_ NLC	**FS**	**FT**	**NLC**	**NLC_ FT**	**No Noise**	**High Freq**	**Music**	**Restaurant**	**Traffic**	**Total Cases**
Subject 1		■		■	■	■	■				**6**
Subject 2				■	■	■	■			■	**6**
Subject 3				■	■	■	■		■		**6**
Subject 4				■	■		■		■		**4**
Subject 5				■	■	■	■				**4**
Subject 6				■			■		■	■	**3**
Subject 7		■		■	■	■		■			**6**
Subject 8		■		■	■	■	■				**6**
Subject 9				■	■	■	■				**4**
Subject 10		■	■	■	■	■	■				**8**
Subject 11		■	■	■	■	■	■		■		**12**
Subject 12	■			■	■		■		■		**6**

Table 6.30: Parameters and their values for selected methods and noise types for each subject

Subject	**Method**	**No Noise**	**High Frequency**	**Music**	**Restaurant**	**Traffic**
1	**FS**	SF: 6 kHz SA: 3 kHz	SF: 6 kHz SA: 2 kHz			
	NLC	CF: 4 WF:0.5	CF: 4 WF:0.7			
	NLC_FT	EF: 5 kHz CF: 4 WF:0.3	EF: 2 kHz CF: 4 WF:0.7			
2	**NLC**	CF: 4 WF:0.7	CF: 4 WF:0.7			CF: 4 WF:0.3
	NLC_FT	EF: 2 kHz CF: 7 WF:0.3	EF: 5 kHz CF: 4 WF:0.7			EF: all CF: 4 WF:0.7
3	**NLC**	CF: 4 WF:0.5	CF: 4 WF:0.7		CF: 4 WF:0.3	
	NLC_FT	EF: 4 kHz CF: 7 WF:0.3	EF: 2 kHz CF: 4 WF:0.7		EF: 5 kHz CF: 5 WF:0.3	
4	**NLC**		CF: 4 WF:0.7		CF: 4 WF:0.3	
	NLC_FT		EF: 2 kHz CF: 4 WF:0.7		EF: 4 kHz CF: 4 WF:0.3	
5	**NLC**	CF: 5 WF:0.3	CF: 4 WF:0.7			
	NLC_FT	EF: 5 kHz CF: 6 WF:0.3	EF: 5 kHz CF: 6 WF:0.7			
6	**NLC**		CF: 6 WF:0.7		CF: 5 WF:0.3	CF: 6 WF:0.7
7	**FS**	SF: 5 kHz SA: 4.85 kHz		SF: 6 kHz SA: 5 kHz		
	NLC	CF: 5 WF:0.5		CF: 5 WF:0.3		
	NLC_FT	EF: 5 kHz CF: 6 WF:0.3		EF: 5 kHz CF: 6 WF:0.3		

Table 6.30 (cont.): Parameters and their values for selected methods and noise types for each subject

Subject	Method	No Noise	High Frequency	Music	Restaurant	Traffic
8	**FS**	SF: 4 kHz SA: 3.85 kHz	SF: 6 kHz SA: 2 kHz			
	NLC	CF: 4 WF:0.5	CF: 4 WF:0.7			
	NLC_FT	EF: 4 kHz CF: 6 WF:0.3	EF: 2 kHz CF: 4 WF:0.7			
9	**NLC**	CF: 4 WF:0.7	CF: 4 WF:0.7			
	NLC_FT	EF: 4 kHz CF: 5 WF:0.3	EF: 4 kHz CF: 5 WF:0.5			
10	**FS**	SF: 5 kHz SA: 2 kHz	SF: 6 kHz SA: 2 kHz			
	FT	SF: 4 kHz SA: 2 kHz	SF: 6 kHz SA: 2 kHz			
	NLC	CF: 4 WF:0.7	CF: 4 WF:0.7			
	NLC_FT	EF: 4 kHz CF: 5 WF:0.5	EF: 4 kHz CF: 4 WF:0.7			
11	**FS**	SF: 4 kHz SA: 2 kHz	SF: 6 kHz SA: 2 kHz		SF: 6 kHz SA: 5 kHz	
	FT	SF: 6 kHz SA: 2 kHz	SF: 4 kHz SA: 3 kHz		SF: 4 kHz SA: 3 kHz	
	NLC	CF: 4 WF:0.7	CF: 4 WF:0.7		CF: 4 WF:0.3	
	NLC_FT	EF: 4 kHz CF: 4 WF:0.3	EF: 4 kHz CF: 4 WF:0.7		EF: 5 kHz CF: 4 WF:0.3	
12	**FS**		SF: 6 kHz SA: 3 kHz		SF: 6 kHz SA: 5 kHz	
	NLC		CF: 4 WF:0.7		CF: 7 WF:0.3	
	NLC_FT		EF: 2 kHz CF: 4 WF:0.7		EF: 5 kHz CF: 6 WF:0.3	

General findings for all results:

- There was no intelligibility increment using the amplification method provided. Only for Subject 12, amplification with non linear compression got intelligibility increment.
- Non linear compression and non linear compression with frequency transposition provided the highest intelligibility increment for all subjects (only exception for Subject 6)
- Generally, all subjects got intelligibility increment in noiseless and high frequency noisy environment.
- Generally, none of the subjects got intelligibility increment in musical and traffic noise cases.
- The minimum number of methods (one method) that provided intelligibility increment was for Subject 6 and the maximum number of methods (four methods) that provided intelligibility increment was for Subject 10 and Subject 11.
- The minimum of the total number cases (three cases) that provided intelligibility increment was for Subject 6 and the maximum of the total number cases (twelve cases) that provided intelligibility increment was for Subject 11.

6.2. Experiment IV: Modified Rhyme Testing with Normal Hearing Subjects

6.2.1. Objectives

- Using HLS with combined suprathreshold effects in frequency lowering studies for the first time in the literature.
- Applying selected FLMs and the values of their parameters for different noisy environments to normal hearing subjects in MRT.
- For providing exact recommendation to each subject, showing both the intelligibility increment of SII and the performance increment in word

scores of MRT after the HLS for significant FLMs with respect to the amplification method.

In order to achieve the above-mentioned objectives, only selected methods in Experiment III were applied. After frequency lowering processing, sounds were simulated by HLS using the audiograms of each hearing impaired subject. After the simulation, SII for all sounds were calculated. Then, normal hearing subjects listened to frequency lowered and simulated sounds. For carrying out the correlation analysis with the SII, the average value of the results of three normal hearing subjects were used for each simulated hearing impaired subject. According to the statistical analysis, methods which provided higher performance increment in word scores for each noisy environment were recommended in place of the amplification method for each subject.

6.2.2. Subjects

Audiograms of the hearing impaired subjects of Experiment II were simulated by HLS. In this experiment, thirty-six normal hearing subjects (twenty male and sixteen female), participated in the MRT. The average value of the results obtained from three normal hearing subjects was compared with the result obtained from the hearing impaired subject whose audiogram was used in simulation. The selection criteria were the same with Experiment II.

6.2.3. Stimuli

Same input sounds and noise sounds were used as in Experiment III. According to the results of Experiment III, only female speech was used in this experiment, because the gender of the speaker was not significant.

6.2.4. Experiment Design

The basic steps and applied statistical analysis of the Experiment IV are depicted in the Figure 6.2. In this experiment, first, the frequency lowering algorithms were applied to unprocessed sounds. Then, these sounds were processed to simulate hearing loss according to the hearing thresholds of hearing impaired subjects. Normal hearing subjects listened to the frequency lowered and simulated sounds in rhyme testing. The intelligibility indexes of processed sounds were calculated by SII and the percentages of correct responses of rhyme test were determined by MRT. The results of SII and MRT were analyzed by correlation analysis.

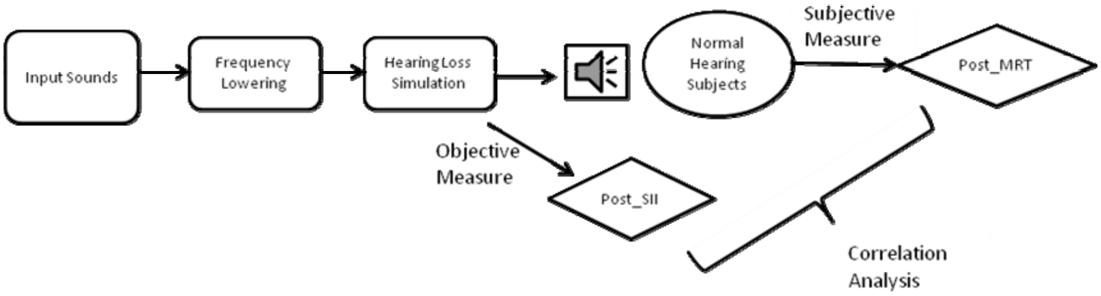


Figure 6.2: Schematic diagram of workflow for Experiment IV

For MRT, the same procedures were applied as in the previous MRT experiment (Experiment II). Generally, all subjects listened to 8 or 9 lists (200 or 225 words in total) in the test and it took 30-33 minutes per subject. All subjects were trained until they got used to the MRT procedures. Written instructions were delivered to each participant at the beginning of the experiment.

6.2.5. Implementation

Previously developed HLS and FLMs were used in this experiment. Therefore no additional implementation was needed for Experiment IV.

6.2.6. Results & Discussion of Experiment IV

Reliability and Correlation Analysis

Note that in this section, references to Subject X do not indicate the actual subject with the hearing loss, but the overall group of normal hearing subjects who listened to sounds simulating the hearing loss of Subject X.

Reliability and correlation analysis of each subject with the mean values of SII and MRT can be seen from Table 6.31.

According to the reliability analysis, all subject groups, except for Subject 1, showed consistent behavior in the MRT. The results of the Subject 1 is negligible (very close to the minimum threshold of 70% of reliability analysis). For all subjects, the mean Cronbach's alpha is 0.88 and 0.85 for Experiment IV and Experiment II, respectively.

The grand means of SII and MRT are 0.36 and 63, respectively. In the correlation analysis, correlation coefficients for "no noise" cases for Subject 4, Subject 6 and Subject 12 could not be calculated, because test cases for these subjects, only included "noisy" cases. In the "no noise" case analysis, except for three subjects (Subject 1, Subject 5 and Subject 10), the results of SII and MRT showed similar behavior for each subject. Also, in noisy cases, except for four subjects (Subject 4, Subject 7, Subject 10 and Subject 11), the results of SII and MRT showed similar behavior. All results for both SII and MRT tests are listed in the APPENDIX E.

In the case of any inconsistencies between the SII and MRT results, which occur mostly for the noisy cases, the MRT results should be taken into account, since MRT is a more reliable test of speech intelligibility than SII.

Table 6.31: Reliability coefficients of normal hearing subjects, mean values of SII and MRT and correlation analysis of each Subject for "no noise" and noisy cases (N/A: Not Applicable).

	Reliability of Normal Hearing Subjects	**Mean Values**		**Correlation (Spearman's rho)**	
	(Cronbach's alpha)	**SII**	**MRT**	**"no noise" case**	**noisy cases**
Subject 1	0.67	0.46	74	0.15	0.6
Subject 2	0.92	0.43	67	0.76	0.62
Subject 3	0.95	0.4	49	1	0.76
Subject 4	0.91	0.2	77	N/A	0.24
Subject 5	0.93	0.28	55	0.11	0.93
Subject 6	0.74	0.12	44	N/A	0.61
Subject 7	0.95	0.42	57	0.93	0. 32
Subject 8	0.88	0.49	66	0.93	0.97
Subject 9	0.83	0.5	68	0.79	0.76
Subject 10	0.93	0.42	73	0.36	0.35
Subject 11	0.99	0.38	75	0.61	0.53
Subject 12	0.96	0.21	54	N/A	0.81

Graphical Comparisons of MRT and SII

The comparison between SII and MRT can be seen from the Figure 6.3 and Figure 6.4, according to the selected methods and noise, respectively.

According to the figures, the results of MRT are higher than SII. While amplification values of SII are in a very narrow range, the percentages of the MRT of amplification vary. This situation occurs mostly for the high frequency noise cases (Figure 6.4).

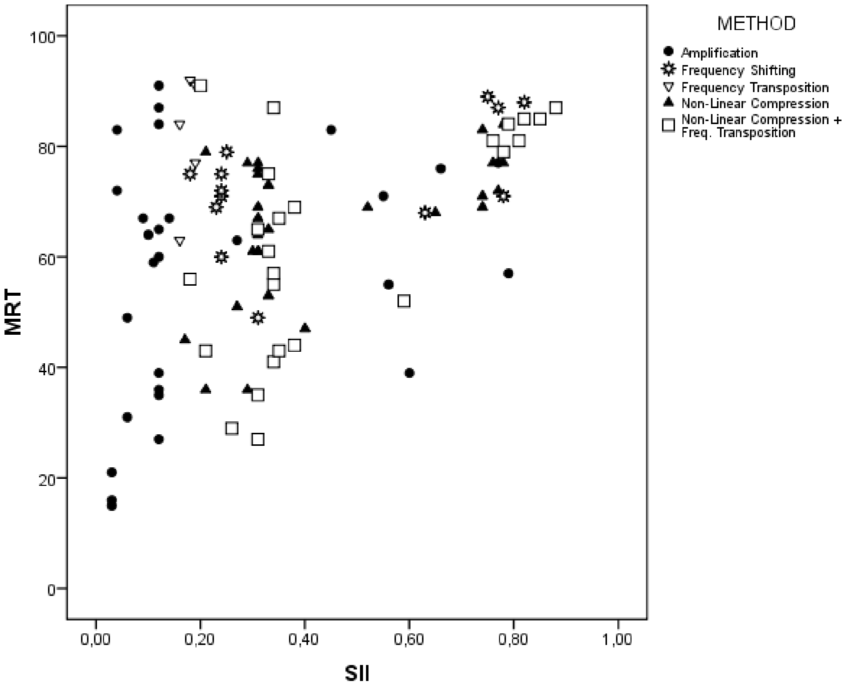


Figure 6.3: Scatter plot of SII and MRT for selected cases with respect to methods

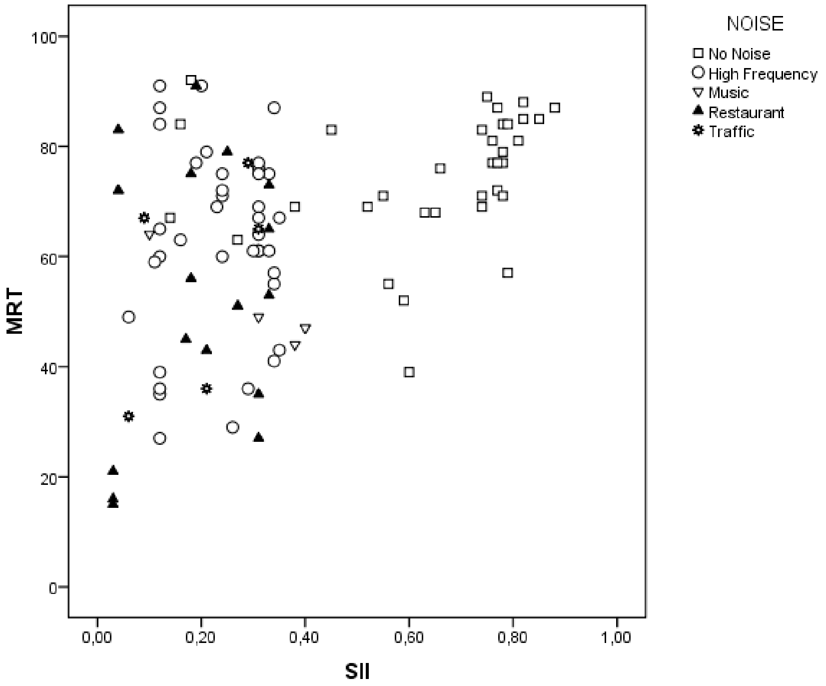


Figure 6.4: Scatter plot of SII and MRT for selected cases with respect to noise types.

Increment Values of SII and MRT after the FLMs

The general picture of increment values according to the selected methods for each subject can be seen from Table 6.32, Table 6.33 and Table 6.34. In these tables, only increment values of the selected methods and noisy environments are shown. Increment values are calculated by subtracting the value of each case from the value of the amplification method according to the same noise types.

For the intelligibility increments of SII, the highest intelligibility increments were obtained for Subject 1, Subject 7, Subject 8, Subject 9 and Subject 10. The highest intelligibility increments for all subjects were obtained for all “no noise” cases as expected. Among the noise types, the highest intelligibility increment was obtained for the “music” noise.

For the performance increments of MRT, the highest performance increments were obtained for five subjects (Subject 2, Subject 3, Subject 6, Subject 8, and Subject 12) for all significant methods and noisy environments. However, for other subjects, MRT gave negative performance increments in some cases according to the amplification values. The common factor for these results was “high frequency” noise type, especially for Subject 5, Subject 9, Subject 10 and Subject 11. These are expected results for the “high frequency” noise type, because after processing with frequency lowering, the noise was shifted to audible bands, whereas the amplification only technique keeps the noise in inaudible bands. Thus, the amplification method got higher performance increments in word scores than combined FLMs for high frequency noise types.

Table 6.32: The differences of all methods from the amplification method for showing the increment values of both SII and MRT and averages of “no noise” and noisy cases for Subject 1 to Subject 4.

			Subject 1		**Subject 2**		**Subject 3**		**Subject 4**	
#	**METHOD**	**NOISE**	**SII**	**MRT**	**SII**	**MRT**	**SII**	**MRT**	**SII**	**MRT**
1	NLC	No Noise	0.29	-12	-0.02	15	0.14	30		
2	NLC	High Frequency	0.19	1	0.19	37	0.19	26	0.19	-7
3	NLC	Restaurant					0.30	37	0.29	-10
4	NLC	Traffic			0.20	10				
5	NLC_FT	No Noise	0.31	-2	0.09	30	0.22	46		
6	NLC_FT	High Frequency	0.21	15	0.23	28	0.22	20	0.08	7
7	NLC_FT	Restaurant					0.28	11	0.14	-27
8	NLC_FT	Traffic			0.22	-2				
9	FS	No Noise	0.30	6						
10	FS	High Frequency	0.12	11						

Table 6.33: The differences of all methods from the amplification method for showing the increment values of both SII and MRT and averages of “no noise” and noisy cases for Subject 5 to Subject 8.

			Subject 5		**Subject 6**		**Subject 7**		**Subject 8**	
#	**METHOD**	**NOISE**	**SII**	**MRT**	**SII**	**MRT**	**SII**	**MRT**	**SII**	**MRT**
1	NLC	No Noise	0.38	2			0.38	5	0.18	28
2	NLC	High Frequency	0.18	-23	0.15	30			0.19	33
3	NLC	Music					0.30	17		
4	NLC	Restaurant			0.14	24				
5	NLC	Traffic			0.15	5				
6	NLC_FT	No Noise	0.24	2			0.22	-11	0.25	26
7	NLC_FT	High Frequency	0.15	-30					0.22	5
8	NLC_FT	Music					0.28	-20		
9	FS	No Noise					0.36	5	0.21	32
10	FS	High Frequency							0.12	39
11	FS	Music					0.21	-15		

Table 6.34: The differences of all methods from the amplification method for showing the increment values of both SII and MRT and averages of “no noise” and noisy cases for Subject 9 to Subject 12.

IMPROVEMENTS			**Subject 9**		**Subject 10**		**Subject 11**		**Subject 12**	
#	**METHOD**	**NOISE**	**SII**	**MRT**	**SII**	**MRT**	**SII**	**MRT**	**SII**	**MRT**
1	NLC	No Noise	0.12	8	0.21	6	0.01	0		
2	NLC	High Frequency	0.18	-4	0.19	-24	0.19	-12	0.19	37
4	NLC	Restaurant					0.29	-7	0.24	36
5	NLC_FT	No Noise	0.12	3	0.24	13	0.08	8		
6	NLC_FT	High Frequency	0.23	-22	0.21	-30	0.22	-30	0.22	60
7	NLC_FT	Restaurant					0.27	-37	0.18	28
8	FS	No Noise			0.23	0	0.05	11		
9	FS	High Frequency			0.12	-31	0.12	-15	0.09	42
10	FS	Restaurant					0.21	-7	0.15	60
11	FT	No Noise			-0.39	13	-0.59	15		
12	FT	High Frequency			0.04	-28	0.07	-10		
13	FT	Restaurant					0.15	19		

Subject Specific Recommendations

According to the performance increments of MRT (Table 6.32, Table 6.33 and Table 6.34), each subject should use different methods in different environments. The values of the parameters of mentioned algorithms for each noise case were given in Experiment III. Here, subject specific recommendations were done according to the increment values.

For Subject 1;

- In a noise free environment, frequency shifting is the best choice.
- In a high frequency noisy environment, one of the selected FLMs (NLC, NLC_FT, and FS) should be used instead of amplification. However, the highest benefit can be provided from the NLC_FT algorithm.

For Subject 2;

- In a noise free environment, one of the selected FLMs (NLC, NLC_FT) should be used instead of amplification. However, the highest benefit can be provided from the NLC_FT algorithm.

- For high frequency noisy environment, both significant FLMs can be used instead of amplification.
- In traffic, only the NLC method should be used instead of amplification.

For Subject 3;

- All selected FLMs (NLC, NLC_FT) got higher performance increment than amplification for both noise free and noisy environments (high frequency, traffic).
- The NLC_FT method should be used in a noise free environment.
- NLC should be used in noisy environments to obtain higher speech intelligibility.

For Subject 4;

- The mean performance increment was in the negative direction.
- Except only for one case (NLC_FT in high frequency environment), amplification got better performance increment in word scores than other selected FLMs (NLC, NLC_FT).
- This can be explained by the hearing threshold of Subject 4, which is the lowest of all subjects.
- Thus, there is no need for extra processing for this subject. The standard method can be used to obtain enough speech intelligibility.

For Subject 5;

- Some performance increments were achieved for selected FLMs (NLC, NLC_FT) for a noise free environment.
- There was a decline in performance increments for FLMs in high frequency noisy environments (the role of high frequency noise in FLMs was explained before).

For Subject 6;

- There is only one selected FLM (NLC).

- This method got the highest performance increments for all noisy environments. The NLC method should be used for this subject in all cases.
- Also, these results are consistent with his/her hearing thresholds, because Subject 6 has one of the highest hearing loss thresholds.

For Subject 7;

- The mean performance increment was in the negative direction.
- Among the selected FLMs (NLC, NLC_FT, and FS), NLC and FS should be used instead of amplification for noise free environments.
- In musical environments, only the NLC method can be used. Otherwise, amplification can be selected for that subject.

For Subject 8;

- All selected FLMs (NLC, NLC_FT, and FS) showed better performance than amplification.
- Among the selected FLMs, to obtain the highest performance increment, FS should be used instead of amplification for all environments.

For Subject 9;

- The mean performance increment was in the negative direction.
- In noise free environments, both selected FLMs (NLC, NLC_FT) should be used instead of amplification.
- In musical environments, amplification can get enough speech intelligibility for this subject.

For Subject 10;

- The mean performance increment was in the negative direction.
- In noise free environments, all selected FLMs (NLC, NLC_FT, FS, and FT) can be used instead of amplification.
- Only the FS method showed the same performance with amplification.
- For high frequency noisy environments, amplification got the highest MRT score among all significant FLMs.Thus, in high frequency noisy

environments, amplification should be used for this subject (the role of high frequency noise in FLMs was explained before).

For Subject 11;

- The mean performance increment was in the negative direction.
- Similar to the correlation results of Subject 11, amplification got higher MRT scores for all significant FLMs in high frequency noisy and restaurant noise environments, except the FT method in restaurants.
- All selected FLMs (NLC, NLC_FT, FS, and FT) showed better performance than amplification in a noise free environment. Also the NLC method showed the same performance as amplification in a noise free environment.

For Subject 12;

- All selected FLMs (NLC, NLC_FT, FS) gave better performance than amplification.
- The highest performance increments (60%) in all subjects were achieved for this subject. These performance increments were for NLC_FT in high frequency noisy environment and for FS in a restaurant noise environment.

6.3. Experiment V: Rhyme Testing with Hearing Impaired Subjects

6.3.1. Objectives

- Using the same hearing impaired subjects (first group) of Experiment I for comparing the results of Experiment IV
- Applying combined FLMs on hearing impaired subjects
- Using new hearing impaired subjects (second group) for comparing the results of SII and MRT for FLMs
- Showing the consistency and reliability of both HLS and FLMs by both groups of hearing impaired subjects

In order to achieve the above-mentioned objectives, selected FLMs with their parameters for each subject were applied to the sounds for MRT. The hearing impaired subjects listened to frequency lowered sounds without simulation. The increment values of both SII and MRT with respect to the amplification method were compared with the results of FLMs.

6.3.2. Subjects

There were two groups with four hearing impaired subjects for each in this experiment. The first group was constructed with the four hearing impaired subjects of Experiment II (Subject 1, Subject 9, Subject 11, Subject 12). The personal problems, not being in Ankara and not accepting to participate to test for a second time were the main reasons of not reaching the rest of the hearing impaired subjects of Experiment II. The audiological and demographic information of participants from Experiment II can be found in the related chapter of Experiment II.

There were four new hearing impaired subjects in the second group. The selection criteria were same as the hearing impaired subjects of Experiment II. The audiological and demographic information can be found in Table 6.35 and Table 6.36.

Table 6.35: Audiometric measurements of both ears of the new hearing impaired subjects for standard frequencies and information of tested ear for Experiment V

	250	500	1000	2000	4000	6000	8000	Ear Tested
Subject 1 L	15	20	15	15	60	60	55	
Subject 1 R	15	15	15	45	80	90	85	■
Subject 2 L	20	15	15	50	50	70	70	■
Subject 2 R	20	15	15	35	50	70	70	
Subject 3 L	10	10	30	55	55	50	50	
Subject 3 R	15	15	30	50	55	65	65	■
Subject 4 L	15	15	10	10	45	60	60	■
Subject 4 R	15	15	10	20	55	55	55	

Table 6.36: Information about new hearing impaired subjects of Experiment V

				Hearing Loss			
	Gender	**Age**	**Education Level**	**Ear**	**Cause**	**Duration**	**Hearing Aid**
New Subject 1	M	57	University	Both	High Pressure	2 years	No
New Subject 2	F	55	University	Both	Unknown	3 years	No
New Subject 3	F	58	University	Both	Unknown	3 years	No
New Subject 4	M	48	High School	Both	Unknown	5 years	No

6.3.3. Stimuli

The same input sounds and noise sounds were used as in Experiment IV. For the first group of hearing impaired subjects, the choice of FLMs was done according to the maximum and minimum performance increments in Experiment IV. In this way, the comparison among the FLMs was observed more easily by comparing different situations.

For the second group of hearing impaired subjects,

- At first, the audiogram information was taken from the selected hearing impaired subjects.
- The hearing of these subjects were simulated with HLS.
- The SII values for all FLMs and values of their parameters were calculated with an offline study like in Experiment III.
- According to the results of the offline study, the FLMs were selected for each subject.
- At last, the stimuli were prepared with selected FLMs and related amplification method for comparison.

6.3.4. Experiment Design

The basic steps and applied statistical analysis of the Experiment V are shown in Figure 6.5. In this experiment, first, the frequency lowering algorithms were applied to unprocessed sounds. Then, both groups of hearing impaired subjects listened to these sounds in rhyme testing. The percentages of correct responses of the rhyme test were determined by MRT for both groups. The analysis for the first group of hearing impaired subjects was done by comparing the results of the MRT of Experiment IV and this experiment. On the other hand, the intelligibility indexes of unprocessed sounds were calculated by SII only for the second group of hearing impaired subjects. The analysis for the second group of hearing impaired subjects was done by comparing the results of SII and MRT.

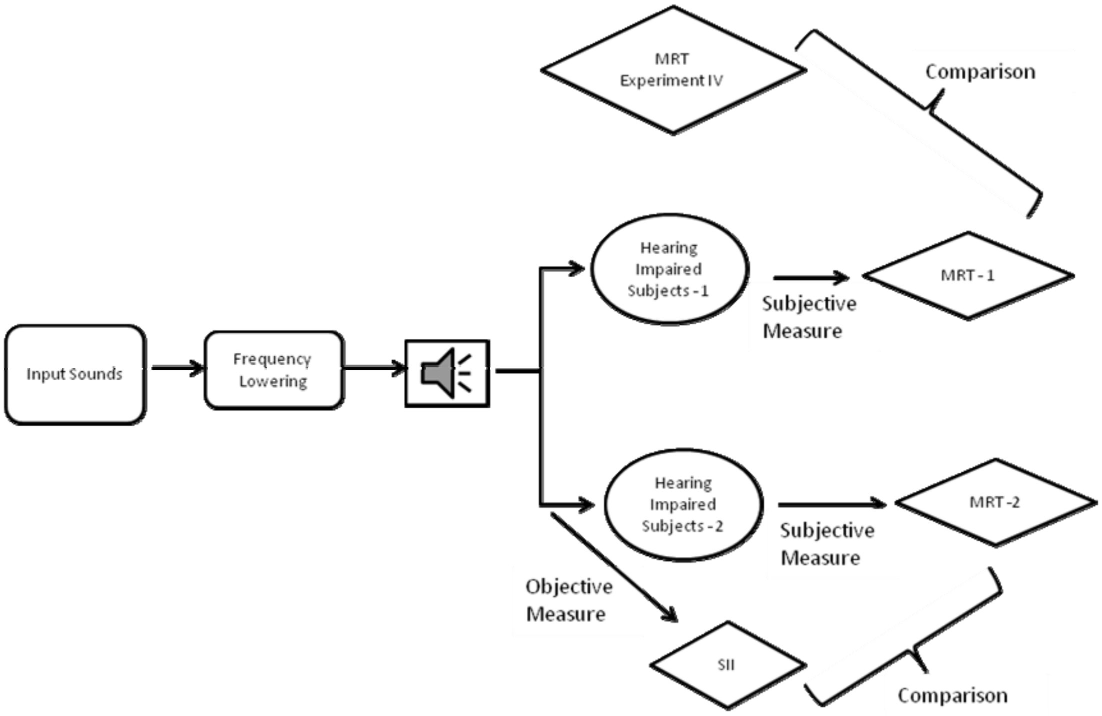


Figure 6.5: Schematic diagram of workflow for Experiment V

The same MRT lists of Experiment II for hearing impaired subjects were used in this experiment. The same procedures were applied to subjects with Experiment II.

6.3.5. Implementation

Previously developed FLMs were used in this experiment. There was no need for extra implementation for Experiment V.

6.3.6. Results & Discussion of Experiment V

The results of the first group can be seen in Table 6.37 and Table 6.38.

Table 6.37: Comparison table of experiments IV and V according to performance increments with respect to amplification method and MRT results of Subject 1 and Subject 9.

			Subject 1				Subject 9			
			Exp. IV		Exp. V		Exp. IV		Exp. V	
#	**METHOD**	**NOISE**	**Imp.**	**MRT**	**Imp.**	**MRT**	**Imp.**	**MRT**	**Imp.**	**MRT**
1	NLC	No Noise					8	84	12	84
2	NLC_FT	High Frequency	15	75	12	84	-22	43	-20	52
3	FS	No Noise	6	89	12	84				
4	AMP	No Noise		83		72		76		72
5	AMP	High Frequency		60		72		65		72

Table 6.38: Comparison of experiments IV and V according to performance increments with respect to amplification method and MRT results of Subject 11 and Subject 12.

			Subject 11				Subject 12			
			Exp. IV		Exp. V		Exp. IV		Exp. V	
#	**METHOD**	**NOISE**	**Imp.**	**MRT**	**Imp.**	**MRT**	**Imp.**	**MRT**	**Imp.**	**MRT**
1	NLC	High Frequency					37	64	40	68
2	NLC	Restaurant					36	51	38	60
3	NLC_FT	Restaurant	-37	35	-48	24				
4	FS	Restaurant					60	75	80	92
5	FT	No Noise	15	92	0	76				
6	FT	Restaurant	19	91	4	76				
7	AMP	No Noise		77		76				
8	AMP	High Frequency						27		28
9	AMP	Restaurant		72		72		15		12

For Subject 1;

- The percentage values of noise free and high frequency environments for the amplification method are slightly different. However, the mean values of both experiments are similar (71% and 72% for Experiment IV and V, respectively).
- The positive performance increments were achieved for both selected FLMs in the same way as with Experiment IV.
- Although the percentage values of noise free and high frequency environments for the amplification method are slightly different, the mean values of both experiments are similar (82% and 84% for Experiment IV and V, respectively).
- In Experiment V, the higher performance increment (6%) was observed for noise free environment and lower performance increment (3%) was observed for high frequency environment with respect to Experiment IV. However these differences are negligible amounts for MRT.
- As a conclusion, the results showed clearly the reliability and the usability of HLS and FLMs for Subject 1.

For Subject 9;

- The percentage values of noise free and high frequency environments for the amplification method are slightly different. However, the mean values of both experiments are similar like Subject 1 (71% and 72% for Experiment IV and Experiment V, respectively).
- For observing the behavior and getting the true comparison of MRT results, the maximum and minimum performance increments were selected for Subject 9.
- The positive and negative performance increments were achieved for both selected FLMs in the same way as with Experiment IV.
- In Experiment V, the higher performance increments (4% and 2%) were observed for both noise free environment and high frequency environment with respect to Experiment IV, respectively. However, those differences are negligible amounts for MRT.

- As a conclusion, the results showed clearly the reliability and the usability of HLS and FLMs for Subject 9.

For Subject 11;

- The percentage values of noise free and restaurant environments for the amplification method are slightly different. However, the mean values of both experiments are similar like Subject 1 (75% and 74% for Experiment IV and Experiment V, respectively).
- For observing the behavior and getting the true comparison of MRT results, the maximum and minimum performance increments were selected for Subject 11.
- The positive and negative performance increments were achieved for both selected FLMs in the same way with the Experiment IV.
- Only for the frequency transposition in a noise free environment, was the same percentage value (0% performance increment) of MRT observed for Experiment V.
- There was a 15% performance increment in Experiment IV. In Experiment V, lower performance increments (in the range of 11% and 15%) were observed for both noise free environments and restaurant environments with respect to Experiment IV, respectively. However these differences are negligible amounts for MRT.
- As a conclusion, the results showed clearly the reliability and the usability of HLS and FLMs for Subject 11.

For Subject 12;

- The percentage values of restaurant and high frequency environments for the amplification method are slightly different. However, the mean values of both experiments are similar (21% and 20% for Experiment IV and Experiment V, respectively).
- The positive performance increments were achieved for both selected FLMs in the same way and a similar difference to the amplification results was observed in the FLM results as with Experiment IV.

- Although the percentage values of the restaurant and high frequency environments for the amplification method are slightly different, the mean values of both experiments are similar (63% and 73% for Experiment IV and Experiment V, respectively).
- There is a difference between the performance increments of Experiment IV and Experiment V for NLC and FS methods. While the difference performance increment in NLC was 2%, the difference performance increment in FS increased to 20% in Experiment V. This is the only different value for the Experiment V among all the subjects.
- As a conclusion, the results showed clearly the reliability and the usability of HLS and FLMs for Subject 12.

For the second group of hearing impaired subjects, the FLMs which provided maximum increment values for both SII and MRT for each noisy environment were listed in APPENDIX F. The results for four new hearing impaired subjects can be seen from the Table 6.39 and Table 6.40.

Table 6.39: Comparison table of SII and MRT according to increment values with respect to amplification method of New Subject 1 and New Subject 2.

			New Subject 1				**New Subject 2**			
			SII		**MRT**		**SII**		**MRT**	
#	**METHOD**	**NOISE**	**IMP**	**AVG**	**IMP**	**AVG**	**IMP**	**AVG**	**IMP**	**AVG**
1	NLC	Restaurant	0.29	0.32	68	68				
2	NLC_FT	No Noise	0.16	0.84	8	88				
3	NLC_FT	Music					0.33	0.49	8	80
4	A_NLC_FT	No Noise					0.08	0.82	-4	84
5	A_FT	High Frequency	0.19	0.32	76	76	0.20	0.32	12	84
6	AMP	No Noise		0.68		80		0.74		88
7	AMP	High Frequency		0.13		0		0.12		72
8	AMP	Restaurant		0.03		0				
9	AMP	Music						0.16		72

Table 6.40: Comparison table of SII and MRT according to increment values with respect to amplification method of New Subject 3 and New Subject 4.

			New Subject 3				New Subject 4			
			SII		MRT		SII		MRT	
#	**METHOD**	**NOISE**	**IMP**	**AVG**	**IMP**	**AVG**	**IMP**	**AVG**	**IMP**	**AVG**
1	NLC	Music	0.26	0.42	16	76	0.25	0.42	16	52
2	NLC_FT	No Noise					0.05	0.90	12	96
3	NLC_FT	High Frequency	0.24	0.36	20	64				
4	A_FT	No Noise	0.08	0.79	16	72				
5	A_FT	High Frequency					0.20	0.32	16	88
6	AMP	No Noise		0.71		56		0.85		84
7	AMP	High Frequency		0.12		44		0.12		72
8	AMP	Music		0.16		60		0.17		36

For the New Subject 1;

- The NLC method in restaurant noise, NLC_FT method without noise and A_FT method in high frequency noise was compared with the amplification method for the same noises.
- The value of the SII and the percentage of the related MRT gave generally consistent results.
- For the lower percentages of the MRT, SII gives lower values.
- Although the difference of the noisy cases of SII value from the noise free cases of SII value is very high, there are not similar differences for the percentages of the MRT. Again, this shows the high response of SII to the noise.
- The "0" percentages of the amplification method for noisy environments occurred for New Subject 1, because either the subject did not understand the words or was not willing to complete the tests.
- For the same noisy environments, 68% and 76% of the words were identified by New Subject 1 for the NLC method in restaurant noise and A_FT method in high frequency noise, respectively.
- In MRT, New Subject 1 showed higher performance for FLMs than the amplification method for all cases
- The results showed the necessity of the usage of FLMs for New Subject 1 for all environments.

For the New Subject 2;

- A_NLC_FT method without noise, NLC_FT method in music noise and A_FT method in high frequency noise were compared with the amplification method for the same noises.
- While NLC_FT method and A_FT method showed higher performance than the amplification method, A_NLC_FT method showed worse performance than the amplification method. However, this small difference (-4%) can be negligible for the MRT, because this difference corresponds to only one answer in MRT.
- Generally, New Subject 2 should use FLMs in noisy environments to obtain more speech intelligibility.
- For noise free environments, the FLM or amplification methods can be used because they achieve similar speech intelligibility.

For the New Subject 3;

- The NLC method in music noise, NLC_FT method in high frequency noise and A_FT method without noise were compared with the amplification method for the same noises.
- The value of the SII and the percentage of the related MRT gave consistent results.
- In MRT, New Subject 3 showed higher performance for FLMs than the amplification method for all cases (16% and 18% higher performance increments for noise free and noisy environments, respectively)
- The results showed the necessity of the usage of FLMs for New Subject 3 for all environments.

For the New Subject 4;

- The NLC method in music noise, A_FT method in high frequency noise and NLC_FT method without noise were compared with the amplification method for the same noises.
- The value of the SII and the percentage of the related MRT gave consistent results.

- In MRT, New Subject 4 showed higher performance for FLMs than the amplification method for all cases (12% and 16% higher performance increments for noise free and noisy environments, respectively)
- The results showed the necessity of the usage of FLMs for New Subject 4 for all environments.

General View for All Hearing Impaired Subjects

As a conclusion, for both groups of hearing impaired subjects, MRT gave generally consistent results with SII.

For the first group of hearing impaired subjects,

- There were 10 different comparisons of FLMs with the amplification method.
- Similar results were achieved between normal hearing subjects and hearing impaired subjects at 9 cases (90% success).
- In one case, the FLM gave the same MRT value as the amplification method (0% improvement).

For the second group of hearing impaired subjects,

- There were 12 different comparisons of FLMs with the amplification method.
- FLMs showed higher performance than the amplification method at 11 cases (91.6% success).
- In one case, the FLM showed lower performance than amplification method (-4% improvement) and this is a very small decrement for MRT.

This experiment was done for extra validation of both HLS and FLMs, although their validations were done in the previous studies. Also, with this experiment, the necessity of usage of FLMs with subject specific values and the performance increments of FLMs with respect to the amplification method were shown very clearly with both old and new groups of hearing impaired subjects.

CHAPTER 7

GENERAL DISCUSSION

Although discussions were included after the results of each experiment, the discussion of general overview of the thesis will be done in this chapter.

For achieving the objectives of the project, two main studies were realized in this thesis. The first study was for developing and implementing the hearing loss simulation; the second study was for developing and implementing the frequency lowering algorithms. In total, five experiments were done in these studies. There were two experiments for both studies and there was an extra one experiment for evaluation of both studies.

In Experiment I, among five different methods, the combined method of all suprathreshold effects (Method 5) was selected for the implementation of the HLS. Eight parameters and their related fifty values were evaluated in Experiment I to find the optimum method. The expected decaying behavior of the SII value was observed for all parameters for the higher threshold audiogram levels. According to the audiogram versus SII results, the highest SII value was obtained by Method 5 for both male and female speech sounds.

As an objective measure, SII was selected as it has been widely used in speech intelligibility studies. SII has advantages of calculation according to different band importance weightings for different speech materials.

The HLS was developed with the same implementation in the literature with a minor change in the loudness recruitment. Experiment I showed the importance of the selection of the method and its parameters for HLS related studies, because speech intelligibility changes for different methods and parameters. Therefore, this selection can directly affect the results. Thus, the optimum methods and parameters of HLS should be selected to obtain the highest performance for each specific study of HLS.

In Experiment II, HLS was evaluated by both SII and MRT. MRT was developed for the Turkish language. Test sounds were prepared for three different parameters and eight different values. SII and MRT were tested for both hearing impaired and normal hearing subjects. This experiment showed both the reliability of the HLS and the relationship between the SII and MRT.

The expected difference among the phonetics of the Turkish language was not found. Their spectral components, ESSLs, were very close to each other for the same gender of speaker. Only a difference between the genders of speakers was observed for all phonetics. Thus, the word list according to phonetics of Turkish language was used only for increasing the diversity of the MRT lists.

Similar mean values of both SII and MRT for unsimulated and simulated sounds showed the reliability of the HLS. On the other hand, according to the interaction analysis, MRT showed more consistent results than SII.

The difference analysis showed the effect of HLS on different parameters and subjects. The difference percentage values are in the range of approximately ± 15% and ± 30%, respectively. These results showed the importance of the selection of parameters and subjects in HLS studies.

In Experiment III, the preparation for MRT was done with different choices of the FLMs and noisy environments. This offline study was prepared to eliminate the methods that do not provide substantial gain in intelligibility. By this way, the total number of test cases and thereby the duration of the MRT tests could be reduced for the subjects.

Hearing losses of the same subjects of Experiment II were simulated to get meaningful comparisons. The main noise types (crowd at a restaurant, traffic noise and musical noise) that people commonly encounter in their daily lives were selected for noisy sounds. In addition, high frequency noise was included in the tests as it was expected to have a different interaction with the FLMs than the other noise types. All sounds were constructed with 0 dB SNR level.

Besides the four mostly used basic FLMs, new combinations of FLMs were developed for Experiment III. Generally, in the literature each method is used alone. The general procedures of basic FLMs were retained in all methods. All extra combinations were developed to get more improvement in speech intelligibility and for providing the advantages of each method. The general criteria in combining the methods were not having any overlapping frequency bands or any gap after the frequency lowering with any of the methods. Thus, unwanted distortions were eliminated at the beginning of the study.

According to the results, the lowest benefit was obtained for Subject 4 as was expected. The lowest intelligibility increment was provided by the amplification method (standard hearing aid method) and the highest intelligibility increment was provided by the combined method of non linear compression and frequency transposition. Generally all methods with the amplification (A_FS, A_FT, A_NLC, A_NLC_FT) provided lower intelligibility increment than the methods without amplification (FS, FT, NLC, NLC_FT) (Table 6.3.). These results confirmed our predictions about the combination of methods instead of amplification. The highest speech intelligibility increment was provided for noise free cases, as expected.

By this experiment, subject specific advices can be given for different environments with the specific FLM and its specific parameter values to obtain the highest speech intelligibility increment.

In Experiment IV, comparison of the performance increments of the significant methods with the amplification method was investigated by MRT for each subject. The same sounds used in MRT of Experiment II were processed with the significant FLMs. The results of increment values for both SII and MRT were compared for each subject. As a result, the exact methods that provided the highest improvement were specified for each subject.

When the highest improvement of all significant methods for the same noisy environment is considered for each subject, 28 different cases occur for all subjects. Among these cases, FLMs showed better performance than the amplification method in 23 noisy environment cases (83%). Only in 5 cases (17%), did the amplification method show better performance than all other FLMs.

When the higher improvements of all significant methods for each noisy environment are considered for each subject, 71 different cases occur for all subjects. Among the 71 different cases of the MRT, the selected FLMs showed better performance than amplification in 45 cases (63.4%). Only in the 24 cases (33.8%), did amplification show better performance than the related selected FLMs and in 2 cases (2.8%), amplification and related selected FLMs showed the same performance.

From the general view, the highest performance increments were achieved for the subjects with worse threshold levels and the lowest performance increments were achieved for the subjects with better threshold levels, as expected. For four subjects (Subject 3, Subject 6, Subject 8, Subject 12), all selected FLMs gave higher performance increments than amplification.

For noise free environments, according to the average value of the maximum performance increments of the subjects (Subject 1, Subject 2, Subject 3, Subject 6, Subject 8, and Subject 12), the mean performance increment was 23% (minimum: 0% for Subject 6, maximum: 46% for Subject 3). For all subjects, the average value of the maximum performance increments was 17% (minimum: 0% for Subject 6, maximum: 46% for Subject 3).

*For noisy environments, a*ccording to the average value of the maximum performance increments of the subjects (Subject 1, Subject 2, Subject 3, Subject 6, Subject 8, and Subject 12), the mean performance increment was 36% (minimum: 15% for Subject 1, maximum: 60% for Subject 12). For all subjects, the average value of the maximum performance increments was 18% (minimum: -24% for Subject 10, maximum: 60% for Subject 12).

*For all environments, a*ccording to the average value of the maximum performance increments of the subjects (Subject 1, Subject 2, Subject 3, Subject 6, Subject 8, and Subject 12), the mean performance increment was 38% (minimum: 15% for Subject 1, maximum: 60% for Subject 12). For all subjects, the average value of the maximum performance increments was 24% (minimum: 2% for Subject 5, maximum: 60% for Subject 12).

According to the average value of performance increments, the selected methods gave higher performance increment in noisy environments for all subjects.

Only for high frequency noise, did amplification show better performance than other methods. This was an expected result since FLMs transfer the noise to audible bands, although with simple amplification, the noise is left at those bands where hearing loss is predominant. Thus, hearing impaired subjects are not affected from this noise after the amplification.

Selection of the subjects is an important factor for the HLS studies. The selection of subjects with different hearing threshold levels was taken into account in this study. Also, the demographic and educational properties of the subjects may affect the results. These effects were shown in this thesis.

In correlation studies of SII and MRT, there were uncorrelated results for some cases (no noise cases for Subject 1, Subject 7, Subject 10; noisy cases for Subject 4, Subject 7, Subject 10, Subject 11). Although these results are consistent with the results of Experiment II, an extra experiment (Experiment V) was designed with the same hearing impaired subjects of Experiment II. By this experiment, an extra validation check for both HLS and MRT was done.

In Experiment V, among ten cases of first group of subjects, there were nine performance increments (90%) in the same way as with Experiment IV. Among twelve cases of second group of subjects, there were eleven higher MRT percentages (91.6%) than amplification method. These results showed that developed HLS and FLMs were reliable and usable with both hearing impaired and normal hearing subjects in similar studies.

CHAPTER 8

CONCLUSIONS

In this thesis, mainly two studies were carried out for HLS and FLM. Two experiments were done for each study and one comparison experiment was done for both studies. For both studies, offline experiments were done for determining the optimum and significant parameters and designs of the next MRT experiments. SII measure was used as an evaluation tool in offline experiments. In the rhyme testing experiments (Experiment II, Experiment IV and Experiment V), the results of MRT and related values of SII were compared for reliability and validation. At these experiments, both hearing impaired and normal hearing subjects were used.

In this study, the validation of the HLS was done with SII and MRT, which are the two of the best known objective and subjective measures. Yet, similar studies can also be done with other objective and subjective measures for extra control.

Hearing loss with the combined suprathreshold effects was simulated. As suprathreshold effects, spectral smearing simulation (for reduced frequency selectivity) and loudness recruitment simulation (for reduced audibility and loudness recruitment) were used.

MRT lists were developed for Turkish language for the first time in the literature. In the MRT, three different test lists were used to obtain detailed information. These are six words list with the same first character, six words list with the same last character and six words list redesigned according to the Turkish language phonetics. On the other hand, preparing the MRT list with respect to the phonetics of the Turkish language did not give comparable results for the different properties of the phonetics. Thus, this type of list with the selected phonetics is not meaningful for MRT studies in Turkish.

In this study, different combinations of the FLMs and all their parameters were investigated for the subjects. All different cases were tried under four different noisy environments and a noise free environment.

The significant methods were used in MRT for validation of the results and observing the performance increment with respect to the amplification method. According to the results, SII of all FLMs gave higher performance increment than amplification. The work described in this thesis provides a new approach for frequency lowering studies. The usage of combined methods was investigated for the first time in this study and it is expected that similar studies will follow the approach of this thesis.

When the low satisfaction rates of the hearing impaired subjects from the hearing aids and the low efficiency of the methods for them are considered, this study area will be open and attractive for researchers for a long time.

Maybe the most important future study will be the hardware implementation of these FLMs into the hearing aids. In our study, the hardware considerations were taken into account only by considering minimum, efficient and fast working algorithms. However, based on the guidelines obtained from this research work, the development can focus on implementation on DSPs and hearing aids.

The core findings of this thesis are listed below:

- Optimum and significant frequency lowering methods and values of the parameters were selected by offline studies.
- Hearing loss simulation was developed and tested with both objective and subjective measures.
- Modified rhyme test was developed for the Turkish language.
- Modified rhyme test was applied to both hearing impaired and normal hearing subjects.
- Different combined frequency lowering methods were developed.

- The optimum values of the parameters of frequency lowering methods were determined to obtain the highest speech intelligibility for each subject for five different noisy environments.
- Hearing loss simulation with suprathreshold effects was used in frequency lowering methods study.
- The validation of hearing loss simulation and frequency lowering methods was done with an extra experiment.

As a result of this study, the necessity of using different FLMs with different parameters was shown for different hearing impaired subjects for different noisy environments. Individualized treatment of hearing loss is essential for improving speech intelligibility further than is possible with simple amplification based hearing aids. With the implementation of FLMs, hearing impaired subjects' satisfaction from the hearing aids can be increased as better audibility of sounds from the surroundings are provided. The problems associated with high frequency sounds are the main causes for dissatisfaction. By overcoming these problems, the quality of life of the hearing impaired people can be increased.

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APPENDICES

APPENDIX A: The Results of MRT and SII in Experiment II

					BEFORE SIMULATION		AFTER SIMULATION	
NO	**SUBJECT**	**GENDER**	**SNR**	**TEST**	**MRT**	**SII**	**MRT**	**SII**
1	1	Female	0	FC	84	0.12	73	0.26
2	1	Female	-3	FC	72	0.05	44	0.16
3	1	Female	No Noise	LC	68	0.36	56	0.63
4	1	Female	-3	LC	28	0.08	28	0.13
5	1	Male	No Noise	FC	84	0.45	43	0.48
6	1	Male	-3	FC	76	0.07	35	0.09
7	1	Male	No Noise	LC	84	0.51	49	0.5
8	1	Male	-3	LC	64	0.07	39	0.1
9	1	Female	No Noise	TP	86	0.47	66	0.63
10	1	Female	-3	TP	76	0.07	57	0.13
11	1	Male	No Noise	TP	88	0.58	50	0.52
12	1	Male	-3	TP	72	0.08	47	0.1
13	2	Female	No Noise	FC	60	0.61	67	0.75
14	2	Female	-3	FC	68	0.06	68	0.16
15	2	Female	0	LC	80	0.2	60	0.27
16	2	Female	-3	LC	40	0.08	40	0.16
17	2	Male	No Noise	FC	60	0.73	52	0.42
18	2	Male	-3	FC	48	0.07	44	0.07
19	2	Male	0	LC	80	0.17	61	0.15
20	2	Male	-3	LC	28	0.07	35	0.1
21	2	Female	No Noise	TP	80	0.68	77	0.67
22	2	Female	-3	TP	48	0.07	51	0.14
23	2	Male	No Noise	TP	76	0.72	64	0.54
24	2	Male	-3	TP	46	0.08	53	0.09
25	3	Female	No Noise	FC	36	0.45	77	0.8
26	3	Female	0	FC	48	0.13	63	0.33
27	3	Female	0	LC	56	0.19	52	0.36
28	3	Female	-3	LC	20	0.07	32	0.24

					BEFORE SIMULATION		**AFTER SIMULATION**	
NO	**SUBJECT**	**GENDER**	**SNR**	**TEST**	**MRT**	**SII**	**MRT**	**SII**
29	3	Male	0	FC	56	0.16	52	0.18
30	3	Male	0	LC	64	0.17	61	0.19
31	3	Male	-3	LC	24	0.07	32	0.13
32	3	Female	0	TP	50	0.16	50	0.31
33	3	Female	-3	TP	42	0.08	63	0.21
34	3	Male	0	TP	58	0.17	57	0.22
35	4	Female	0	FC	64	0.16	69	0.12
36	4	Female	-3	FC	48	0.06	77	0.06
37	4	Female	No Noise	LC	88	0.79	73	0.42
38	4	Female	-3	LC	56	0.08	57	0.05
39	4	Male	0	FC	48	0.17	68	0.09
40	4	Male	No Noise	LC	80	0.78	73	0.4
41	4	Male	-3	LC	40	0.07	45	0.06
42	4	Female	0	TP	74	0.17	71	0.08
43	4	Female	-3	TP	66	0.07	70	0.05
44	4	Male	0	TP	76	0.17	68	0.09
45	5	Female	No Noise	FC	44	0.18	64	0.43
46	5	Female	0	FC	28	0.1	57	0.06
47	5	Female	No Noise	LC	56	0.24	61	0.37
48	5	Female	0	LC	16	0.17	25	0.05
49	5	Male	No Noise	FC	36	0.26	52	0.41
50	5	Male	0	FC	32	0.14	40	0.08
51	5	Male	No Noise	LC	44	0.3	43	0.39
52	5	Male	0	LC	12	0.15	39	0.08
53	5	Female	No Noise	TP	38	0.25	63	0.43
54	5	Female	0	TP	46	0.13	63	0.06
55	5	Male	No Noise	TP	46	0.33	58	0.4
56	5	Male	0	TP	36	0.15	49	0.06
57	6	Female	No Noise	FC	60	0.07	81	0.56
58	6	Female	0	FC	40	0.07	64	0.1
59	6	Female	0	LC	76	0.12	60	0.1
60	6	Female	-3	LC	36	0.06	52	0.05
61	6	Male	No Noise	FC	48	0.13	69	0.57
62	6	Male	0	FC	56	0.11	52	0.12
63	6	Male	0	LC	20	0.12	24	0.1
64	6	Male	-3	LC	20	0.06	24	0.06
65	6	Female	No Noise	TP	62	0.11	73	0.53
66	6	Female	0	TP	60	0.09	64	0.1
67	6	Male	No Noise	TP	52	0.18	69	0.55
68	6	Male	0	TP	60	0.13	47	0.11

					BEFORE SIMULATION		AFTER SIMULATION	
NO	**SUBJECT**	**GENDER**	**SNR**	**TEST**	**MRT**	**SII**	**MRT**	**SII**
69	7	Female	No Noise	FC	56	0.29	56	0.55
70	7	Female	No Noise	LC	68	0.35	61	0.4
71	7	Female	-3	LC	32	0.08	43	0.06
72	7	Male	No Noise	FC	60	0.36	63	0.57
73	7	Male	-3	FC	60	0.07	39	0.09
74	7	Male	No Noise	LC	84	0.39	51	0.45
75	7	Female	No Noise	TP	78	0.36	69	0.44
76	7	Female	-3	TP	60	0.07	60	0.06
77	7	Male	No Noise	TP	52	0.43	55	0.47
78	7	Male	-3	TP	48	0.08	47	0.08
79	8	Female	No Noise	FC	60	0.42	76	0.52
80	8	Female	No Noise	LC	68	0.5	65	0.43
81	8	Female	-3	LC	44	0.08	43	0.04
82	8	Male	No Noise	FC	84	0.57	71	0.26
83	8	Male	-3	FC	64	0.07	49	0.03
84	8	Male	No Noise	LC	88	0.62	72	0.28
85	8	Female	0	TP	60	0.16	63	0.07
86	8	Female	-3	TP	62	0.07	65	0.03
87	8	Male	No Noise	TP	76	0.62	67	0.3
88	8	Male	-3	TP	58	0.08	53	0.03
89	9	Female	0	FC	68	0.15	67	0.09
90	9	Female	-3	FC	60	0.06	61	0.05
91	9	Female	0	LC	88	0.2	65	0.07
92	9	Male	0	FC	76	0.17	63	0.12
93	9	Male	-3	FC	72	0.07	48	0.07
94	9	Male	No Noise	LC	72	0.71	53	0.46
95	9	Male	0	LC	76	0.17	49	0.11
96	9	Female	0	TP	88	0.17	71	0.07
97	9	Male	0	TP	90	0.17	56	0.1
98	9	Male	-3	TP	60	0.08	47	0.06
99	10	Female	No Noise	FC	68	0.42	89	0.53
100	10	Female	0	FC	60	0.12	57	0.13
101	10	Female	0	LC	60	0.19	68	0.1
102	10	Male	0	FC	68	0.16	65	0.13
103	10	Male	-3	FC	64	0.07	44	0.07
104	10	Male	No Noise	LC	48	0.66	68	0.54
105	10	Male	0	LC	32	0.17	37	0.14
106	10	Female	0	TP	52	0.15	76	0.1
107	10	Male	0	TP	52	0.17	60	0.13
108	10	Male	-3	TP	44	0.08	49	0.07

					BEFORE SIMULATION		**AFTER SIMULATION**	
NO	**SUBJECT**	**GENDER**	**SNR**	**TEST**	**MRT**	**SII**	**MRT**	**SII**
109	11	Female	-3	FC	56	0.06	59	0.05
110	11	Female	No Noise	LC	96	0.66	61	0.4
111	11	Male	0	FC	72	0.17	53	0.11
112	11	Male	0	LC	52	0.17	48	0.12
113	11	Male	-3	LC	60	0.07	55	0.07
114	11	Female	No Noise	TP	80	0.68	78	0.38
115	11	Female	-3	TP	64	0.07	65	0.04
116	11	Male	No Noise	TP	76	0.73	79	0.47
117	11	Male	0	TP	68	0.17	61	0.1
118	12	Female	-3	FC	32	0.06	56	0.04
119	12	Female	No Noise	LC	80	0.43	56	0.37
120	12	Female	0	LC	52	0.16	59	0.08
121	12	Male	No Noise	FC	48	0.47	75	0.35
122	12	Male	-3	FC	36	0.07	57	0.04
123	12	Male	-3	LC	20	0.07	47	0.04
124	12	Female	No Noise	TP	70	0.43	81	0.37
125	12	Male	-3	TP	66	0.08	55	0.04

APPENDIX B: The Results of SII and MRT of Turkish Phonetics in Experiment II

No	SUBJECT	GENDER	SNR	PHONETIC	MRT	SII
1	1	Female	No Noise	Compactness	9	0.32
2	1	Female	-3	Compactness	8	0.16
3	1	Female	No Noise	Sustention	9	0.43
4	1	Female	-3	Sustention	8	0.27
5	1	Female	No Noise	Sibilation	10	0.61
6	1	Female	-3	Sibilation	7	0.31
7	1	Female	No Noise	Nasality	7	0.43
8	1	Female	-3	Nasality	8	0.47
9	1	Female	No Noise	Graveness	8	0.40
10	1	Female	-3	Graveness	6	0.31
11	1	Male	No Noise	Compactness	8	0.02
12	1	Male	-3	Compactness	5	0
13	1	Male	No Noise	Sustention	8	0
14	1	Male	-3	Sustention	9	0.03
15	1	Male	No Noise	Sibilation	9	0.03
16	1	Male	-3	Sibilation	6	0.23
17	1	Male	No Noise	Nasality	10	0.08
18	1	Male	-3	Nasality	8	0.35
19	1	Male	No Noise	Graveness	9	0.20
20	1	Male	-3	Graveness	8	0.29
21	2	Female	No Noise	Compactness	9	0.44
22	2	Female	-3	Compactness	5	0.30
23	2	Female	No Noise	Sustention	9	0.32
24	2	Female	-3	Sustention	4	0.20
25	2	Female	No Noise	Sibilation	7	0.37
26	2	Female	-3	Sibilation	5	0.24
27	2	Female	No Noise	Nasality	8	0.34
28	2	Female	-3	Nasality	4	0.17
29	2	Female	No Noise	Graveness	7	0.38
30	2	Female	-3	Graveness	5	0.24
31	2	Male	No Noise	Compactness	10	0.18
32	2	Male	-3	Compactness	6	0.42
33	2	Male	No Noise	Sustention	5	0.29
34	2	Male	-3	Sustention	2	0.29
35	2	Male	No Noise	Sibilation	8	0.17
36	2	Male	-3	Sibilation	2	0.23
37	2	Male	No Noise	Nasality	6	0.14

No	SUBJECT	GENDER	SNR	PHONETIC	MRT	SII
38	2	Male	-3	Nasality	7	0.24
39	2	Male	No Noise	Graveness	9	0.12
40	2	Male	-3	Graveness	7	0.27
41	3	Female	0	Compactness	5	0.90
42	3	Female	-3	Compactness	4	0.21
43	3	Female	0	Sustention	5	0.88
44	3	Female	-3	Sustention	4	0.33
45	3	Female	0	Sibilation	6	0.88
46	3	Female	-3	Sibilation	5	0.39
47	3	Female	0	Nasality	4	0.87
48	3	Female	-3	Nasality	4	0.51
49	3	Female	0	Graveness	5	0.87
50	3	Female	-3	Graveness	3	0.39
51	3	Male	0	Compactness	8	0.16
52	3	Male	0	Sustention	4	0.26
53	3	Male	0	Sibilation	6	0.09
54	3	Male	0	Nasality	7	0.29
55	3	Male	0	Graveness	5	0.16
56	4	Female	0	Compactness	8	0.87
57	4	Female	-3	Compactness	9	0.39
58	4	Female	0	Sustention	7	0.88
59	4	Female	-3	Sustention	6	0.25
60	4	Female	0	Sibilation	6	0.89
61	4	Female	-3	Sibilation	7	0.29
62	4	Female	0	Nasality	9	0.90
63	4	Female	-3	Nasality	7	0.22
64	4	Female	0	Graveness	7	0.87
65	4	Female	-3	Graveness	5	0.28
66	4	Male	0	Compactness	9	0.36
67	4	Male	0	Sustention	5	0.20
68	4	Male	0	Sibilation	8	0.57
69	4	Male	0	Nasality	8	0.31
70	4	Male	0	Graveness	9	0.48
71	5	Female	No Noise	Compactness	6	0.45
72	5	Female	0	Compactness	6	0.21
73	5	Female	No Noise	Sustention	4	0.59
74	5	Female	0	Sustention	1	0.56
75	5	Female	No Noise	Sibilation	1	0.39
76	5	Female	0	Sibilation	4	0.66
77	5	Female	No Noise	Nasality	4	0.58
78	5	Female	0	Nasality	6	0.39
79	5	Female	No Noise	Graveness	4	0.58

No	SUBJECT	GENDER	SNR	PHONETIC	MRT	SII
80	5	Female	0	Graveness	6	0.49
81	5	Male	No Noise	Compactness	4	0.38
82	5	Male	0	Compactness	4	0.74
83	5	Male	No Noise	Sustention	3	0.51
84	5	Male	0	Sustention	3	0.48
85	5	Male	No Noise	Sibilation	4	0.37
86	5	Male	0	Sibilation	2	0.54
87	5	Male	No Noise	Nasality	5	0.37
88	5	Male	0	Nasality	3	0.38
89	5	Male	No Noise	Graveness	7	0.24
90	5	Male	0	Graveness	6	0.49
91	6	Female	No Noise	Compactness	5	0.25
92	6	Female	0	Compactness	6	0.53
93	6	Female	No Noise	Sustention	6	0.47
94	6	Female	0	Sustention	3	0.22
95	6	Female	No Noise	Sibilation	8	0.49
96	6	Female	0	Sibilation	5	0.47
97	6	Female	No Noise	Nasality	6	0.21
98	6	Female	0	Nasality	8	0.60
99	6	Female	No Noise	Graveness	7	0.57
100	6	Female	0	Graveness	7	0.39
101	6	Male	No Noise	Compactness	5	0.27
102	6	Male	0	Compactness	4	0.38
103	6	Male	No Noise	Sustention	3	0.21
104	6	Male	0	Sustention	2	0.48
105	6	Male	No Noise	Sibilation	6	0.27
106	6	Male	0	Sibilation	5	0.33
107	6	Male	No Noise	Nasality	7	0.42
108	6	Male	0	Nasality	10	0.27
109	6	Male	No Noise	Graveness	6	0.42
110	6	Male	0	Graveness	9	0.58
111	7	Female	No Noise	Compactness	8	0.67
112	7	Female	-3	Compactness	7	0.59
113	7	Female	No Noise	Sustention	6	0.39
114	7	Female	-3	Sustention	6	0.60
115	7	Female	No Noise	Sibilation	10	0.50
116	7	Female	-3	Sibilation	6	0.25
117	7	Female	No Noise	Nasality	7	0.54
118	7	Female	-3	Nasality	7	0.49
119	7	Female	No Noise	Graveness	8	0.22
120	7	Female	-3	Graveness	4	0.51
121	7	Male	No Noise	Compactness	4	0.47

No	SUBJECT	GENDER	SNR	PHONETIC	MRT	SII
122	7	Male	-3	Compactness	5	0.41
123	7	Male	No Noise	Sustention	8	0.39
124	7	Male	-3	Sustention	2	0.31
125	7	Male	No Noise	Sibilation	7	0.33
126	7	Male	-3	Sibilation	5	0.37
127	7	Male	No Noise	Nasality	4	0.25
128	7	Male	-3	Nasality	5	0.35
129	7	Male	No Noise	Graveness	4	0.36
130	7	Male	-3	Graveness	7	0.25
131	8	Female	0	Compactness	5	0.04
132	8	Female	-3	Compactness	6	0.02
133	8	Female	0	Sustention	7	0.15
134	8	Female	-3	Sustention	7	0.13
135	8	Female	0	Sibilation	4	0.06
136	8	Female	-3	Sibilation	4	0.04
137	8	Female	0	Nasality	6	0.12
138	8	Female	-3	Nasality	6	0.10
139	8	Female	0	Graveness	8	0.07
140	8	Female	-3	Graveness	9	0.05
141	8	Male	No Noise	Compactness	7	0.27
142	8	Male	-3	Compactness	6	0.37
143	8	Male	No Noise	Sustention	8	0.28
144	8	Male	-3	Sustention	6	0.40
145	8	Male	No Noise	Sibilation	9	0.55
146	8	Male	-3	Sibilation	4	0.48
147	8	Male	No Noise	Nasality	5	0.41
148	8	Male	-3	Nasality	6	0.41
149	8	Male	No Noise	Graveness	8	0.33
150	8	Male	-3	Graveness	8	0.30
151	9	Female	0	Compactness	9	0.08
152	9	Female	0	Sustention	8	0.06
153	9	Female	0	Sibilation	10	0.04
154	9	Female	0	Nasality	9	0.03
155	9	Female	0	Graveness	8	0.11
156	9	Male	0	Compactness	10	0.35
157	9	Male	-3	Compactness	6	0.27
158	9	Male	0	Sustention	7	0.29
159	9	Male	-3	Sustention	6	0.34
160	9	Male	0	Sibilation	10	0.26
161	9	Male	-3	Sibilation	6	0.61
162	9	Male	0	Nasality	8	0.21
163	9	Male	-3	Nasality	6	0.63

No	SUBJECT	GENDER	SNR	PHONETIC	MRT	SII
164	9	Male	0	Graveness	10	0.54
165	9	Male	-3	Graveness	7	0.72
166	10	Female	0	Compactness	8	0.09
167	10	Female	0	Sustention	4	0.05
168	10	Female	0	Sibilation	6	0.02
169	10	Female	0	Nasality	4	0.12
170	10	Female	0	Graveness	4	0.10
171	10	Male	0	Compactness	5	0.39
172	10	Male	-3	Compactness	4	0.77
173	10	Male	0	Sustention	4	0.65
174	10	Male	-3	Sustention	3	0.68
175	10	Male	0	Sibilation	7	0.39
176	10	Male	-3	Sibilation	6	0.62
177	10	Male	0	Nasality	7	0.53
178	10	Male	-3	Nasality	4	0.59
179	10	Male	0	Graveness	4	0.25
180	10	Male	-3	Graveness	6	0.56
181	11	Female	No Noise	Compactness	8	0
182	11	Female	-3	Compactness	7	0
183	11	Female	No Noise	Sustention	8	0.03
184	11	Female	-3	Sustention	7	0.03
185	11	Female	No Noise	Sibilation	10	0
186	11	Female	-3	Sibilation	7	0
187	11	Female	No Noise	Nasality	6	0.01
188	11	Female	-3	Nasality	7	0.01
189	11	Female	No Noise	Graveness	8	0
190	11	Female	-3	Graveness	5	0
191	11	Male	No Noise	Compactness	8	0.47
192	11	Male	0	Compactness	7	0.60
193	11	Male	No Noise	Sustention	7	0.22
194	11	Male	0	Sustention	6	0.55
195	11	Male	No Noise	Sibilation	9	0.44
196	11	Male	0	Sibilation	6	0.39
197	11	Male	No Noise	Nasality	7	0.18
198	11	Male	0	Nasality	7	0.54
199	11	Male	No Noise	Graveness	7	0.36
200	11	Male	0	Graveness	8	0.53
201	12	Female	No Noise	Compactness	9	0.02
202	12	Female	No Noise	Sustention	2	0.02
203	12	Female	No Noise	Sibilation	6	0
204	12	Female	No Noise	Nasality	9	0
205	12	Female	No Noise	Graveness	7	0.02

No	SUBJECT	GENDER	SNR	PHONETIC	MRT	SII
206	12	Male	-3	Compactness	7	0.21
207	12	Male	-3	Sustention	5	0.41
208	12	Male	-3	Sibilation	7	0.12
209	12	Male	-3	Nasality	7	0.39
210	12	Male	-3	Graveness	9	0.15

APPENDIX C: The Results of Intelligibility Increments of Each Method in Experiment III

NO	SUBJECT	PROCESSING METHOD	NOISE	GENDER	SII (Unprocessed)	SII (Processed)	IMP.
1	1	A	No Noise	Female	0.24	0.45	0.21
2	1	A	No Noise	Male	0.24	0.63	0.39
3	1	A	High Frequency	Female	0.09	0.12	0.03
4	1	A	High Frequency	Male	0.08	0.15	0.07
5	1	A	Restaurant	Female	0.08	0.03	-0.05
6	1	A	Restaurant	Male	0.08	0.04	-0.04
7	1	A	Music	Female	0.14	0.13	-0.01
8	1	A	Music	Male	0.13	0.22	0.09
9	1	A	Traffic	Female	0.07	0.09	0.02
10	1	A	Traffic	Male	0.07	0.11	0.04
11	1	A_FS	No Noise	Female	0.24	0.59	0.35
12	1	A_FS	No Noise	Male	0.24	0.61	0.37
13	1	A_FS	High Frequency	Female	0.09	0.23	0.14
14	1	A_FS	High Frequency	Male	0.08	0.22	0.14
15	1	A_FS	Restaurant	Female	0.08	0.20	0.12
16	1	A_FS	Restaurant	Male	0.08	0.19	0.11
17	1	A_FS	Music	Female	0.14	0.21	0.07
18	1	A_FS	Music	Male	0.13	0.20	0.07
19	1	A_FS	Traffic	Female	0.07	0.21	0.14
20	1	A_FS	Traffic	Male	0.07	0.21	0.14
21	1	A_FT	No Noise	Female	0.24	0.55	0.31
22	1	A_FT	No Noise	Male	0.24	0.61	0.37
23	1	A_FT	High Frequency	Female	0.09	0.23	0.14
24	1	A_FT	High Frequency	Male	0.08	0.22	0.14
25	1	A_FT	Restaurant	Female	0.08	0.19	0.11
26	1	A_FT	Restaurant	Male	0.08	0.19	0.11
27	1	A_FT	Music	Female	0.14	0.21	0.07
28	1	A_FT	Music	Male	0.13	0.19	0.06
29	1	A_FT	Traffic	Female	0.07	0.20	0.13
30	1	A_FT	Traffic	Male	0.07	0.20	0.13
31	1	A_NLC	No Noise	Female	0.24	0.57	0.33

NO	**SUBJECT**	**PROCESSING METHOD**	**NOISE**	**GENDER**	**SII (Unprocessed)**	**SII (Processed)**	**IMP.**
32	1	A_NLC	No Noise	Male	0.24	0.61	0.37
33	1	A_NLC	High Frequency	Female	0.09	0.23	0.14
34	1	A_NLC	High Frequency	Male	0.08	0.21	0.13
35	1	A_NLC	Restaurant	Female	0.08	0.18	0.10
36	1	A_NLC	Restaurant	Male	0.08	0.18	0.10
37	1	A_NLC	Music	Female	0.14	0.20	0.06
38	1	A_NLC	Music	Male	0.13	0.19	0.06
39	1	A_NLC	Traffic	Female	0.07	0.20	0.13
40	1	A_NLC	Traffic	Male	0.07	0.20	0.13
41	1	FS	No Noise	Female	0.24	0.75	0.51
42	1	FS	No Noise	Male	0.24	0.75	0.51
43	1	FS	High Frequency	Female	0.09	0.24	0.15
44	1	FS	High Frequency	Male	0.08	0.24	0.16
45	1	FS	Restaurant	Female	0.08	0.25	0.17
46	1	FS	Restaurant	Male	0.08	0.24	0.16
47	1	FS	Music	Female	0.14	0.33	0.19
48	1	FS	Music	Male	0.13	0.30	0.17
49	1	FS	Traffic	Female	0.07	0.24	0.17
50	1	FS	Traffic	Male	0.07	0.22	0.15
51	1	FT	No Noise	Female	0.24	0.75	0.51
52	1	FT	No Noise	Male	0.24	0.75	0.51
53	1	FT	High Frequency	Female	0.09	0.25	0.16
54	1	FT	High Frequency	Male	0.08	0.23	0.15
55	1	FT	Restaurant	Female	0.08	0.18	0.10
56	1	FT	Restaurant	Male	0.08	0.22	0.14
57	1	FT	Music	Female	0.14	0.25	0.11
58	1	FT	Music	Male	0.13	0.30	0.17
59	1	FT	Traffic	Female	0.07	0.21	0.14
60	1	FT	Traffic	Male	0.07	0.21	0.14
61	1	NLC	No Noise	Female	0.24	0.74	0.50
62	1	NLC	No Noise	Male	0.24	0.74	0.50
63	1	NLC	High Frequency	Female	0.09	0.31	0.22
64	1	NLC	High Frequency	Male	0.08	0.31	0.23
65	1	NLC	Restaurant	Female	0.08	0.33	0.25
66	1	NLC	Restaurant	Male	0.08	0.32	0.24
67	1	NLC	Music	Female	0.14	0.41	0.27

NO	SUBJECT	PROCESSING METHOD	NOISE	GENDER	SII (Unprocessed)	SII (Processed)	IMP.
68	1	NLC	Music	Male	0.13	0.43	0.30
69	1	NLC	Traffic	Female	0.07	0.29	0.22
70	1	NLC	Traffic	Male	0.07	0.29	0.22
71	1	A_NLC_FT	No Noise	Female	0.24	0.58	0.34
72	1	A_NLC_FT	No Noise	Male	0.24	0.59	0.35
73	1	A_NLC_FT	High Frequency	Female	0.09	0.24	0.15
74	1	A_NLC_FT	High Frequency	Male	0.08	0.22	0.14
75	1	A_NLC_FT	Restaurant	Female	0.08	0.20	0.12
76	1	A_NLC_FT	Restaurant	Male	0.08	0.18	0.10
77	1	A_NLC_FT	Music	Female	0.14	0.22	0.08
78	1	A_NLC_FT	Music	Male	0.13	0.19	0.06
79	1	A_NLC_FT	Traffic	Female	0.07	0.21	0.14
80	1	A_NLC_FT	Traffic	Male	0.07	0.20	0.13
81	1	NLC_FT	No Noise	Female	0.24	0.76	0.52
82	1	NLC_FT	No Noise	Male	0.24	0.75	0.51
83	1	NLC_FT	High Frequency	Female	0.09	0.33	0.24
84	1	NLC_FT	High Frequency	Male	0.08	0.31	0.23
85	1	NLC_FT	Restaurant	Female	0.08	0.31	0.23
86	1	NLC_FT	Restaurant	Male	0.08	0.39	0.31
87	1	NLC_FT	Music	Female	0.14	0.49	0.35
88	1	NLC_FT	Music	Male	0.13	0.51	0.38
89	1	NLC_FT	Traffic	Female	0.07	0.28	0.21
90	1	NLC_FT	Traffic	Male	0.07	0.35	0.28
91	2	A	No Noise	Female	0.70	0.79	0.09
92	2	A	No Noise	Male	0.70	0.79	0.09
93	2	A	High Frequency	Female	0.20	0.12	-0.08
94	2	A	High Frequency	Male	0.18	0.15	-0.03
95	2	A	Restaurant	Female	0.22	0.04	-0.18
96	2	A	Restaurant	Male	0.20	0.04	-0.16
97	2	A	Music	Female	0.31	0.15	-0.16
98	2	A	Music	Male	0.28	0.23	-0.05
99	2	A	Traffic	Female	0.15	0.09	-0.06
100	2	A	Traffic	Male	0.13	0.11	-0.02
101	2	A_FS	No Noise	Female	0.70	0.76	0.06
102	2	A_FS	No Noise	Male	0.70	0.77	0.07
103	2	A_FS	High Frequency	Female	0.20	0.36	0.16

NO	SUBJECT	PROCESSING METHOD	NOISE	GENDER	SII (Unprocessed)	SII (Processed)	IMP.
104	2	A_FS	High Frequency	Male	0.18	0.35	0.17
105	2	A_FS	Restaurant	Female	0.22	0.27	0.05
106	2	A_FS	Restaurant	Male	0.20	0.30	0.10
107	2	A_FS	Music	Female	0.31	0.31	0.00
108	2	A_FS	Music	Male	0.28	0.33	0.05
109	2	A_FS	Traffic	Female	0.15	0.34	0.19
110	2	A_FS	Traffic	Male	0.13	0.35	0.22
111	2	A_FT	No Noise	Female	0.70	0.79	0.09
112	2	A_FT	No Noise	Male	0.70	0.75	0.05
113	2	A_FT	High Frequency	Female	0.20	0.38	0.18
114	2	A_FT	High Frequency	Male	0.18	0.36	0.18
115	2	A_FT	Restaurant	Female	0.22	0.26	0.04
116	2	A_FT	Restaurant	Male	0.20	0.31	0.11
117	2	A_FT	Music	Female	0.31	0.30	-0.01
118	2	A_FT	Music	Male	0.28	0.30	0.02
119	2	A_FT	Traffic	Female	0.15	0.37	0.22
120	2	A_FT	Traffic	Male	0.13	0.35	0.22
121	2	A_NLC	No Noise	Female	0.70	0.74	0.04
122	2	A_NLC	No Noise	Male	0.70	0.73	0.03
123	2	A_NLC	High Frequency	Female	0.20	0.37	0.17
124	2	A_NLC	High Frequency	Male	0.18	0.35	0.17
125	2	A_NLC	Restaurant	Female	0.22	0.27	0.05
126	2	A_NLC	Restaurant	Male	0.20	0.30	0.10
127	2	A_NLC	Music	Female	0.31	0.32	0.01
128	2	A_NLC	Music	Male	0.28	0.34	0.06
129	2	A_NLC	Traffic	Female	0.15	0.34	0.19
130	2	A_NLC	Traffic	Male	0.13	0.35	0.22
131	2	FS	No Noise	Female	0.70	0.79	0.09
132	2	FS	No Noise	Male	0.70	0.79	0.09
133	2	FS	High Frequency	Female	0.20	0.24	0.04
134	2	FS	High Frequency	Male	0.18	0.24	0.06
135	2	FS	Restaurant	Female	0.22	0.25	0.03
136	2	FS	Restaurant	Male	0.20	0.24	0.04
137	2	FS	Music	Female	0.31	0.34	0.03
138	2	FS	Music	Male	0.28	0.31	0.03
139	2	FS	Traffic	Female	0.15	0.24	0.09

NO	**SUBJECT**	**PROCESSING METHOD**	**NOISE**	**GENDER**	**SII (Unprocessed)**	**SII (Processed)**	**IMP.**
140	2	FS	Traffic	Male	0.13	0.22	0.09
141	2	FT	No Noise	Female	0.70	0.81	0.11
142	2	FT	No Noise	Male	0.70	0.78	0.08
143	2	FT	High Frequency	Female	0.20	0.25	0.05
144	2	FT	High Frequency	Male	0.18	0.23	0.05
145	2	FT	Restaurant	Female	0.22	0.18	-0.04
146	2	FT	Restaurant	Male	0.20	0.22	0.02
147	2	FT	Music	Female	0.31	0.26	-0.05
148	2	FT	Music	Male	0.28	0.30	0.02
149	2	FT	Traffic	Female	0.15	0.21	0.06
150	2	FT	Traffic	Male	0.13	0.21	0.08
151	2	NLC	No Noise	Female	0.70	0.77	0.07
152	2	NLC	No Noise	Male	0.70	0.76	0.06
153	2	NLC	High Frequency	Female	0.20	0.31	0.11
154	2	NLC	High Frequency	Male	0.18	0.32	0.14
155	2	NLC	Restaurant	Female	0.22	0.33	0.11
156	2	NLC	Restaurant	Male	0.20	0.32	0.12
157	2	NLC	Music	Female	0.31	0.42	0.11
158	2	NLC	Music	Male	0.28	0.43	0.15
159	2	NLC	Traffic	Female	0.15	0.29	0.14
160	2	NLC	Traffic	Male	0.13	0.30	0.17
161	2	A_NLC_FT	No Noise	Female	0.70	0.84	0.14
162	2	A_NLC_FT	No Noise	Male	0.70	0.78	0.08
163	2	A_NLC_FT	High Frequency	Female	0.20	0.37	0.17
164	2	A_NLC_FT	High Frequency	Male	0.18	0.35	0.17
165	2	A_NLC_FT	Restaurant	Female	0.22	0.28	0.06
166	2	A_NLC_FT	Restaurant	Male	0.20	0.29	0.09
167	2	A_NLC_FT	Music	Female	0.31	0.27	-0.04
168	2	A_NLC_FT	Music	Male	0.28	0.31	0.03
169	2	A_NLC_FT	Traffic	Female	0.15	0.32	0.17
170	2	A_NLC_FT	Traffic	Male	0.13	0.32	0.19
171	2	NLC_FT	No Noise	Female	0.70	0.88	0.18
172	2	NLC_FT	No Noise	Male	0.70	0.81	0.11
173	2	NLC_FT	High Frequency	Female	0.20	0.35	0.15
174	2	NLC_FT	High Frequency	Male	0.18	0.33	0.15
175	2	NLC_FT	Restaurant	Female	0.22	0.31	0.09

NO	SUBJECT	PROCESSING METHOD	NOISE	GENDER	SII (Unprocessed)	SII (Processed)	IMP.
176	2	NLC_FT	Restaurant	Male	0.20	0.40	0.20
177	2	NLC_FT	Music	Female	0.31	0.49	0.18
178	2	NLC_FT	Music	Male	0.28	0.52	0.24
179	2	NLC_FT	Traffic	Female	0.15	0.31	0.16
180	2	NLC_FT	Traffic	Male	0.13	0.34	0.21
181	3	A	No Noise	Female	0.53	0.60	0.07
182	3	A	No Noise	Male	0.53	0.69	0.16
183	3	A	High Frequency	Female	0.10	0.12	0.02
184	3	A	High Frequency	Male	0.08	0.15	0.07
185	3	A	Restaurant	Female	0.08	0.03	-0.05
186	3	A	Restaurant	Male	0.08	0.04	-0.04
187	3	A	Music	Female	0.23	0.11	-0.12
188	3	A	Music	Male	0.21	0.19	-0.02
189	3	A	Traffic	Female	0.15	0.09	-0.06
190	3	A	Traffic	Male	0.13	0.11	-0.02
191	3	A_FS	No Noise	Female	0.53	0.72	0.19
192	3	A_FS	No Noise	Male	0.53	0.71	0.18
193	3	A_FS	High Frequency	Female	0.10	0.18	0.08
194	3	A_FS	High Frequency	Male	0.08	0.17	0.09
195	3	A_FS	Restaurant	Female	0.08	0.21	0.13
196	3	A_FS	Restaurant	Male	0.08	0.19	0.11
197	3	A_FS	Music	Female	0.23	0.22	-0.01
198	3	A_FS	Music	Male	0.21	0.21	0.00
199	3	A_FS	Traffic	Female	0.15	0.20	0.05
200	3	A_FS	Traffic	Male	0.13	0.19	0.06
201	3	A_FT	No Noise	Female	0.53	0.70	0.17
202	3	A_FT	No Noise	Male	0.53	0.71	0.18
203	3	A_FT	High Frequency	Female	0.10	0.17	0.07
204	3	A_FT	High Frequency	Male	0.08	0.18	0.10
205	3	A_FT	Restaurant	Female	0.08	0.15	0.07
206	3	A_FT	Restaurant	Male	0.08	0.18	0.10
207	3	A_FT	Music	Female	0.23	0.19	-0.04
208	3	A_FT	Music	Male	0.21	0.21	0.00
209	3	A_FT	Traffic	Female	0.15	0.15	0.00
210	3	A_FT	Traffic	Male	0.13	0.15	0.02
211	3	A_NLC	No Noise	Female	0.53	0.70	0.17
212	3	A_NLC	No Noise	Male	0.53	0.71	0.18

NO	SUBJECT	PROCESSING METHOD	NOISE	GENDER	SII (Unprocessed)	SII (Processed)	IMP.
213	3	A_NLC	High Frequency	Female	0.10	0.17	0.07
214	3	A_NLC	High Frequency	Male	0.08	0.17	0.09
215	3	A_NLC	Restaurant	Female	0.08	0.20	0.12
216	3	A_NLC	Restaurant	Male	0.08	0.18	0.10
217	3	A_NLC	Music	Female	0.23	0.22	-0.01
218	3	A_NLC	Music	Male	0.21	0.24	0.03
219	3	A_NLC	Traffic	Female	0.15	0.18	0.03
220	3	A_NLC	Traffic	Male	0.13	0.16	0.03
221	3	FS	No Noise	Female	0.53	0.77	0.24
222	3	FS	No Noise	Male	0.53	0.75	0.22
223	3	FS	High Frequency	Female	0.10	0.24	0.14
224	3	FS	High Frequency	Male	0.08	0.24	0.16
225	3	FS	Restaurant	Female	0.08	0.25	0.17
226	3	FS	Restaurant	Male	0.08	0.24	0.16
227	3	FS	Music	Female	0.23	0.32	0.09
228	3	FS	Music	Male	0.21	0.29	0.08
229	3	FS	Traffic	Female	0.15	0.24	0.09
230	3	FS	Traffic	Male	0.13	0.22	0.09
231	3	FT	No Noise	Female	0.53	0.76	0.23
232	3	FT	No Noise	Male	0.53	0.73	0.20
233	3	FT	High Frequency	Female	0.10	0.25	0.15
234	3	FT	High Frequency	Male	0.08	0.23	0.15
235	3	FT	Restaurant	Female	0.08	0.18	0.10
236	3	FT	Restaurant	Male	0.08	0.22	0.14
237	3	FT	Music	Female	0.23	0.25	0.02
238	3	FT	Music	Male	0.21	0.29	0.08
239	3	FT	Traffic	Female	0.15	0.21	0.06
240	3	FT	Traffic	Male	0.13	0.21	0.08
241	3	NLC	No Noise	Female	0.53	0.74	0.21
242	3	NLC	No Noise	Male	0.53	0.71	0.18
243	3	NLC	High Frequency	Female	0.10	0.31	0.21
244	3	NLC	High Frequency	Male	0.08	0.32	0.24
245	3	NLC	Restaurant	Female	0.08	0.33	0.25
246	3	NLC	Restaurant	Male	0.08	0.32	0.24
247	3	NLC	Music	Female	0.23	0.41	0.18
248	3	NLC	Music	Male	0.21	0.43	0.22

NO	SUBJECT	PROCESSING METHOD	NOISE	GENDER	SII (Unprocessed)	SII (Processed)	IMP.
249	3	NLC	Traffic	Female	0.15	0.29	0.14
250	3	NLC	Traffic	Male	0.13	0.30	0.17
251	3	A_NLC_FT	No Noise	Female	0.53	0.71	0.18
252	3	A_NLC_FT	No Noise	Male	0.53	0.70	0.17
253	3	A_NLC_FT	High Frequency	Female	0.10	0.18	0.08
254	3	A_NLC_FT	High Frequency	Male	0.08	0.17	0.09
255	3	A_NLC_FT	Restaurant	Female	0.08	0.22	0.14
256	3	A_NLC_FT	Restaurant	Male	0.08	0.20	0.12
257	3	A_NLC_FT	Music	Female	0.23	0.23	0.00
258	3	A_NLC_FT	Music	Male	0.21	0.21	0.00
259	3	A_NLC_FT	Traffic	Female	0.15	0.21	0.06
260	3	A_NLC_FT	Traffic	Male	0.13	0.19	0.06
261	3	NLC_FT	No Noise	Female	0.53	0.82	0.29
262	3	NLC_FT	No Noise	Male	0.53	0.75	0.22
263	3	NLC_FT	High Frequency	Female	0.10	0.34	0.24
264	3	NLC_FT	High Frequency	Male	0.08	0.32	0.24
265	3	NLC_FT	Restaurant	Female	0.08	0.31	0.23
266	3	NLC_FT	Restaurant	Male	0.08	0.38	0.30
267	3	NLC_FT	Music	Female	0.23	0.49	0.26
268	3	NLC_FT	Music	Male	0.21	0.50	0.29
269	3	NLC_FT	Traffic	Female	0.15	0.29	0.14
270	3	NLC_FT	Traffic	Male	0.13	0.32	0.19
271	4	A	No Noise	Female	0.89	0.87	-0.02
272	4	A	No Noise	Male	0.89	0.84	-0.05
273	4	A	High Frequency	Female	0.16	0.12	-0.04
274	4	A	High Frequency	Male	0.15	0.15	0.00
275	4	A	Restaurant	Female	0.14	0.04	-0.10
276	4	A	Restaurant	Male	0.14	0.05	-0.09
277	4	A	Music	Female	0.39	0.18	-0.21
278	4	A	Music	Male	0.34	0.25	-0.09
279	4	A	Traffic	Female	0.26	0.09	-0.17
280	4	A	Traffic	Male	0.24	0.11	-0.13
281	4	A_FS	No Noise	Female	0.89	0.81	-0.08
282	4	A_FS	No Noise	Male	0.89	0.78	-0.11
283	4	A_FS	High Frequency	Female	0.16	0.32	0.16
284	4	A_FS	High Frequency	Male	0.15	0.32	0.17

NO	SUBJECT	PROCESSING METHOD	NOISE	GENDER	SII (Unprocessed)	SII (Processed)	IMP.
285	4	A_FS	Restaurant	Female	0.14	0.24	0.10
286	4	A_FS	Restaurant	Male	0.14	0.25	0.11
287	4	A_FS	Music	Female	0.39	0.28	-0.11
288	4	A_FS	Music	Male	0.34	0.29	-0.05
289	4	A_FS	Traffic	Female	0.26	0.30	0.04
290	4	A_FS	Traffic	Male	0.24	0.30	0.06
291	4	A_FT	No Noise	Female	0.89	0.81	-0.08
292	4	A_FT	No Noise	Male	0.89	0.76	-0.13
293	4	A_FT	High Frequency	Female	0.16	0.33	0.17
294	4	A_FT	High Frequency	Male	0.15	0.33	0.18
295	4	A_FT	Restaurant	Female	0.14	0.21	0.07
296	4	A_FT	Restaurant	Male	0.14	0.27	0.13
297	4	A_FT	Music	Female	0.39	0.27	-0.12
298	4	A_FT	Music	Male	0.34	0.28	-0.06
299	4	A_FT	Traffic	Female	0.26	0.30	0.04
300	4	A_FT	Traffic	Male	0.24	0.32	0.08
301	4	A_NLC	No Noise	Female	0.89	0.78	-0.11
302	4	A_NLC	No Noise	Male	0.89	0.74	-0.15
303	4	A_NLC	High Frequency	Female	0.16	0.32	0.16
304	4	A_NLC	High Frequency	Male	0.15	0.33	0.18
305	4	A_NLC	Restaurant	Female	0.14	0.23	0.09
306	4	A_NLC	Restaurant	Male	0.14	0.26	0.12
307	4	A_NLC	Music	Female	0.39	0.30	-0.09
308	4	A_NLC	Music	Male	0.34	0.32	-0.02
309	4	A_NLC	Traffic	Female	0.26	0.30	0.04
310	4	A_NLC	Traffic	Male	0.24	0.32	0.08
311	4	FS	No Noise	Female	0.89	0.83	-0.06
312	4	FS	No Noise	Male	0.89	0.80	-0.09
313	4	FS	High Frequency	Female	0.16	0.24	0.08
314	4	FS	High Frequency	Male	0.15	0.24	0.09
315	4	FS	Restaurant	Female	0.14	0.25	0.11
316	4	FS	Restaurant	Male	0.14	0.24	0.10
317	4	FS	Music	Female	0.39	0.35	-0.04
318	4	FS	Music	Male	0.34	0.31	-0.03
319	4	FS	Traffic	Female	0.26	0.24	-0.02
320	4	FS	Traffic	Male	0.24	0.22	-0.02
321	4	FT	No Noise	Female	0.89	0.82	-0.07

NO	SUBJECT	PROCESSING METHOD	NOISE	GENDER	SII (Unprocessed)	SII (Processed)	IMP.
322	4	FT	No Noise	Male	0.89	0.80	-0.09
323	4	FT	High Frequency	Female	0.16	0.25	0.09
324	4	FT	High Frequency	Male	0.15	0.23	0.08
325	4	FT	Restaurant	Female	0.14	0.18	0.04
326	4	FT	Restaurant	Male	0.14	0.22	0.08
327	4	FT	Music	Female	0.39	0.26	-0.13
328	4	FT	Music	Male	0.34	0.30	-0.04
329	4	FT	Traffic	Female	0.26	0.21	-0.05
330	4	FT	Traffic	Male	0.24	0.21	-0.03
331	4	NLC	No Noise	Female	0.89	0.78	-0.11
332	4	NLC	No Noise	Male	0.89	0.76	-0.13
333	4	NLC	High Frequency	Female	0.16	0.31	0.15
334	4	NLC	High Frequency	Male	0.15	0.31	0.16
335	4	NLC	Restaurant	Female	0.14	0.33	0.19
336	4	NLC	Restaurant	Male	0.14	0.32	0.18
337	4	NLC	Music	Female	0.39	0.42	0.03
338	4	NLC	Music	Male	0.34	0.43	0.09
339	4	NLC	Traffic	Female	0.26	0.30	0.04
340	4	NLC	Traffic	Male	0.24	0.30	0.06
341	4	A_NLC_FT	No Noise	Female	0.89	0.87	-0.02
342	4	A_NLC_FT	No Noise	Male	0.89	0.81	-0.08
343	4	A_NLC_FT	High Frequency	Female	0.16	0.29	0.13
344	4	A_NLC_FT	High Frequency	Male	0.15	0.31	0.16
345	4	A_NLC_FT	Restaurant	Female	0.14	0.25	0.11
346	4	A_NLC_FT	Restaurant	Male	0.14	0.24	0.10
347	4	A_NLC_FT	Music	Female	0.39	0.29	-0.10
348	4	A_NLC_FT	Music	Male	0.34	0.32	-0.02
349	4	A_NLC_FT	Traffic	Female	0.26	0.28	0.02
350	4	A_NLC_FT	Traffic	Male	0.24	0.28	0.04
351	4	NLC_FT	No Noise	Female	0.89	0.91	0.02
352	4	NLC_FT	No Noise	Male	0.89	0.85	-0.04
353	4	NLC_FT	High Frequency	Female	0.16	0.36	0.20
354	4	NLC_FT	High Frequency	Male	0.15	0.33	0.18
355	4	NLC_FT	Restaurant	Female	0.14	0.32	0.18
356	4	NLC_FT	Restaurant	Male	0.14	0.41	0.27
357	4	NLC_FT	Music	Female	0.39	0.49	0.10

NO	SUBJECT	PROCESSING METHOD	NOISE	GENDER	SII (Unprocessed)	SII (Processed)	IMP.
358	4	NLC_FT	Music	Male	0.34	0.52	0.18
359	4	NLC_FT	Traffic	Female	0.26	0.32	0.06
360	4	NLC_FT	Traffic	Male	0.24	0.34	0.10
361	5	A	No Noise	Female	0.25	0.14	-0.11
362	5	A	No Noise	Male	0.25	0.19	-0.06
363	5	A	High Frequency	Female	0.09	0.11	0.02
364	5	A	High Frequency	Male	0.08	0.14	0.06
365	5	A	Restaurant	Female	0.06	0.03	-0.03
366	5	A	Restaurant	Male	0.06	0.04	-0.02
367	5	A	Music	Female	0.16	0.06	-0.10
368	5	A	Music	Male	0.16	0.09	-0.07
369	5	A	Traffic	Female	0.10	0.08	-0.02
370	5	A	Traffic	Male	0.10	0.11	0.01
371	5	A_FS	No Noise	Female	0.25	0.39	0.14
372	5	A_FS	No Noise	Male	0.25	0.38	0.13
373	5	A_FS	High Frequency	Female	0.09	0.24	0.15
374	5	A_FS	High Frequency	Male	0.08	0.23	0.15
375	5	A_FS	Restaurant	Female	0.06	0.20	0.14
376	5	A_FS	Restaurant	Male	0.06	0.19	0.13
377	5	A_FS	Music	Female	0.16	0.22	0.06
378	5	A_FS	Music	Male	0.16	0.21	0.05
379	5	A_FS	Traffic	Female	0.10	0.22	0.12
380	5	A_FS	Traffic	Male	0.10	0.21	0.11
381	5	A_FT	No Noise	Female	0.25	0.38	0.13
382	5	A_FT	No Noise	Male	0.25	0.37	0.12
383	5	A_FT	High Frequency	Female	0.09	0.23	0.14
384	5	A_FT	High Frequency	Male	0.08	0.22	0.14
385	5	A_FT	Restaurant	Female	0.06	0.18	0.12
386	5	A_FT	Restaurant	Male	0.06	0.18	0.12
387	5	A_FT	Music	Female	0.16	0.22	0.06
388	5	A_FT	Music	Male	0.16	0.20	0.04
389	5	A_FT	Traffic	Female	0.10	0.21	0.11
390	5	A_FT	Traffic	Male	0.10	0.20	0.10
391	5	A_NLC	No Noise	Female	0.25	0.38	0.13
392	5	A_NLC	No Noise	Male	0.25	0.37	0.12
393	5	A_NLC	High Frequency	Female	0.09	0.23	0.14

NO	**SUBJECT**	**PROCESSING METHOD**	**NOISE**	**GENDER**	**SII (Unprocessed)**	**SII (Processed)**	**IMP.**
394	5	A_NLC	High Frequency	Male	0.08	0.22	0.14
395	5	A_NLC	Restaurant	Female	0.06	0.18	0.12
396	5	A_NLC	Restaurant	Male	0.06	0.18	0.12
397	5	A_NLC	Music	Female	0.16	0.21	0.05
398	5	A_NLC	Music	Male	0.16	0.20	0.04
399	5	A_NLC	Traffic	Female	0.10	0.21	0.11
400	5	A_NLC	Traffic	Male	0.10	0.20	0.10
401	5	FS	No Noise	Female	0.25	0.47	0.22
402	5	FS	No Noise	Male	0.25	0.51	0.26
403	5	FS	High Frequency	Female	0.09	0.24	0.15
404	5	FS	High Frequency	Male	0.08	0.24	0.16
405	5	FS	Restaurant	Female	0.06	0.19	0.13
406	5	FS	Restaurant	Male	0.06	0.24	0.18
407	5	FS	Music	Female	0.16	0.22	0.06
408	5	FS	Music	Male	0.16	0.24	0.08
409	5	FS	Traffic	Female	0.10	0.22	0.12
410	5	FS	Traffic	Male	0.10	0.22	0.12
411	5	FT	No Noise	Female	0.25	0.44	0.19
412	5	FT	No Noise	Male	0.25	0.46	0.21
413	5	FT	High Frequency	Female	0.09	0.25	0.16
414	5	FT	High Frequency	Male	0.08	0.23	0.15
415	5	FT	Restaurant	Female	0.06	0.17	0.11
416	5	FT	Restaurant	Male	0.06	0.21	0.15
417	5	FT	Music	Female	0.16	0.22	0.06
418	5	FT	Music	Male	0.16	0.26	0.10
419	5	FT	Traffic	Female	0.10	0.21	0.11
420	5	FT	Traffic	Male	0.10	0.21	0.11
421	5	NLC	No Noise	Female	0.25	0.52	0.27
422	5	NLC	No Noise	Male	0.25	0.54	0.29
423	5	NLC	High Frequency	Female	0.09	0.29	0.20
424	5	NLC	High Frequency	Male	0.08	0.31	0.23
425	5	NLC	Restaurant	Female	0.06	0.33	0.27
426	5	NLC	Restaurant	Male	0.06	0.30	0.24
427	5	NLC	Music	Female	0.16	0.36	0.20
428	5	NLC	Music	Male	0.16	0.39	0.23
429	5	NLC	Traffic	Female	0.10	0.28	0.18

NO	SUBJECT	PROCESSING METHOD	NOISE	GENDER	SII (Unprocessed)	SII (Processed)	IMP.
430	5	NLC	Traffic	Male	0.10	0.29	0.19
431	5	A_NLC_FT	No Noise	Female	0.25	0.38	0.13
432	5	A_NLC_FT	No Noise	Male	0.25	0.37	0.12
433	5	A_NLC_FT	High Frequency	Female	0.09	0.24	0.15
434	5	A_NLC_FT	High Frequency	Male	0.08	0.22	0.14
435	5	A_NLC_FT	Restaurant	Female	0.06	0.18	0.12
436	5	A_NLC_FT	Restaurant	Male	0.06	0.18	0.12
437	5	A_NLC_FT	Music	Female	0.16	0.23	0.07
438	5	A_NLC_FT	Music	Male	0.16	0.21	0.05
439	5	A_NLC_FT	Traffic	Female	0.10	0.21	0.11
440	5	A_NLC_FT	Traffic	Male	0.10	0.20	0.10
441	5	NLC_FT	No Noise	Female	0.25	0.38	0.13
442	5	NLC_FT	No Noise	Male	0.25	0.55	0.30
443	5	NLC_FT	High Frequency	Female	0.09	0.26	0.17
444	5	NLC_FT	High Frequency	Male	0.08	0.27	0.19
445	5	NLC_FT	Restaurant	Female	0.06	0.18	0.12
446	5	NLC_FT	Restaurant	Male	0.06	0.33	0.27
447	5	NLC_FT	Music	Female	0.16	0.25	0.09
448	5	NLC_FT	Music	Male	0.16	0.37	0.21
449	5	NLC_FT	Traffic	Female	0.10	0.24	0.14
450	5	NLC_FT	Traffic	Male	0.10	0.27	0.17
451	6	A	No Noise	Female	0.19	0.06	-0.13
452	6	A	No Noise	Male	0.18	0.08	-0.10
453	6	A	High Frequency	Female	0.05	0.06	0.01
454	6	A	High Frequency	Male	0.05	0.08	0.03
455	6	A	Restaurant	Female	0.04	0.03	-0.01
456	6	A	Restaurant	Male	0.04	0.04	0.00
457	6	A	Music	Female	0.11	0.03	-0.08
458	6	A	Music	Male	0.11	0.05	-0.06
459	6	A	Traffic	Female	0.08	0.06	-0.02
460	6	A	Traffic	Male	0.08	0.08	0.00
461	6	A_FS	No Noise	Female	0.19	0.19	0.00
462	6	A_FS	No Noise	Male	0.18	0.23	0.05
463	6	A_FS	High Frequency	Female	0.05	0.17	0.12
464	6	A_FS	High Frequency	Male	0.05	0.29	0.24
465	6	A_FS	Restaurant	Female	0.04	0.17	0.13

NO	SUBJECT	PROCESSING METHOD	NOISE	GENDER	SII (Unprocessed)	SII (Processed)	IMP.
466	6	A_FS	Restaurant	Male	0.04	0.19	0.15
467	6	A_FS	Music	Female	0.11	0.18	0.07
468	6	A_FS	Music	Male	0.11	0.21	0.10
469	6	A_FS	Traffic	Female	0.08	0.17	0.09
470	6	A_FS	Traffic	Male	0.08	0.20	0.12
471	6	A_FT	No Noise	Female	0.19	0.20	0.01
472	6	A_FT	No Noise	Male	0.18	0.24	0.06
473	6	A_FT	High Frequency	Female	0.05	0.18	0.13
474	6	A_FT	High Frequency	Male	0.05	0.21	0.16
475	6	A_FT	Restaurant	Female	0.04	0.17	0.13
476	6	A_FT	Restaurant	Male	0.04	0.20	0.16
477	6	A_FT	Music	Female	0.11	0.19	0.08
478	6	A_FT	Music	Male	0.11	0.22	0.11
479	6	A_FT	Traffic	Female	0.08	0.18	0.10
480	6	A_FT	Traffic	Male	0.08	0.21	0.13
481	6	A_NLC	No Noise	Female	0.19	0.19	0.00
482	6	A_NLC	No Noise	Male	0.18	0.24	0.06
483	6	A_NLC	High Frequency	Female	0.05	0.18	0.13
484	6	A_NLC	High Frequency	Male	0.05	0.21	0.16
485	6	A_NLC	Restaurant	Female	0.04	0.17	0.13
486	6	A_NLC	Restaurant	Male	0.04	0.20	0.16
487	6	A_NLC	Music	Female	0.11	0.19	0.08
488	6	A_NLC	Music	Male	0.11	0.22	0.11
489	6	A_NLC	Traffic	Female	0.08	0.18	0.10
490	6	A_NLC	Traffic	Male	0.08	0.21	0.13
491	6	FS	No Noise	Female	0.19	0.21	0.02
492	6	FS	No Noise	Male	0.18	0.23	0.05
493	6	FS	High Frequency	Female	0.05	0.19	0.14
494	6	FS	High Frequency	Male	0.05	0.20	0.15
495	6	FS	Restaurant	Female	0.04	0.25	0.21
496	6	FS	Restaurant	Male	0.04	0.18	0.14
497	6	FS	Music	Female	0.11	0.15	0.04
498	6	FS	Music	Male	0.11	0.21	0.10
499	6	FS	Traffic	Female	0.08	0.18	0.10
500	6	FS	Traffic	Male	0.08	0.20	0.12
501	6	FT	No Noise	Female	0.19	0.20	0.01
502	6	FT	No Noise	Male	0.18	0.18	0.00

NO	SUBJECT	PROCESSING METHOD	NOISE	GENDER	SII (Unprocessed)	SII (Processed)	IMP.
503	6	FT	High Frequency	Female	0.05	0.19	0.14
504	6	FT	High Frequency	Male	0.05	0.18	0.13
505	6	FT	Restaurant	Female	0.04	0.14	0.10
506	6	FT	Restaurant	Male	0.04	0.13	0.09
507	6	FT	Music	Female	0.11	0.14	0.03
508	6	FT	Music	Male	0.11	0.14	0.03
509	6	FT	Traffic	Female	0.08	0.17	0.09
510	6	FT	Traffic	Male	0.08	0.16	0.08
511	6	NLC	No Noise	Female	0.19	0.27	0.08
512	6	NLC	No Noise	Male	0.18	0.30	0.12
513	6	NLC	High Frequency	Female	0.05	0.21	0.16
514	6	NLC	High Frequency	Male	0.05	0.22	0.17
515	6	NLC	Restaurant	Female	0.04	0.17	0.13
516	6	NLC	Restaurant	Male	0.04	0.21	0.17
517	6	NLC	Music	Female	0.11	0.20	0.09
518	6	NLC	Music	Male	0.11	0.23	0.12
519	6	NLC	Traffic	Female	0.08	0.21	0.13
520	6	NLC	Traffic	Male	0.08	0.21	0.13
521	6	A_NLC_FT	No Noise	Female	0.19	0.23	0.04
522	6	A_NLC_FT	No Noise	Male	0.18	0.24	0.06
523	6	A_NLC_FT	High Frequency	Female	0.05	0.18	0.13
524	6	A_NLC_FT	High Frequency	Male	0.05	0.21	0.16
525	6	A_NLC_FT	Restaurant	Female	0.04	0.17	0.13
526	6	A_NLC_FT	Restaurant	Male	0.04	0.20	0.16
527	6	A_NLC_FT	Music	Female	0.11	0.19	0.08
528	6	A_NLC_FT	Music	Male	0.11	0.22	0.11
529	6	A_NLC_FT	Traffic	Female	0.08	0.18	0.10
530	6	A_NLC_FT	Traffic	Male	0.08	0.21	0.13
531	6	NLC_FT	No Noise	Female	0.19	0.19	0.00
532	6	NLC_FT	No Noise	Male	0.18	0.29	0.11
533	6	NLC_FT	High Frequency	Female	0.05	0.17	0.12
534	6	NLC_FT	High Frequency	Male	0.05	0.20	0.15
535	6	NLC_FT	Restaurant	Female	0.04	0.12	0.08
536	6	NLC_FT	Restaurant	Male	0.04	0.19	0.15
537	6	NLC_FT	Music	Female	0.11	0.12	0.01
538	6	NLC_FT	Music	Male	0.11	0.21	0.10

NO	SUBJECT	PROCESSING METHOD	NOISE	GENDER	SII (Unprocessed)	SII (Processed)	IMP.
539	6	NLC_FT	Traffic	Female	0.08	0.19	0.11
540	6	NLC_FT	Traffic	Male	0.08	0.19	0.11
541	7	A	No Noise	Female	0.20	0.27	0.07
542	7	A	No Noise	Male	0.21	0.40	0.19
543	7	A	High Frequency	Female	0.08	0.12	0.04
544	7	A	High Frequency	Male	0.08	0.15	0.07
545	7	A	Restaurant	Female	0.07	0.03	-0.04
546	7	A	Restaurant	Male	0.07	0.04	-0.03
547	7	A	Music	Female	0.12	0.10	-0.02
548	7	A	Music	Male	0.12	0.17	0.05
549	7	A	Traffic	Female	0.09	0.09	0.00
550	7	A	Traffic	Male	0.08	0.11	0.03
551	7	A_FS	No Noise	Female	0.20	0.43	0.23
552	7	A_FS	No Noise	Male	0.21	0.46	0.25
553	7	A_FS	High Frequency	Female	0.08	0.27	0.19
554	7	A_FS	High Frequency	Male	0.08	0.20	0.12
555	7	A_FS	Restaurant	Female	0.07	0.23	0.16
556	7	A_FS	Restaurant	Male	0.07	0.27	0.20
557	7	A_FS	Music	Female	0.12	0.27	0.15
558	7	A_FS	Music	Male	0.12	0.30	0.18
559	7	A_FS	Traffic	Female	0.09	0.26	0.17
560	7	A_FS	Traffic	Male	0.08	0.29	0.21
561	7	A_FT	No Noise	Female	0.20	0.43	0.23
562	7	A_FT	No Noise	Male	0.21	0.46	0.25
563	7	A_FT	High Frequency	Female	0.08	0.27	0.19
564	7	A_FT	High Frequency	Male	0.08	0.29	0.21
565	7	A_FT	Restaurant	Female	0.07	0.22	0.15
566	7	A_FT	Restaurant	Male	0.07	0.27	0.20
567	7	A_FT	Music	Female	0.12	0.27	0.15
568	7	A_FT	Music	Male	0.12	0.30	0.18
569	7	A_FT	Traffic	Female	0.09	0.26	0.17
570	7	A_FT	Traffic	Male	0.08	0.29	0.21
571	7	A_NLC	No Noise	Female	0.20	0.43	0.23
572	7	A_NLC	No Noise	Male	0.21	0.45	0.24
573	7	A_NLC	High Frequency	Female	0.08	0.26	0.18
574	7	A_NLC	High Frequency	Male	0.08	0.29	0.21

NO	SUBJECT	PROCESSING METHOD	NOISE	GENDER	SII (Unprocessed)	SII (Processed)	IMP.
575	7	A_NLC	Restaurant	Female	0.07	0.22	0.15
576	7	A_NLC	Restaurant	Male	0.07	0.27	0.20
577	7	A_NLC	Music	Female	0.12	0.26	0.14
578	7	A_NLC	Music	Male	0.12	0.30	0.18
579	7	A_NLC	Traffic	Female	0.09	0.26	0.17
580	7	A_NLC	Traffic	Male	0.08	0.29	0.21
581	7	FS	No Noise	Female	0.20	0.63	0.43
582	7	FS	No Noise	Male	0.21	0.68	0.47
583	7	FS	High Frequency	Female	0.08	0.24	0.16
584	7	FS	High Frequency	Male	0.08	0.24	0.16
585	7	FS	Restaurant	Female	0.07	0.25	0.18
586	7	FS	Restaurant	Male	0.07	0.24	0.17
587	7	FS	Music	Female	0.12	0.31	0.19
588	7	FS	Music	Male	0.12	0.31	0.19
589	7	FS	Traffic	Female	0.09	0.24	0.15
590	7	FS	Traffic	Male	0.08	0.22	0.14
591	7	FT	No Noise	Female	0.20	0.61	0.41
592	7	FT	No Noise	Male	0.21	0.64	0.43
593	7	FT	High Frequency	Female	0.08	0.25	0.17
594	7	FT	High Frequency	Male	0.08	0.23	0.15
595	7	FT	Restaurant	Female	0.07	0.18	0.11
596	7	FT	Restaurant	Male	0.07	0.22	0.15
597	7	FT	Music	Female	0.12	0.26	0.14
598	7	FT	Music	Male	0.12	0.30	0.18
599	7	FT	Traffic	Female	0.09	0.21	0.12
600	7	FT	Traffic	Male	0.08	0.21	0.13
601	7	NLC	No Noise	Female	0.20	0.65	0.45
602	7	NLC	No Noise	Male	0.21	0.66	0.45
603	7	NLC	High Frequency	Female	0.08	0.31	0.23
604	7	NLC	High Frequency	Male	0.08	0.32	0.24
605	7	NLC	Restaurant	Female	0.07	0.33	0.26
606	7	NLC	Restaurant	Male	0.07	0.33	0.26
607	7	NLC	Music	Female	0.12	0.40	0.28
608	7	NLC	Music	Male	0.12	0.43	0.31
609	7	NLC	Traffic	Female	0.09	0.29	0.20
610	7	NLC	Traffic	Male	0.08	0.30	0.22
611	7	A_NLC_FT	No Noise	Female	0.20	0.45	0.25

NO	SUBJECT	PROCESSING METHOD	NOISE	GENDER	SII (Unprocessed)	SII (Processed)	IMP.
612	7	A_NLC_FT	No Noise	Male	0.21	0.45	0.24
613	7	A_NLC_FT	High Frequency	Female	0.08	0.28	0.20
614	7	A_NLC_FT	High Frequency	Male	0.08	0.29	0.21
615	7	A_NLC_FT	Restaurant	Female	0.07	0.22	0.15
616	7	A_NLC_FT	Restaurant	Male	0.07	0.27	0.20
617	7	A_NLC_FT	Music	Female	0.12	0.29	0.17
618	7	A_NLC_FT	Music	Male	0.12	0.30	0.18
619	7	A_NLC_FT	Traffic	Female	0.09	0.26	0.17
620	7	A_NLC_FT	Traffic	Male	0.08	0.29	0.21
621	7	NLC_FT	No Noise	Female	0.20	0.59	0.39
622	7	NLC_FT	No Noise	Male	0.21	0.67	0.46
623	7	NLC_FT	High Frequency	Female	0.08	0.33	0.25
624	7	NLC_FT	High Frequency	Male	0.08	0.31	0.23
625	7	NLC_FT	Restaurant	Female	0.07	0.28	0.21
626	7	NLC_FT	Restaurant	Male	0.07	0.39	0.32
627	7	NLC_FT	Music	Female	0.12	0.38	0.26
628	7	NLC_FT	Music	Male	0.12	0.49	0.37
629	7	NLC_FT	Traffic	Female	0.09	0.29	0.20
630	7	NLC_FT	Traffic	Male	0.08	0.35	0.27
631	8	A	No Noise	Female	0.36	0.56	0.20
632	8	A	No Noise	Male	0.36	0.70	0.34
633	8	A	High Frequency	Female	0.10	0.12	0.02
634	8	A	High Frequency	Male	0.10	0.15	0.05
635	8	A	Restaurant	Female	0.08	0.03	-0.05
636	8	A	Restaurant	Male	0.07	0.04	-0.03
637	8	A	Music	Female	0.19	0.11	-0.08
638	8	A	Music	Male	0.18	0.20	0.02
639	8	A	Traffic	Female	0.16	0.09	-0.07
640	8	A	Traffic	Male	0.14	0.11	-0.03
641	8	A_FS	No Noise	Female	0.36	0.66	0.30
642	8	A_FS	No Noise	Male	0.36	0.68	0.32
643	8	A_FS	High Frequency	Female	0.10	0.28	0.18
644	8	A_FS	High Frequency	Male	0.10	0.27	0.17
645	8	A_FS	Restaurant	Female	0.08	0.25	0.17
646	8	A_FS	Restaurant	Male	0.07	0.24	0.17
647	8	A_FS	Music	Female	0.19	0.27	0.08

NO	SUBJECT	PROCESSING METHOD	NOISE	GENDER	SII (Unprocessed)	SII (Processed)	IMP.
648	8	A_FS	Music	Male	0.18	0.26	0.08
649	8	A_FS	Traffic	Female	0.16	0.26	0.10
650	8	A_FS	Traffic	Male	0.14	0.26	0.12
651	8	A_FT	No Noise	Female	0.36	0.62	0.26
652	8	A_FT	No Noise	Male	0.36	0.67	0.31
653	8	A_FT	High Frequency	Female	0.10	0.27	0.17
654	8	A_FT	High Frequency	Male	0.10	0.26	0.16
655	8	A_FT	Restaurant	Female	0.08	0.22	0.14
656	8	A_FT	Restaurant	Male	0.07	0.23	0.16
657	8	A_FT	Music	Female	0.19	0.26	0.07
658	8	A_FT	Music	Male	0.18	0.25	0.07
659	8	A_FT	Traffic	Female	0.16	0.25	0.09
660	8	A_FT	Traffic	Male	0.14	0.24	0.10
661	8	A_NLC	No Noise	Female	0.36	0.65	0.29
662	8	A_NLC	No Noise	Male	0.36	0.68	0.32
663	8	A_NLC	High Frequency	Female	0.10	0.26	0.16
664	8	A_NLC	High Frequency	Male	0.10	0.26	0.16
665	8	A_NLC	Restaurant	Female	0.08	0.21	0.13
666	8	A_NLC	Restaurant	Male	0.07	0.23	0.16
667	8	A_NLC	Music	Female	0.19	0.25	0.06
668	8	A_NLC	Music	Male	0.18	0.25	0.07
669	8	A_NLC	Traffic	Female	0.16	0.24	0.08
670	8	A_NLC	Traffic	Male	0.14	0.24	0.10
671	8	FS	No Noise	Female	0.36	0.77	0.41
672	8	FS	No Noise	Male	0.36	0.75	0.39
673	8	FS	High Frequency	Female	0.10	0.24	0.14
674	8	FS	High Frequency	Male	0.10	0.24	0.14
675	8	FS	Restaurant	Female	0.08	0.25	0.17
676	8	FS	Restaurant	Male	0.07	0.24	0.17
677	8	FS	Music	Female	0.19	0.33	0.14
678	8	FS	Music	Male	0.18	0.29	0.11
679	8	FS	Traffic	Female	0.16	0.24	0.08
680	8	FS	Traffic	Male	0.14	0.22	0.08
681	8	FT	No Noise	Female	0.36	0.76	0.40
682	8	FT	No Noise	Male	0.36	0.73	0.37
683	8	FT	High Frequency	Female	0.10	0.25	0.15

NO	SUBJECT	PROCESSING METHOD	NOISE	GENDER	SII (Unprocessed)	SII (Processed)	IMP.
684	8	FT	High Frequency	Male	0.10	0.23	0.13
685	8	FT	Restaurant	Female	0.08	0.18	0.10
686	8	FT	Restaurant	Male	0.07	0.22	0.15
687	8	FT	Music	Female	0.19	0.25	0.06
688	8	FT	Music	Male	0.18	0.29	0.11
689	8	FT	Traffic	Female	0.16	0.21	0.05
690	8	FT	Traffic	Male	0.14	0.21	0.07
691	8	NLC	No Noise	Female	0.36	0.74	0.38
692	8	NLC	No Noise	Male	0.36	0.72	0.36
693	8	NLC	High Frequency	Female	0.10	0.31	0.21
694	8	NLC	High Frequency	Male	0.10	0.32	0.22
695	8	NLC	Restaurant	Female	0.08	0.31	0.23
696	8	NLC	Restaurant	Male	0.07	0.33	0.26
697	8	NLC	Music	Female	0.19	0.41	0.22
698	8	NLC	Music	Male	0.18	0.43	0.25
699	8	NLC	Traffic	Female	0.16	0.29	0.13
700	8	NLC	Traffic	Male	0.14	0.30	0.16
701	8	A_NLC_FT	No Noise	Female	0.36	0.65	0.29
702	8	A_NLC_FT	No Noise	Male	0.36	0.65	0.29
703	8	A_NLC_FT	High Frequency	Female	0.10	0.29	0.19
704	8	A_NLC_FT	High Frequency	Male	0.10	0.26	0.16
705	8	A_NLC_FT	Restaurant	Female	0.08	0.23	0.15
706	8	A_NLC_FT	Restaurant	Male	0.07	0.22	0.15
707	8	A_NLC_FT	Music	Female	0.19	0.28	0.09
708	8	A_NLC_FT	Music	Male	0.18	0.28	0.10
709	8	A_NLC_FT	Traffic	Female	0.16	0.27	0.11
710	8	A_NLC_FT	Traffic	Male	0.14	0.24	0.10
711	8	NLC_FT	No Noise	Female	0.36	0.81	0.45
712	8	NLC_FT	No Noise	Male	0.36	0.76	0.40
713	8	NLC_FT	High Frequency	Female	0.10	0.34	0.24
714	8	NLC_FT	High Frequency	Male	0.10	0.32	0.22
715	8	NLC_FT	Restaurant	Female	0.08	0.32	0.24
716	8	NLC_FT	Restaurant	Male	0.07	0.39	0.32
717	8	NLC_FT	Music	Female	0.19	0.49	0.30
718	8	NLC_FT	Music	Male	0.18	0.50	0.32
719	8	NLC_FT	Traffic	Female	0.16	0.30	0.14

NO	SUBJECT	PROCESSING METHOD	NOISE	GENDER	SII (Unprocessed)	SII (Processed)	IMP.
720	8	NLC_FT	Traffic	Male	0.14	0.33	0.19
721	9	A	No Noise	Female	0.34	0.66	0.32
722	9	A	No Noise	Male	0.34	0.79	0.45
723	9	A	High Frequency	Female	0.10	0.12	0.02
724	9	A	High Frequency	Male	0.09	0.15	0.06
725	9	A	Restaurant	Female	0.08	0.04	-0.04
726	9	A	Restaurant	Male	0.08	0.05	-0.03
727	9	A	Music	Female	0.20	0.18	-0.02
728	9	A	Music	Male	0.19	0.25	0.06
729	9	A	Traffic	Female	0.13	0.09	-0.04
730	9	A	Traffic	Male	0.12	0.11	-0.01
731	9	A_FS	No Noise	Female	0.34	0.75	0.41
732	9	A_FS	No Noise	Male	0.34	0.77	0.43
733	9	A_FS	High Frequency	Female	0.10	0.28	0.18
734	9	A_FS	High Frequency	Male	0.09	0.28	0.19
735	9	A_FS	Restaurant	Female	0.08	0.25	0.17
736	9	A_FS	Restaurant	Male	0.08	0.26	0.18
737	9	A_FS	Music	Female	0.20	0.27	0.07
738	9	A_FS	Music	Male	0.19	0.29	0.10
739	9	A_FS	Traffic	Female	0.13	0.27	0.14
740	9	A_FS	Traffic	Male	0.12	0.27	0.15
741	9	A_FT	No Noise	Female	0.34	0.75	0.41
742	9	A_FT	No Noise	Male	0.34	0.77	0.43
743	9	A_FT	High Frequency	Female	0.10	0.29	0.19
744	9	A_FT	High Frequency	Male	0.09	0.27	0.18
745	9	A_FT	Restaurant	Female	0.08	0.24	0.16
746	9	A_FT	Restaurant	Male	0.08	0.25	0.17
747	9	A_FT	Music	Female	0.20	0.27	0.07
748	9	A_FT	Music	Male	0.19	0.28	0.09
749	9	A_FT	Traffic	Female	0.13	0.27	0.14
750	9	A_FT	Traffic	Male	0.12	0.27	0.15
751	9	A_NLC	No Noise	Female	0.34	0.76	0.42
752	9	A_NLC	No Noise	Male	0.34	0.76	0.42
753	9	A_NLC	High Frequency	Female	0.10	0.27	0.17
754	9	A_NLC	High Frequency	Male	0.09	0.27	0.18
755	9	A_NLC	Restaurant	Female	0.08	0.22	0.14

NO	**SUBJECT**	**PROCESSING METHOD**	**NOISE**	**GENDER**	**SII (Unprocessed)**	**SII (Processed)**	**IMP.**
756	9	A_NLC	Restaurant	Male	0.08	0.24	0.16
757	9	A_NLC	Music	Female	0.20	0.25	0.05
758	9	A_NLC	Music	Male	0.19	0.28	0.09
759	9	A_NLC	Traffic	Female	0.13	0.25	0.12
760	9	A_NLC	Traffic	Male	0.12	0.27	0.15
761	9	FS	No Noise	Female	0.34	0.80	0.46
762	9	FS	No Noise	Male	0.34	0.80	0.46
763	9	FS	High Frequency	Female	0.10	0.24	0.14
764	9	FS	High Frequency	Male	0.09	0.24	0.15
765	9	FS	Restaurant	Female	0.08	0.25	0.17
766	9	FS	Restaurant	Male	0.08	0.24	0.16
767	9	FS	Music	Female	0.20	0.35	0.15
768	9	FS	Music	Male	0.19	0.31	0.12
769	9	FS	Traffic	Female	0.13	0.24	0.11
770	9	FS	Traffic	Male	0.12	0.22	0.10
771	9	FT	No Noise	Female	0.34	0.79	0.45
772	9	FT	No Noise	Male	0.34	0.79	0.45
773	9	FT	High Frequency	Female	0.10	0.25	0.15
774	9	FT	High Frequency	Male	0.09	0.23	0.14
775	9	FT	Restaurant	Female	0.08	0.18	0.10
776	9	FT	Restaurant	Male	0.08	0.22	0.14
777	9	FT	Music	Female	0.20	0.26	0.06
778	9	FT	Music	Male	0.19	0.30	0.11
779	9	FT	Traffic	Female	0.13	0.21	0.08
780	9	FT	Traffic	Male	0.12	0.21	0.09
781	9	NLC	No Noise	Female	0.34	0.78	0.44
782	9	NLC	No Noise	Male	0.34	0.77	0.43
783	9	NLC	High Frequency	Female	0.10	0.30	0.20
784	9	NLC	High Frequency	Male	0.09	0.32	0.23
785	9	NLC	Restaurant	Female	0.08	0.33	0.25
786	9	NLC	Restaurant	Male	0.08	0.33	0.25
787	9	NLC	Music	Female	0.20	0.42	0.22
788	9	NLC	Music	Male	0.19	0.43	0.24
789	9	NLC	Traffic	Female	0.13	0.29	0.16
790	9	NLC	Traffic	Male	0.12	0.30	0.18
791	9	A_NLC_FT	No Noise	Female	0.34	0.75	0.41
792	9	A_NLC_FT	No Noise	Male	0.34	0.76	0.42

NO	SUBJECT	PROCESSING METHOD	NOISE	GENDER	SII (Unprocessed)	SII (Processed)	IMP.
793	9	A_NLC_FT	High Frequency	Female	0.10	0.28	0.18
794	9	A_NLC_FT	High Frequency	Male	0.09	0.27	0.18
795	9	A_NLC_FT	Restaurant	Female	0.08	0.23	0.15
796	9	A_NLC_FT	Restaurant	Male	0.08	0.25	0.17
797	9	A_NLC_FT	Music	Female	0.20	0.30	0.10
798	9	A_NLC_FT	Music	Male	0.19	0.28	0.09
799	9	A_NLC_FT	Traffic	Female	0.13	0.28	0.15
800	9	A_NLC_FT	Traffic	Male	0.12	0.27	0.15
801	9	NLC_FT	No Noise	Female	0.34	0.78	0.44
802	9	NLC_FT	No Noise	Male	0.34	0.82	0.48
803	9	NLC_FT	High Frequency	Female	0.10	0.35	0.25
804	9	NLC_FT	High Frequency	Male	0.09	0.32	0.23
805	9	NLC_FT	Restaurant	Female	0.08	0.31	0.23
806	9	NLC_FT	Restaurant	Male	0.08	0.41	0.33
807	9	NLC_FT	Music	Female	0.20	0.49	0.29
808	9	NLC_FT	Music	Male	0.19	0.52	0.33
809	9	NLC_FT	Traffic	Female	0.13	0.31	0.18
810	9	NLC_FT	Traffic	Male	0.12	0.33	0.21
811	10	A	No Noise	Female	0.33	0.55	0.22
812	10	A	No Noise	Male	0.30	0.73	0.43
813	10	A	High Frequency	Female	0.06	0.12	0.06
814	10	A	High Frequency	Male	0.06	0.15	0.09
815	10	A	Restaurant	Female	0.05	0.04	-0.01
816	10	A	Restaurant	Male	0.05	0.04	-0.01
817	10	A	Music	Female	0.17	0.16	-0.01
818	10	A	Music	Male	0.16	0.24	0.08
819	10	A	Traffic	Female	0.12	0.09	-0.03
820	10	A	Traffic	Male	0.10	0.11	0.01
821	10	A_FS	No Noise	Female	0.33	0.66	0.33
822	10	A_FS	No Noise	Male	0.30	0.69	0.39
823	10	A_FS	High Frequency	Female	0.06	0.17	0.11
824	10	A_FS	High Frequency	Male	0.06	0.16	0.10
825	10	A_FS	Restaurant	Female	0.05	0.16	0.11
826	10	A_FS	Restaurant	Male	0.05	0.15	0.10
827	10	A_FS	Music	Female	0.17	0.17	0.00
828	10	A_FS	Music	Male	0.16	0.16	0.00

NO	SUBJECT	PROCESSING METHOD	NOISE	GENDER	SII (Unprocessed)	SII (Processed)	IMP.
829	10	A_FS	Traffic	Female	0.12	0.16	0.04
830	10	A_FS	Traffic	Male	0.10	0.14	0.04
831	10	A_FT	No Noise	Female	0.33	0.63	0.30
832	10	A_FT	No Noise	Male	0.30	0.69	0.39
833	10	A_FT	High Frequency	Female	0.06	0.16	0.10
834	10	A_FT	High Frequency	Male	0.06	0.15	0.09
835	10	A_FT	Restaurant	Female	0.05	0.15	0.10
836	10	A_FT	Restaurant	Male	0.05	0.15	0.10
837	10	A_FT	Music	Female	0.17	0.17	0.00
838	10	A_FT	Music	Male	0.16	0.17	0.01
839	10	A_FT	Traffic	Female	0.12	0.16	0.04
840	10	A_FT	Traffic	Male	0.10	0.14	0.04
841	10	A_NLC	No Noise	Female	0.33	0.65	0.32
842	10	A_NLC	No Noise	Male	0.30	0.69	0.39
843	10	A_NLC	High Frequency	Female	0.06	0.15	0.09
844	10	A_NLC	High Frequency	Male	0.06	0.16	0.10
845	10	A_NLC	Restaurant	Female	0.05	0.15	0.10
846	10	A_NLC	Restaurant	Male	0.05	0.15	0.10
847	10	A_NLC	Music	Female	0.17	0.16	-0.01
848	10	A_NLC	Music	Male	0.16	0.17	0.01
849	10	A_NLC	Traffic	Female	0.12	0.14	0.02
850	10	A_NLC	Traffic	Male	0.10	0.14	0.04
851	10	FS	No Noise	Female	0.33	0.78	0.45
852	10	FS	No Noise	Male	0.30	0.77	0.47
853	10	FS	High Frequency	Female	0.06	0.24	0.18
854	10	FS	High Frequency	Male	0.06	0.24	0.18
855	10	FS	Restaurant	Female	0.05	0.25	0.20
856	10	FS	Restaurant	Male	0.05	0.24	0.19
857	10	FS	Music	Female	0.17	0.34	0.17
858	10	FS	Music	Male	0.16	0.31	0.15
859	10	FS	Traffic	Female	0.12	0.24	0.12
860	10	FS	Traffic	Male	0.10	0.22	0.12
861	10	FT	No Noise	Female	0.33	0.78	0.45
862	10	FT	No Noise	Male	0.30	0.78	0.48
863	10	FT	High Frequency	Female	0.06	0.25	0.19
864	10	FT	High Frequency	Male	0.06	0.23	0.17

NO	SUBJECT	PROCESSING METHOD	NOISE	GENDER	SII (Unprocessed)	SII (Processed)	IMP.
865	10	FT	Restaurant	Female	0.05	0.18	0.13
866	10	FT	Restaurant	Male	0.05	0.22	0.17
867	10	FT	Music	Female	0.17	0.26	0.09
868	10	FT	Music	Male	0.16	0.30	0.14
869	10	FT	Traffic	Female	0.12	0.21	0.09
870	10	FT	Traffic	Male	0.10	0.21	0.11
871	10	NLC	No Noise	Female	0.33	0.76	0.43
872	10	NLC	No Noise	Male	0.30	0.75	0.45
873	10	NLC	High Frequency	Female	0.06	0.31	0.25
874	10	NLC	High Frequency	Male	0.06	0.30	0.24
875	10	NLC	Restaurant	Female	0.05	0.32	0.27
876	10	NLC	Restaurant	Male	0.05	0.33	0.28
877	10	NLC	Music	Female	0.17	0.42	0.25
878	10	NLC	Music	Male	0.16	0.43	0.27
879	10	NLC	Traffic	Female	0.12	0.30	0.18
880	10	NLC	Traffic	Male	0.10	0.28	0.18
881	10	A_NLC_FT	No Noise	Female	0.33	0.65	0.32
882	10	A_NLC_FT	No Noise	Male	0.30	0.66	0.36
883	10	A_NLC_FT	High Frequency	Female	0.06	0.17	0.11
884	10	A_NLC_FT	High Frequency	Male	0.06	0.16	0.10
885	10	A_NLC_FT	Restaurant	Female	0.05	0.17	0.12
886	10	A_NLC_FT	Restaurant	Male	0.05	0.14	0.09
887	10	A_NLC_FT	Music	Female	0.17	0.18	0.01
888	10	A_NLC_FT	Music	Male	0.16	0.17	0.01
889	10	A_NLC_FT	Traffic	Female	0.12	0.16	0.04
890	10	A_NLC_FT	Traffic	Male	0.10	0.15	0.05
891	10	NLC_FT	No Noise	Female	0.33	0.79	0.46
892	10	NLC_FT	No Noise	Male	0.30	0.79	0.49
893	10	NLC_FT	High Frequency	Female	0.06	0.33	0.27
894	10	NLC_FT	High Frequency	Male	0.06	0.29	0.23
895	10	NLC_FT	Restaurant	Female	0.05	0.31	0.26
896	10	NLC_FT	Restaurant	Male	0.05	0.40	0.35
897	10	NLC_FT	Music	Female	0.17	0.49	0.32
898	10	NLC_FT	Music	Male	0.16	0.52	0.36
899	10	NLC_FT	Traffic	Female	0.12	0.30	0.18
900	10	NLC_FT	Traffic	Male	0.10	0.35	0.25
901	11	A	No Noise	Female	0.52	0.77	0.25

NO	SUBJECT	PROCESSING METHOD	NOISE	GENDER	SII (Unprocessed)	SII (Processed)	IMP.
902	11	A	No Noise	Male	0.52	0.83	0.31
903	11	A	High Frequency	Female	0.10	0.12	0.02
904	11	A	High Frequency	Male	0.09	0.15	0.06
905	11	A	Restaurant	Female	0.08	0.04	-0.04
906	11	A	Restaurant	Male	0.07	0.05	-0.02
907	11	A	Music	Female	0.29	0.18	-0.11
908	11	A	Music	Male	0.27	0.25	-0.02
909	11	A	Traffic	Female	0.17	0.09	-0.08
910	11	A	Traffic	Male	0.16	0.11	-0.05
911	11	A_FS	No Noise	Female	0.52	0.79	0.27
912	11	A_FS	No Noise	Male	0.52	0.80	0.28
913	11	A_FS	High Frequency	Female	0.10	0.28	0.18
914	11	A_FS	High Frequency	Male	0.09	0.18	0.09
915	11	A_FS	Restaurant	Female	0.08	0.19	0.11
916	11	A_FS	Restaurant	Male	0.07	0.19	0.12
917	11	A_FS	Music	Female	0.29	0.19	-0.10
918	11	A_FS	Music	Male	0.27	0.18	-0.09
919	11	A_FS	Traffic	Female	0.17	0.19	0.02
920	11	A_FS	Traffic	Male	0.16	0.18	0.02
921	11	A_FT	No Noise	Female	0.52	0.78	0.26
922	11	A_FT	No Noise	Male	0.52	0.81	0.29
923	11	A_FT	High Frequency	Female	0.10	0.19	0.09
924	11	A_FT	High Frequency	Male	0.09	0.18	0.09
925	11	A_FT	Restaurant	Female	0.08	0.19	0.11
926	11	A_FT	Restaurant	Male	0.07	0.19	0.12
927	11	A_FT	Music	Female	0.29	0.19	-0.10
928	11	A_FT	Music	Male	0.27	0.19	-0.08
929	11	A_FT	Traffic	Female	0.17	0.18	0.01
930	11	A_FT	Traffic	Male	0.16	0.16	0.00
931	11	A_NLC	No Noise	Female	0.52	0.79	0.27
932	11	A_NLC	No Noise	Male	0.52	0.79	0.27
933	11	A_NLC	High Frequency	Female	0.10	0.18	0.08
934	11	A_NLC	High Frequency	Male	0.09	0.18	0.09
935	11	A_NLC	Restaurant	Female	0.08	0.18	0.10
936	11	A_NLC	Restaurant	Male	0.07	0.18	0.11

NO	SUBJECT	PROCESSING METHOD	NOISE	GENDER	SII (Unprocessed)	SII (Processed)	IMP.
937	11	A_NLC	Music	Female	0.29	0.18	-0.11
938	11	A_NLC	Music	Male	0.27	0.19	-0.08
939	11	A_NLC	Traffic	Female	0.17	0.17	0.00
940	11	A_NLC	Traffic	Male	0.16	0.16	0.00
941	11	FS	No Noise	Female	0.52	0.82	0.30
942	11	FS	No Noise	Male	0.52	0.80	0.28
943	11	FS	High Frequency	Female	0.10	0.24	0.14
944	11	FS	High Frequency	Male	0.09	0.24	0.15
945	11	FS	Restaurant	Female	0.08	0.25	0.17
946	11	FS	Restaurant	Male	0.07	0.24	0.17
947	11	FS	Music	Female	0.29	0.35	0.06
948	11	FS	Music	Male	0.27	0.31	0.04
949	11	FS	Traffic	Female	0.17	0.24	0.07
950	11	FS	Traffic	Male	0.16	0.22	0.06
951	11	FT	No Noise	Female	0.52	0.82	0.30
952	11	FT	No Noise	Male	0.52	0.79	0.27
953	11	FT	High Frequency	Female	0.10	0.25	0.15
954	11	FT	High Frequency	Male	0.09	0.23	0.14
955	11	FT	Restaurant	Female	0.08	0.18	0.10
956	11	FT	Restaurant	Male	0.07	0.22	0.15
957	11	FT	Music	Female	0.29	0.26	-0.03
958	11	FT	Music	Male	0.27	0.30	0.03
959	11	FT	Traffic	Female	0.17	0.21	0.04
960	11	FT	Traffic	Male	0.16	0.21	0.05
961	11	NLC	No Noise	Female	0.52	0.78	0.26
962	11	NLC	No Noise	Male	0.52	0.76	0.24
963	11	NLC	High Freq.	Female	0.10	0.31	0.21
964	11	NLC	High Frequency	Male	0.09	0.32	0.23
965	11	NLC	Restaurant	Female	0.08	0.33	0.25
966	11	NLC	Restaurant	Male	0.07	0.33	0.26
967	11	NLC	Music	Female	0.29	0.42	0.13
968	11	NLC	Music	Male	0.27	0.43	0.16
969	11	NLC	Traffic	Female	0.17	0.29	0.12
970	11	NLC	Traffic	Male	0.16	0.30	0.14
971	11	A_NLC_FT	No Noise	Female	0.52	0.77	0.25
972	11	A_NLC_FT	No Noise	Male	0.52	0.80	0.28
973	11	A_NLC_FT	High Frequency	Female	0.10	0.20	0.10

NO	SUBJECT	PROCESSING METHOD	NOISE	GENDER	SII (Unprocessed)	SII (Processed)	IMP.
974	11	A_NLC_FT	High Frequency	Male	0.09	0.18	0.09
975	11	A_NLC_FT	Restaurant	Female	0.08	0.20	0.12
976	11	A_NLC_FT	Restaurant	Male	0.07	0.17	0.10
977	11	A_NLC_FT	Music	Female	0.29	0.20	-0.09
978	11	A_NLC_FT	Music	Male	0.27	0.18	-0.09
979	11	A_NLC_FT	Traffic	Female	0.17	0.19	0.02
980	11	A_NLC_FT	Traffic	Male	0.16	0.19	0.03
981	11	NLC_FT	No Noise	Female	0.52	0.85	0.33
982	11	NLC_FT	No Noise	Male	0.52	0.83	0.31
983	11	NLC_FT	High Frequency	Female	0.10	0.34	0.24
984	11	NLC_FT	High Frequency	Male	0.09	0.31	0.22
985	11	NLC_FT	Restaurant	Female	0.08	0.31	0.23
986	11	NLC_FT	Restaurant	Male	0.07	0.41	0.34
987	11	NLC_FT	Music	Female	0.29	0.49	0.20
988	11	NLC_FT	Music	Male	0.27	0.52	0.25
989	11	NLC_FT	Traffic	Female	0.17	0.30	0.13
990	11	NLC_FT	Traffic	Male	0.16	0.35	0.19
991	12	A	No Noise	Female	0.46	0.48	0.02
992	12	A	No Noise	Male	0.46	0.51	0.05
993	12	A	High Frequency	Female	0.09	0.12	0.03
994	12	A	High Frequency	Male	0.08	0.15	0.07
995	12	A	Restaurant	Female	0.07	0.03	-0.04
996	12	A	Restaurant	Male	0.06	0.04	-0.02
997	12	A	Music	Female	0.19	0.09	-0.10
998	12	A	Music	Male	0.17	0.11	-0.06
999	12	A	Traffic	Female	0.13	0.09	-0.04
1000	12	A	Traffic	Male	0.12	0.11	-0.01
1001	12	A_FS	No Noise	Female	0.46	0.52	0.06
1002	12	A_FS	No Noise	Male	0.46	0.54	0.08
1003	12	A_FS	High Frequency	Female	0.09	0.27	0.18
1004	12	A_FS	High Frequency	Male	0.08	0.27	0.19
1005	12	A_FS	Restaurant	Female	0.07	0.22	0.15
1006	12	A_FS	Restaurant	Male	0.06	0.25	0.19
1007	12	A_FS	Music	Female	0.19	0.27	0.08
1008	12	A_FS	Music	Male	0.17	0.27	0.10

NO	SUBJECT	PROCESSING METHOD	NOISE	GENDER	SII (Unprocessed)	SII (Processed)	IMP.
1009	12	A_FS	Traffic	Female	0.13	0.25	0.12
1010	12	A_FS	Traffic	Male	0.12	0.26	0.14
1011	12	A_FT	No Noise	Female	0.46	0.49	0.03
1012	12	A_FT	No Noise	Male	0.46	0.54	0.08
1013	12	A_FT	High Frequency	Female	0.09	0.28	0.19
1014	12	A_FT	High Frequency	Male	0.08	0.26	0.18
1015	12	A_FT	Restaurant	Female	0.07	0.20	0.13
1016	12	A_FT	Restaurant	Male	0.06	0.25	0.19
1017	12	A_FT	Music	Female	0.19	0.27	0.08
1018	12	A_FT	Music	Male	0.17	0.27	0.10
1019	12	A_FT	Traffic	Female	0.13	0.25	0.12
1020	12	A_FT	Traffic	Male	0.12	0.26	0.14
1021	12	A_NLC	No Noise	Female	0.46	0.53	0.07
1022	12	A_NLC	No Noise	Male	0.46	0.55	0.09
1023	12	A_NLC	High Frequency	Female	0.09	0.26	0.17
1024	12	A_NLC	High Frequency	Male	0.08	0.28	0.20
1025	12	A_NLC	Restaurant	Female	0.07	0.22	0.15
1026	12	A_NLC	Restaurant	Male	0.06	0.27	0.21
1027	12	A_NLC	Music	Female	0.19	0.26	0.07
1028	12	A_NLC	Music	Male	0.17	0.29	0.12
1029	12	A_NLC	Traffic	Female	0.13	0.25	0.12
1030	12	A_NLC	Traffic	Male	0.12	0.28	0.16
1031	12	FS	No Noise	Female	0.46	0.66	0.20
1032	12	FS	No Noise	Male	0.46	0.65	0.19
1033	12	FS	High Frequency	Female	0.09	0.23	0.14
1034	12	FS	High Frequency	Male	0.08	0.23	0.15
1035	12	FS	Restaurant	Female	0.07	0.18	0.11
1036	12	FS	Restaurant	Male	0.06	0.24	0.18
1037	12	FS	Music	Female	0.19	0.22	0.03
1038	12	FS	Music	Male	0.17	0.24	0.07
1039	12	FS	Traffic	Female	0.13	0.19	0.06
1040	12	FS	Traffic	Male	0.12	0.22	0.10
1041	12	FT	No Noise	Female	0.46	0.56	0.10
1042	12	FT	No Noise	Male	0.46	0.56	0.10
1043	12	FT	High Frequency	Female	0.09	0.23	0.14
1044	12	FT	High Frequency	Male	0.08	0.23	0.15

NO	SUBJECT	PROCESSING METHOD	NOISE	GENDER	SII (Unprocessed)	SII (Processed)	IMP.
1045	12	FT	Restaurant	Female	0.07	0.15	0.08
1046	12	FT	Restaurant	Male	0.06	0.19	0.13
1047	12	FT	Music	Female	0.19	0.18	-0.01
1048	12	FT	Music	Male	0.17	0.23	0.06
1049	12	FT	Traffic	Female	0.13	0.20	0.07
1050	12	FT	Traffic	Male	0.12	0.20	0.08
1051	12	NLC	No Noise	Female	0.46	0.60	0.14
1052	12	NLC	No Noise	Male	0.46	0.57	0.11
1053	12	NLC	High Frequency	Female	0.09	0.31	0.22
1054	12	NLC	High Frequency	Male	0.08	0.32	0.24
1055	12	NLC	Restaurant	Female	0.07	0.27	0.20
1056	12	NLC	Restaurant	Male	0.06	0.30	0.24
1057	12	NLC	Music	Female	0.19	0.37	0.18
1058	12	NLC	Music	Male	0.17	0.39	0.22
1059	12	NLC	Traffic	Female	0.13	0.28	0.15
1060	12	NLC	Traffic	Male	0.12	0.30	0.18
1061	12	A_NLC_FT	No Noise	Female	0.46	0.50	0.04
1062	12	A_NLC_FT	No Noise	Male	0.46	0.52	0.06
1063	12	A_NLC_FT	High Frequency	Female	0.09	0.28	0.19
1064	12	A_NLC_FT	High Frequency	Male	0.08	0.25	0.17
1065	12	A_NLC_FT	Restaurant	Female	0.07	0.21	0.14
1066	12	A_NLC_FT	Restaurant	Male	0.06	0.23	0.17
1067	12	A_NLC_FT	Music	Female	0.19	0.24	0.05
1068	12	A_NLC_FT	Music	Male	0.17	0.30	0.13
1069	12	A_NLC_FT	Traffic	Female	0.13	0.24	0.11
1070	12	A_NLC_FT	Traffic	Male	0.12	0.25	0.13
1071	12	NLC_FT	No Noise	Female	0.46	0.64	0.18
1072	12	NLC_FT	No Noise	Male	0.46	0.62	0.16
1073	12	NLC_FT	High Frequency	Female	0.09	0.34	0.25
1074	12	NLC_FT	High Frequency	Male	0.08	0.33	0.25
1075	12	NLC_FT	Restaurant	Female	0.07	0.21	0.14
1076	12	NLC_FT	Restaurant	Male	0.06	0.30	0.24
1077	12	NLC_FT	Music	Female	0.19	0.33	0.14
1078	12	NLC_FT	Music	Male	0.17	0.39	0.22
1079	12	NLC_FT	Traffic	Female	0.13	0.30	0.17
1080	12	NLC_FT	Traffic	Male	0.12	0.33	0.21

APPENDIX D: The Values of Parameters of FLMs for the Maximum Intelligibility Increment in Experiment III

				A_FS		A_FT		A_NLC			A_NLC_FT		
NO	**SUBJECT**	**NOISE**	**GENDER**	**SF**	**SA**	**SF**	**SA**	**SF**	**CF**	**WF**	**EF**	**CF**	**WF**
1	1	No Noise	F	5,6	4	5	4	3	4	0.3	5	7	0.3
2	1	No Noise	F			4	3	1,2,3	4	0.5			
3	1	No Noise	F					1,2,3	5	0.7			
4	1	No Noise	M	6	3	4	3	3	4	0.5	5	7	0.3
5	1	No Noise	M					1	4	0.7			
6	1	No Noise	M					3	5	0.7			
7	1	High Frequency	F	all	all	all	all	all	all	all	5	7	0.3
8	1	High Frequency	M	all	all	all	all	all	all	all	all	all	all
9	1	Restaurant	F	5,6	4	4,5	3	all	4,5,6	0.7	5	7	0.3
10	1	Restaurant	F					all	4	0.5			
11	1	Restaurant	M	all	all	4,5	3	all	4	0.5	all	all	all
12	1	Restaurant	M			5	4	all	4	0.7			
13	1	Music	F	all	all	all	all	all	all	all	4,5	4	0.7
14	1	Music	M	all	all	all	all	all	all	all	all	all	all
15	1	Traffic	F	all	all	all	all	all	all	all	all	all	all
16	1	Traffic	M	all	all	all	all	all	all	all	all	all	all
17	2	No Noise	F	4	2,3	6	4	1	4	0.7	5	4	0.5
18	2	No Noise	M	4	3	4	2	1	4	0.7	4	5	0.3
19	2	No Noise	M			5	2				4	7	0.5
20	2	No Noise	M			6	2,3,4,5						
21	2	High Frequency	F	6	3	4,5,6	3	1	4	0.7	all	4	0.7

				A_FS		**A_FT**		**A_NLC**			**A_NLC_FT**		
NO	**SUBJECT**	**NOISE**	**GENDER**	**SF**	**SA**	**SF**	**SA**	**SF**	**CF**	**WF**	**EF**	**CF**	**WF**
22	2	High Frequency	M	6	2,3	4,5	3	3	all	all	6	4	0.7
23	2	Restaurant	F	6	4,5	4,5	3	all	4	0.3	6	6,7	0.3
24	2	Restaurant	F			5	4	2,3	5	0.5			
25	2	Restaurant	M	6	2,3,4	4	3	3	4	0.5	6	6,7	0.5
26	2	Restaurant	M					3	4	0.7	6	5	0.3
27	2	Music	F	6	4	4,5	3	2	5	0.5	6	7	0.3
28	2	Music	F					2	6	0.7			
29	2	Music	M	6	4	4	3	2	5	0.7	6	6	0.5
30	2	Music	M			5	4				6	7	0.7
31	2	Traffic	F	6	3,4	6	3	3	4	0.3	5,6	4,6	0.7
32	2	Traffic	F					3	4,5	0.5			
33	2	Traffic	F					3	5	0.7			
34	2	Traffic	M	6	2,3	all	all	3	4	0.5	6	6	0.7
35	2	Traffic	M					3	4	0.7			
36	3	No Noise	F	5	4	5	4	1,3	4	0.3	5	6	0.3
37	3	No Noise	F			4	3	1,3	4	0.5	6	7	0.3
38	3	No Noise	F					1,3	5	0.7			
39	3	No Noise	M	6	4	5	3,4	1	4	0.7	5	7	0.3
40	3	No Noise	M			4	3						
41	3	High Frequency	F	6	4,5	all	all	all	all	all	6	5,6,7	0.3
42	3	High Frequency	F								6	7	0.5
43	3	High Frequency	F								6	5	0.7
44	3	High Frequency	M	all	all	all	all	3,2	all	all	all	4	0.7
45	3	Restaurant	F	5	4	4,5	3	1	4	0.3	6	6,7	0.3

				A_FS		A_FT		A_NLC			A_NLC_FT		
NO	**SUBJECT**	**NOISE**	**GENDER**	**SF**	**SA**	**SF**	**SA**	**SF**	**CF**	**WF**	**EF**	**CF**	**WF**
46	3	Restaurant	F	6	5	5	4						
47	3	Restaurant	M	5,6	4	4,5	3	all	4	0.3	5,6	7	0.3
48	3	Restaurant	M			5	4	all	4,5	0.5			
49	3	Restaurant	M					all	5	0.7			
50	3	Music	F	5	4	5	4	1	4	0.3	6	6,7	0.3
51	3	Music	F	6	5								
52	3	Music	M	5,6	4	4,5	3	1	4,5	0.7	5	7	0.3
53	3	Music	M	6	3	5	4						
54	3	Traffic	F	5	4	4,5	3	1,2	4	0.3	6	6,7	0.3
55	3	Traffic	F	6	5			1	5	0.3			
56	3	Traffic	M	5,6	4	all	all	1,2	4	0.3	5,6	7	0.3
57	3	Traffic	M					2	4,5	0.5	5,6	7	0.5
58	4	No Noise	F	4	2	6	2	1	4	0.7	4	6	0.7
59	4	No Noise	M	4	3	4	2	1	4	0.7	4	5	0.7
60	4	No Noise	M			6	2,4,5	1	7	0.3			
61	4	High Frequency	F	6	2,3	all	all	3	4,5,6	0.3	5	4	0.7
62	4	High Frequency	F					3	7	0.5	5	4	0.5
63	4	High Frequency	F					3	4	0.7	4	6	0.7
64	4	High Frequency	M	6	3	all	all	3	all	all	6	4	0.7
65	4	Restaurant	F	6	5	5	2,4	2	4	0.3	6	6,7	0.3
66	4	Restaurant	F					2	5	0.5			
67	4	Restaurant	M	6	3	4,5	3	3	4	0.5	6	6,7	0.5
68	4	Restaurant	M			5	4	3	4,5,6	0.7	6	5	0.3
69	4	Music	F	6	4,5	5	4	2,3	4	0.3	6	7	0.3
70	4	Music	F					2,3	5	0.5			

				A_FS		A_FT		A_NLC			A_NLC_FT		
NO	**SUBJECT**	**NOISE**	**GENDER**	**SF**	**SA**	**SF**	**SA**	**SF**	**CF**	**WF**	**EF**	**CF**	**WF**
71	4	Music	M	6	4	4	3	1	4	0.5	6	7	0.7
72	4	Music	M			5	4						
73	4	Traffic	F	5,6	2	all	all	2,3	4	0.3	6	6	0.7
74	4	Traffic	F	5,6	3			2	4	0.5			
75	4	Traffic	F	6	4								
76	4	Traffic	M	6	2,3	4,5	3	3	4	0.5	6	6	0.7
77	4	Traffic	M			5	4	3	6	0.7			
78	5	No Noise	F	all	all	all	all	1,2,3	all	all	all	all	all
79	5	No Noise	M	all	all	all	all	1	all	all	all	all	all
80	5	High Frequency	F	all	all	all	all	all	all	all	4,5	4	0.7
81	5	High Frequency	F								4	5	0.7
82	5	High Frequency	M	all	all	all	all	all	all	all	all	all	all
83	5	Restaurant	F	all	all	all	all	all	all	all	all	all	all
84	5	Restaurant	M	all	all	all	all	all	all	all	all	all	all
85	5	Music	F	all	all	all	all	all	all	all	4,5	4	0.7
86	5	Music	M	all	all	all	all	all	all	all	5	4	0.7
87	5	Traffic	F	all	all	all	all	all	all	all	all	all	all
88	5	Traffic	M	all	all	all	all	all	all	all	all	all	all
89	6	No Noise	F	all	all	all	all	1,2,3	all	all	all	all	all
90	6	No Noise	M	all	all	all	all	1	all	all	all	all	all
91	6	High Frequency	F	all	all	all	all	all	all	all	all	all	all
92	6	High Frequency	M	all	all	all	all	all	all	all	all	all	all
93	6	Restaurant	F	all	all	all	all	all	all	all	all	all	all
94	6	Restaurant	F										
95	6	Restaurant	M	all	all	all	all	all	all	all	all	all	all

				A_FS		A_FT		A_NLC			A_NLC_FT		
NO	**SUBJECT**	**NOISE**	**GENDER**	**SF**	**SA**	**SF**	**SA**	**SF**	**CF**	**WF**	**EF**	**CF**	**WF**
96	6	Music	F	all	all	all	all	all	all	all	all	all	all
97	6	Music	M	all	all	all	all	all	all	all	all	all	all
98	6	Traffic	F	all	all	all	all	all	all	all	all	all	all
99	6	Traffic	M	all	all	all	all	all	all	all	all	all	all
100	7	No Noise	F	all	all	all	all	1,2,3	all	all	all	all	all
101	7	No Noise	M	all	all	4	3	3	all	all	all	all	all
102	7	No Noise	M			5	3,4						
103	7	High Frequency	F	all	all	all	all	all	all	all	4	5	0.7
104	7	High Frequency	M	all	all	all	all	all	all	all	all	all	all
105	7	Restaurant	F	all	all	all	all	all	all	all	all	all	all
106	7	Restaurant	M	all	all	all	all	all	all	all	all	all	all
107	7	Music	F	all	all	all	all	all	all	all	4,5	4	0.7
108	7	Music	M	all	all	all	all	all	all	all	all	all	all
109	7	Traffic	F	all	all	all	all	all	all	all	all	all	all
110	7	Traffic	M	all	all	all	all	all	all	all	all	all	all
111	8	No Noise	F	6	4	5	4	2,3	4	0.3	6	6,7	0.3
112	8	No Noise	F					3	5	0.5			
113	8	No Noise	M	6	4	4	3	3	4	0.5	5	7	0.3
114	8	No Noise	M			5	3,4						
115	8	High Frequency	F	5,6	4	all	all	all	all	all	5	7	0.3
116	8	High Frequency	M	all	all	all	all	all	4,5	all	all	all	all
117	8	Restaurant	F	5	4	4,5	3	all	all	all	4,5	4	0.7
118	8	Restaurant	F			5	4				5	7	0.3
119	8	Restaurant	M	all	all	4,5	3	all	all	all	all	all	all
120	8	Restaurant	M			5	4						

				A_FS		A_FT		A_NLC			A_NLC_FT		
NO	**SUBJECT**	**NOISE**	**GENDER**	**SF**	**SA**	**SF**	**SA**	**SF**	**CF**	**WF**	**EF**	**CF**	**WF**
121	8	Music	F	5,6	4	all	all	3,2	4	0.5	4,5	4	0.7
122	8	Music	F	6	5								
123	8	Music	M	all	all	all	all	all	all	all	4	4	0.7
124	8	Traffic	F	5,6	4	all	all	all	all	all	4,5	4	0.7
125	8	Traffic	F								5	7	0.3
126	8	Traffic	M	all	all	all	all	all	all	all	all	all	all
127	9	No Noise	F	6	3,4	5	4	1	4	0.7	5	7	0.3
128	9	No Noise	F	5	4	4	3				6	4	0.3
129	9	No Noise	F								6	6	0.5
130	9	No Noise	M	6	2,3	4,5	2	1,3	4	0.7	6	5	0.7
131	9	High Frequency	F	all	all	all	all	all	all	all	all	all	all
132	9	High Frequency	M	all	all	all	all	all	all	all	all	all	all
133	9	Restaurant	F	all	3	4,5	3	all	all	all	all	all	all
134	9	Restaurant	M	all	all	all	all	all	all	all	all	all	all
135	9	Music	F	all	all	all	all	all	all	all	4,5	4	0.7
136	9	Music	M	all	all	all	all	all	all	all	all	all	all
137	9	Traffic	F	all	3	all	all	all	all	all	4,5	4	0.7
138	9	Traffic	F	4,5	2						5	4	0.5
139	9	Traffic	M	all	all	all	all	all	all	all	all	all	all
140	10	No Noise	F	5,6	4	4	3	2,3	4	0.5	6	6	0.3
141	10	No Noise	F								5,6	7	0.3
142	10	No Noise	F								6	7	0.5
143	10	No Noise	M	6	3	4	3	1	4	0.7	5	7	0.3
144	10	High Frequency	F	5	4	all	all	all	all	all	5	7	0.3
145	10	High Frequency	M	all	all	all	all	all	4,5	all	all	4,5	all

				A_FS		A_FT		A_NLC			A_NLC_FT		
NO	**SUBJECT**	**NOISE**	**GENDER**	**SF**	**SA**	**SF**	**SA**	**SF**	**CF**	**WF**	**EF**	**CF**	**WF**
146	10	Restaurant	F	5,6	4	4,5	3	1,2	4	0.5	5	7	0.3
147	10	Restaurant	F					1,2	5	0.7			
148	10	Restaurant	M	all	3	4,5	3	all	4	0.7	all	all	all
149	10	Restaurant	M	5,6	4								
150	10	Music	F	4,5,6	3	4,5	3	all	4,5	0.7	6	4	0.3
151	10	Music	F	5,6	4						5	7	0.3
152	10	Music	M	all	all	4	3	1	4	0.7	6	5	0.5
153	10	Traffic	F	all	3	4,5	3	all	all	all	4	5,6,7	0.3
154	10	Traffic	F	5,6	4						5	all	all
155	10	Traffic	F								6	all	all
156	10	Traffic	M	all	all	all	all	all	all	all	all	all	all
157	11	No Noise	F	6	3	5	4	1,3	4	0.7	6	6	0.5
158	11	No Noise	F			4	3				6	6,7	0.7
159	11	No Noise	M	5,6	2	4,5	2	1,2,3	4	0.7	6	4	0.5
160	11	No Noise	M			6	2,3				6	5	0.7
161	11	High Frequency	F	5,6	4	all	all	all	all	all	6	5,6,7	0.3
162	11	High Frequency	F								6	5,6,7	0.5
163	11	High Frequency	M	all	all	all	all	all	all	all	all	all	all
164	11	Restaurant	F	5,6	4	4	3	1,2	4	0.3	5	7	0.3
165	11	Restaurant	F					1,2	4	0.5	6	4	0.3
166	11	Restaurant	F					1,2	5	0.7			
167	11	Restaurant	M	6	3	4	3	all	4,5	0.7	all	all	all
168	11	Music	F	5,6	4	4	3	all	all	all	5	7	0.3
169	11	Music	M	all	all	4	3	1	4	0.7	6	4	0.3
170	11	Music	M					3	4	0.5	6	5	0.5

				A_FS		A_FT		A_NLC			A_NLC_FT		
NO	**SUBJECT**	**NOISE**	**GENDER**	**SF**	**SA**	**SF**	**SA**	**SF**	**CF**	**WF**	**EF**	**CF**	**WF**
171	11	Traffic	F	5,6	4	4,5	3	all	all	all	4	6,7	0.3
172	11	Traffic	F								5	all	0.3
173	11	Traffic	F								6	all	all
174	11	Traffic	M	5,6	4	all	all	all	all	all	6	5	0.5
175	12	No Noise	F	6	5	5	4	2,3	5,6	0.3	6	7	0.3
176	12	No Noise	F			4	3	3	7	0.5			
177	12	No Noise	M	5,6	2	4	3	1	4	0.7	6	5	0.7
178	12	No Noise	M	6	3	5	3,4	3	7	0.7			
179	12	No Noise	M					3	5	0.3			
180	12	High Frequency	F	5,6	2	6	2	all	all	all	4,5	4	0.7
181	12	High Frequency	M	6	3	4,5	3	3	all	all	4	4	0.7
182	12	High Frequency	M			5	4						
183	12	Restaurant	F	6	5	all	all	2,3	5,6	0.3	6	6,7	0.3
184	12	Restaurant	M	6	3	5	4	3	all	all	4,5	4	0.7
185	12	Music	F	4,5,6	2	all	all	2,3	5,6	0.3	all	all	all
186	12	Music	F					2,3	4	0.7			
187	12	Music	M	5	2	all	all	3	all	all	4	4	0.7
188	12	Music	M	6	3								
189	12	Traffic	F	all	2	all	all	3	4,5,6	0.3	all	4	0.7
190	12	Traffic	F					3	6	0.5	4	5,6	0.7
191	12	Traffic	F					3	7	0.7			
192	12	Traffic	M	6	3	4	3	3	all	all	4,5	4	0.7
193	12	Traffic	M			5	4						

				FS		FT		NLC		NLC_FT		
NO	**SUBJECT**	**NOISE**	**GENDER**	**SF**	**SA**	**SF**	**SA**	**CF**	**WF**	**EF**	**CF**	**WF**
1	1	No Noise	F	6	3	4	3	4	0.5	5	4	0.3
2	1	No Noise	F					4	0.7			
3	1	No Noise	F					5	0.7			
4	1	No Noise	M	6	2	4	2	4	0.7	5	5	0.5
5	1	No Noise	M	4	3850	5	2					
6	1	No Noise	M			6	2,3					
7	1	High Frequency	F	6	2,3	4	3	4	0.7	2	4	0.7
8	1	High Frequency	M	4	3850	all	all	4	0.7	2	4	0.7
9	1	Restaurant	F	5	4	4	3	4,6,7	0.3	5	4,5,6	0.3
10	1	Restaurant	F	6	5	5	4, 4850					
11	1	Restaurant	M	5	4850	4	3	4,5	0.3	3,5	5	0.3
12	1	Restaurant	M			5	4			5	6	0.3
13	1	Music	F	6	5	4	3, 3850	6	0.3	5	6	0.3
14	1	Music	F			5	4850					
15	1	Music	M	6	3	4	3	5	0.3	5	6	0.3
16	1	Traffic	F	5,6	4	4	3, 3850	4	0.7	all	4	0.7
17	1	Traffic	F	6	5	5	3,4, 4850	7	0.3			
18	1	Traffic	M	4	3850	4	3, 3850	4	0.7	5	7	0.3
19	1	Traffic	M	5	4, 4850	5	3,4, 4850					
20	2	No Noise	F	4	2,3	6	2	4	0.7	2	7	0.3
21	2	No Noise	F	5,6	2							
22	2	No Noise	M	4	3	6	2	4	0.7	3	6	0.5
23	2	High Frequency	F	6	2,3	4	3	4	0.7	2,5	4	0.7
24	2	High Frequency	M	4	3850	all	All	4	0.7	2	4	0.7

				FS		FT		NLC		NLC_FT		
NO	**SUBJECT**	**NOISE**	**GENDER**	**SF**	**SA**	**SF**	**SA**	**CF**	**WF**	**EF**	**CF**	**WF**
25	2	Restaurant	F	5	4	4	3	4,6,7	0.3	5	4,5,6	0.3
26	2	Restaurant	F	6	5	5	4, 4850					
27	2	Restaurant	M	5	4850	4	3	4,5	0.3	3,5	5	0.3
28	2	Restaurant	M			5	4			5	6	0.3
29	2	Music	F	6	5	4	3	6	0.3	3,5	6	0.3
30	2	Music	F			5	4850					
31	2	Music	M	6	3	4	3	5	0.3	5	6	0.3
32	2	Traffic	F	5,6	4	4	3, 3850	4	0.7	all	4	0.7
33	2	Traffic	F	6	5	5	3,4,4850	7	0.3			
34	2	Traffic	M	4	3850	4	3, 3850	4	0.7	5	7	0.3
35	2	Traffic	M	5	4, 4850	5	3,4,4850			all	4	0.7
36	2	Traffic	M	6	5							
37	3	No Noise	F	4	3850	5	3	4	0.5	4	7	0.3
38	3	No Noise	M	4	3850	6	3	4	0.5	5	6	0.5
39	3	No Noise	M					4	0.7			
40	3	High Frequency	F	6	2,3	4	3	4	0.7	2	4	0.7
41	3	High Frequency	M	4	3850	all	All	4	0.7	2	4	0.7
42	3	Restaurant	F	5	4	4	3	4,6,7	0.3	5	4,5,6	0.3
43	3	Restaurant	F	6	5	5	4, 4850					
44	3	Restaurant	M	5	4850	4	3	4,5	0.3	3,5	5	0.3
45	3	Restaurant	M			5	4					
46	3	Music	F	6	5	4	3, 3850	6	0.3	5	6	0.3
47	3	Music	F			5	4850					
48	3	Music	M	6	3	4	3, 3850	5	0.3	5	5,6	0.3
49	3	Music	M	5	4	5	4850					

				FS		FT		NLC		NLC_FT		
NO	**SUBJECT**	**NOISE**	**GENDER**	**SF**	**SA**	**SF**	**SA**	**CF**	**WF**	**EF**	**CF**	**WF**
50	3	Traffic	F	5,6	4	4	3, 3850	4	0.7	all	4	0.7
51	3	Traffic	F	6	5	5	3,4, 4850	7	0.3			
52	3	Traffic	M	4	3850	4	3, 3850	4	0.7	5	7	0.3
53	3	Traffic	M	5	4, 4850	5	3,4, 4850			all	4	0.7
54	3	Traffic	M	6	5							
55	4	No Noise	F	4	2	6	2	4	0.7	2	7	0.3
56	4	No Noise	M	4	2,3	6	2,5,5850	4	0.7	2	6	0.5
57	4	High Frequency	F	6	2,3	4	3	4	0.7	2	4	0.7
58	4	High Frequency	M	4	3850	all	all	4	0.7	2	4	0.7
59	4	Restaurant	F	5	4	4	3	4,6,7	0.3	5	4,6	0.3
60	4	Restaurant	F	6	5	5	4, 4850					
61	4	Restaurant	M	5	4850	4	3	4,5	0.3	3	5	0.3
62	4	Restaurant	M			5	4					
63	4	Music	F	6	5	4	3, 3850	6	0.3	3,5	6	0.3
64	4	Music	F			5	4850					
65	4	Music	M	6	3	4	3	5	0.3	5	6	0.3
66	4	Traffic	F	5,6	4	4	3, 3850	4	0.7	all	4	0.7
67	4	Traffic	F	6	5	5	3,4, 4850	7	0.3			
68	4	Traffic	M	4	3850	4	3, 3850	4	0.7	5	7	0.3
69	4	Traffic	M	5	4, 4850	5	3,4, 4850			all	4	0.7
70	4	Traffic	M	6	5							
71	5	No Noise	F	6	5850	4	3850	5	0.3	5	6	0.3
72	5	No Noise	M	6	5850	4	3850	5	0.3	5	5	0.3
73	5	High Frequency	F	6	3	4	3	4	0.7	5	6	0.7

				FS		FT		NLC		NLC_FT		
NO	SUBJECT	NOISE	GENDER	SF	SA	SF	SA	CF	WF	EF	CF	WF
74	5	High Frequency	M	4	3850	all	all	4	0.7	5	6,7	0.3
75	5	High Frequency	M							2	4	0.7
76	5	Restaurant	F	5	4	4	3	4	0.3	5	4,5,6	0.3
77	5	Restaurant	F	6	4,5	5	4, 4850					
78	5	Restaurant	M	5	4850	4	3	4,5	0.3	5	7	0.3
79	5	Restaurant	M			5	4					
80	5	Music	F	6	4,5	4	3850	5	0.3	5	6	0.3
81	5	Music	M	6	3	4	3850	5	0.3	5	6	0.3
82	5	Music	M	5	4850							
83	5	Traffic	F	6	3,4,5	4	3, 3850	4	0.7	all	4,6	0.7
84	5	Traffic	F			5	3,4, 4850					
85	5	Traffic	M	4	3850	4	3, 3850	4	0.7	5	7	0.3
86	5	Traffic	M	5	4850	5	3,4, 4850			all	4	0.7
87	6	No Noise	F	5	4	4	3850	5	0.3	5	6	0.70
88	6	No Noise	F	6	4,5							
89	6	No Noise	M	6	5850	4	3850	5	0.3	5	5	0.3
90	6	High Frequency	F	6	4	4	3850	6	0.7	5	6	0.7
91	6	High Frequency	M	6	5850	4	3850	5	0.7	5	5	0.3
92	6	Restaurant	F	5	4	4	3850	5	0.3	4,5	6	0.7
93	6	Restaurant	F	6	5							
94	6	Restaurant	M	6	5850	all	all	5	0.3	5	5,7	0.3
95	6	Music	F	6	4, 5850	5	4	5	0.3	4,5	6	0.7
96	6	Music	F			4	3850					
97	6	Music	M	6	5850	4	3850	5	0.3	5	5,7	0.3
98	6	Traffic	F	6	3,4	4	3, 3850	6	0.7	4,5	6	0.7

				FS		FT		NLC		NLC_FT		
NO	**SUBJECT**	**NOISE**	**GENDER**	**SF**	**SA**	**SF**	**SA**	**CF**	**WF**	**EF**	**CF**	**WF**
99	6	Traffic	F			5	3,4, 4850					
100	6	Traffic	M	6	5850	4	3, 3850	5,6	0.7	5	5	0.3
101	6	Traffic	M			5	3,4, 4850			5	5	0.7
102	7	No Noise	F	5	4850	4	3	5	0.5	5	6	0.30
103	7	No Noise	F			5	4850					
104	7	No Noise	M	5	4850	4	3, 3850	5	0.7	2	5	0.3
105	7	No Noise	M									
106	7	High Frequency	F	6	2,3	4	3	4	0.7	2,4	4	0.7
107	7	High Frequency	M	4	3850	all	all	4	0.7	2	4	0.7
108	7	Restaurant	F	5	4	4	3	4	0.3	5	4,5,6	0.3
109	7	Restaurant	F	6	5	5	4, 4850					
110	7	Restaurant	M	5	4850	4	3	5	0.3	5	5	0.3
111	7	Restaurant	M			5	4					
112	7	Music	F	6	5	4	3, 3850	4,5,6	0.3	5	6	0.3
113	7	Music	F			5	4850					
114	7	Music	M	6	3	4	3	5	0.3	5	5,6	0.3
115	7	Traffic	F	5,6	4	4	3, 3850	4	0.7	all	4	0.7
116	7	Traffic	F	6	5	5	3,4, 4850					
117	7	Traffic	M	4	3850	4	3, 3850	4	0.7	5	7	0.3
118	7	Traffic	M	5	4, 4850	5	3,4, 4850					
119	7	Traffic	M	6	5							
120	8	No Noise	F	4	3850	5	3	4	0.5	4	6, 10	0.3
121	8	No Noise	F									
122	8	No Noise	M	4	3850	5	2,3	4	0.5	4	4	0.3
123	8	No Noise	M			6	2,3,4	4	0.7			

				FS		FT		NLC		NLC_FT		
NO	**SUBJECT**	**NOISE**	**GENDER**	**SF**	**SA**	**SF**	**SA**	**CF**	**WF**	**EF**	**CF**	**WF**
124	8	High Frequency	F	6	2,3	4	3	4	0.7	2	4	0.7
125	8	High Frequency	M	4	3850	all	all	4	0.7	2,4,5	4	0.7
126	8	Restaurant	F	5	4	4	3	4,6,7	0.3	5	4,5,6	0.3
127	8	Restaurant	F	6	5	5	4, 4850					
128	8	Restaurant	M	5	4850	4	3	5	0.3	3	5	0.3
129	8	Restaurant	M			5	4					
130	8	Music	F	6	5	4	3, 3850	6	0.3	5	6	0.3
131	8	Music	F			5	4850					
132	8	Music	M	6	3	4	3, 3850	5	0.3	5	5,6	0.3
133	8	Music	M	5	4	5	4850					
134	8	Traffic	F	5,6	4	4	3, 3850	4	0.7	all	4	0.7
135	8	Traffic	F	6	5	5	3,4, 4850	7	0.3			
136	8	Traffic	M	4	3850	4	3, 3850	4	0.7	5	7	0.3
137	8	Traffic	M	5	4, 4850	5	3,4, 4850			all	4	0.7
138	8	Traffic	M	6	5							
139	9	No Noise	F	4	2	4	2	4	0.7	4	5	0.3
140	9	No Noise	F	5	2	5	2			4	5,6,7	0.5
141	9	No Noise	F									
142	9	No Noise	M	4	2	6	5850	4	0.7	4	5	0.5
143	9	High Frequency	F	6	2,3	4	3	4	0.7	2	4	0.7
144	9	High Frequency	M	4	3850	all	all	4	0.7	2	4	0.7
145	9	Restaurant	F	5	4	4	3	4,6,7	0.3	5	4,5,6	0.3
146	9	Restaurant	F	6	5	5	4, 4850					
147	9	Restaurant	M	5	4850	4	3	5	0.3	3	5	0.3

				FS		FT		NLC		NLC_FT		
NO	**SUBJECT**	**NOISE**	**GENDER**	**SF**	**SA**	**SF**	**SA**	**CF**	**WF**	**EF**	**CF**	**WF**
148	9	Restaurant	M			5	4					
149	9	Music	F	6	5	4	3, 3850	6	0.3	5	6	0.3
150	9	Music	F			5	4850					
151	9	Music	M	6	3	4	3	5	0.3	5	6	0.3
152	9	Traffic	F	5,6	4	4	3, 3850	4	0.7	all	4	0.7
153	9	Traffic	F	6	5	5	3,4, 4850	7	0.3			
154	9	Traffic	M	4	3850	4	3, 3850	4	0.7	5	7	0.3
155	9	Traffic	M	5	4, 4850	5	3,4, 4850			all	4	0.7
156	9	Traffic	M	6	5							
157	10	No Noise	F	5,6	2	4,5	2	4	0.7	4	5	0.5
158	10	No Noise	M	5	2,3	6	2,3	4	0.7	3	6	0.5
159	10	No Noise	M	6	2							
160	10	High Frequency	F	6	2,3	4	3	4	0.7	2,4	4	0.7
161	10	High Frequency	M	4	3850	all	all	4	0.7	2,4,5	4	0.7
162	10	Restaurant	F	5	4	4	3	4,6,7	0.3	5	4,5,6	0.3
163	10	Restaurant	F	6	5	5	4, 4850					
164	10	Restaurant	M	5	4850	4	3	5	0.3	3	5	0.3
165	10	Restaurant	M			5	4					
166	10	Music	F	6	5	4	3, 3850	6	0.3	5	6	0.3
167	10	Music	F			5	4850					
168	10	Music	M	6	3	4	3	5	0.3	5	6	0.3
169	10	Traffic	F	5,6	4	4	3, 3850	4	0.7	all	4	0.7
170	10	Traffic	F	6	5	5	3,4, 4850	7	0.3			
171	10	Traffic	M	4	3850	4	3, 3850	4	0.7	5	7	0.3
172	10	Traffic	M	5	4, 4850	5	3,4, 4850					

				FS		**FT**		**NLC**		**NLC_FT**		
NO	**SUBJECT**	**NOISE**	**GENDER**	**SF**	**SA**	**SF**	**SA**	**CF**	**WF**	**EF**	**CF**	**WF**
173	10	Traffic	M	6	5							
174	11	No Noise	F	4	2	6	2	4	0.7	4	4	0.3
175	11	No Noise	M	4	2,3	6	2,3,4,5, 5850	4	0.7	3	5	0.5
176	11	High Frequency	F	6	2,3	4	3	4	0.7	2,4	4	0.7
177	11	High Frequency	M	4	3850	all	all	4	0.7	all	4	0.7
178	11	Restaurant	F	5	4	4	3	4,6,7	0.3	5	4,5,6	0.3
179	11	Restaurant	F	6	5	5	4, 4850					
180	11	Restaurant	M	5	4850	4	3	5	0.3	3	5	0.3
181	11	Restaurant	M			5	4					
182	11	Music	F	6	5	4	3, 3850	6	0.3	3,5	6	0.3
183	11	Music	F			5	4850					
184	11	Music	M	6	3	4	3	5	0.3	5	6	0.3
185	11	Traffic	F	5,6	4	4	3, 3850	4	0.7	all	4	0.7
186	11	Traffic	F	6	5	5	3,4, 4850	7	0.3			
187	11	Traffic	M	4	3850	4	3, 3850	4	0.7	5	7	0.3
188	11	Traffic	M	5	4, 4850	5	3,4, 4850					
189	11	Traffic	M	6	5							
190	12	No Noise	F	5	4850	5	4850	4,5	0.3	5	7	0.3
191	12	No Noise	M	4	3850	4	2,3, 3850	5	0.3	5	7	0.3
192	12	No Noise	M			5	2,3,4, 4850					
193	12	High Frequency	F	6	2,3	all	all	4	0.7	2	4	0.7
194	12	High Frequency	M	4	3850	all	all	4	0.7	2	4	0.7
195	12	High Frequency	M	5	4850							
196	12	Restaurant	F	6	5	5	4850	6,7	0.3	5	6	0.3
197	12	Restaurant	F	5	4850	4	3850					

				FS		FT		NLC		NLC_FT		
NO	**SUBJECT**	**NOISE**	**GENDER**	**SF**	**SA**	**SF**	**SA**	**CF**	**WF**	**EF**	**CF**	**WF**
198	12	Restaurant	M	5	4850	4	3, 3850	5	0.3	5	7	0.3
199	12	Restaurant	M			5	4, 4850					
200	12	Music	F	6	5	5	4850	6	0.3	5	6	0.3
201	12	Music	F									
202	12	Music	M	5	4850	4	3850	5	0.3	5	6	0.3
203	12	Music	M									
204	12	Traffic	F	6	all	4	3, 3850	4	0.7	all	4	0.7
205	12	Traffic	F			5	3,4, 4850					
206	12	Traffic	M	6	5850	4	3, 3850	4	0.7	all	4	0.7
207	12	Traffic	M	5	4850	5	3,4, 4850					

APPENDIX E: The Results of MRT and SII in Experiment IV

NO	SUBJECT	METHOD	NOISE	SII	MRT
1	1	NLC	No Noise	0.74	71
2	1	NLC	High Frequency	0.31	61
3	1	NLC_FT	No Noise	0.76	81
4	1	NLC_FT	High Frequency	0.33	75
5	1	FS	No Noise	0.75	89
6	1	FS	High Frequency	0.24	71
7	1	A	No Noise	0.45	83
8	1	A	High Frequency	0.12	60
9	2	NLC	No Noise	0.77	72
10	2	NLC	High Frequency	0.31	76
11	2	NLC	Traffic	0.29	77
12	2	NLC_FT	No Noise	0.88	87
13	2	NLC_FT	High Frequency	0.35	67
14	2	NLC_FT	Traffic	0.31	65
15	2	A	No Noise	0.79	57
16	2	A	High Frequency	0.12	39
17	2	A	Traffic	0.09	67
18	3	NLC	No Noise	0.74	69
19	3	NLC	High Frequency	0.31	61
20	3	NLC	Restaurant	0.33	53
21	3	NLC_FT	No Noise	0.82	85
22	3	NLC_FT	High Frequency	0.34	55
23	3	NLC_FT	Restaurant	0.31	27
24	3	A	No Noise	0.6	39
25	3	A	High Frequency	0.12	35
26	3	A	Restaurant	0.03	16
27	4	NLC	High Frequency	0.31	77
28	4	NLC	Restaurant	0.33	73
29	4	NLC_FT	High Frequency	0.2	91
30	4	NLC_FT	Restaurant	0.18	56
31	4	A	High Frequency	0.12	84
32	4	A	Restaurant	0.04	83
33	5	NLC	No Noise	0.52	69
34	5	NLC	High Frequency	0.29	36
35	5	NLC_FT	No Noise	0.38	69
36	5	NLC_FT	High Frequency	0.26	29
37	5	A	No Noise	0.14	67
38	5	A	High Frequency	0.11	59

NO	SUBJECT	METHOD	NOISE	SII	MRT
39	6	NLC	High Frequency	0.21	79
40	6	NLC	Restaurant	0.17	45
41	6	NLC	Traffic	0.21	36
42	6	A	High Frequency	0.06	49
43	6	A	Restaurant	0.03	21
44	6	A	Traffic	0.06	31
45	7	NLC	No Noise	0.65	68
46	7	NLC	Music	0.4	47
47	7	NLC_FT	No Noise	0.59	52
48	7	NLC_FT	Music	0.38	44
49	7	FS	No Noise	0.63	68
50	7	FS	Music	0.31	49
51	7	A	No Noise	0.27	63
52	7	A	Music	0.1	64
53	8	NLC	No Noise	0.74	83
54	8	NLC	High Frequency	0.31	69
55	8	NLC_FT	No Noise	0.81	81
56	8	NLC_FT	High Frequency	0.34	41
57	8	FS	No Noise	0.77	87
58	8	FS	High Frequency	0.24	75
59	8	A	No Noise	0.56	55
60	8	A	High Frequency	0.12	36
61	9	NLC	No Noise	0.78	84
62	9	NLC	High Frequency	0.3	61
63	9	NLC_FT	No Noise	0.78	79
64	9	NLC_FT	High Frequency	0.35	43
65	9	A	No Noise	0.66	76
66	9	A	High Frequency	0.12	65
67	10	NLC	No Noise	0.76	77
68	10	NLC	High Frequency	0.31	67
69	10	NLC_FT	No Noise	0.79	84
70	10	NLC_FT	High Frequency	0.33	61
71	10	FS	No Noise	0.78	71
72	10	FS	High Frequency	0.24	60
73	10	FT	No Noise	0.16	84
74	10	FT	High Frequency	0.16	63
75	10	A	No Noise	0.55	71
76	10	A	High Frequency	0.12	91
77	11	NLC	No Noise	0.78	77
78	11	NLC	High Frequency	0.31	75
79	11	NLC	Restaurant	0.33	65
80	11	NLC_FT	No Noise	0.85	85

NO	SUBJECT	METHOD	NOISE	SII	MRT
81	11	NLC_FT	High Frequency	0.34	57
82	11	NLC_FT	Restaurant	0.31	35
83	11	FS	No Noise	0.82	88
84	11	FS	High Frequency	0.24	72
85	11	FS	Restaurant	0.25	79
86	11	FT	No Noise	0.18	92
87	11	FT	High Frequency	0.19	77
88	11	FT	Restaurant	0.19	91
89	11	A	No Noise	0.77	77
90	11	A	High Frequency	0.12	87
91	11	A	Restaurant	0.04	72
92	12	NLC	High Frequency	0.31	64
93	12	NLC	Restaurant	0.27	51
94	12	NLC_FT	High Frequency	0.34	87
95	12	NLC_FT	Restaurant	0.21	43
96	12	FS	High Frequency	0.23	69
97	12	FS	Restaurant	0.18	75
98	12	A	High Frequency	0.12	27
99	12	A	Restaurant	0.03	15

APPENDIX F: The Values of Parameters of FLMs for the Highest Intelligibility Increment of Second Hearing Impaired Group in Experiment V

		Unprocessed	A		A_FS				A_FT			
Subject	**Noise**	**SII**	**SII**	**IMP**	**SF**	**SA**	**SII**	**IMP**	**SF**	**SA**	**SII**	**IMP**
1	No Noise	0.62	0.68	0.06	4	3	0.77	0.15	5	4	0.77	0.15
1	High Frequency	0.02	0.13	0.11	5	4	0.30	0.28	5	4	0.32	0.30
1	Traffic	0.04	0.09	0.05	5	5	0.29	0.25	5	2	0.28	0.24
1	Music	0.09	0.12	0.03	6	2	0.29	0.20	5	2	0.25	0.16
1	Restaurant	0.01	0.03	0.02	6	2	0.27	0.26	5	2	0.21	0.20
2	No Noise	0.49	0.74	0.25	4	2	0.78	0.29	5	3	0.78	0.29
2	High Frequency	0.32	0.12	-0.20	5	4	0.30	-0.02	5	4	0.32	0.00
2	Traffic	0.20	0.09	-0.11	5	5	0.29	0.09	5	2	0.29	0.09
2	Music	0.07	0.16	0.09	5	5	0.28	0.21	5	2	0.26	0.19
2	Restaurant	0.36	0.04	-0.32	6	2	0.26	-0.10	5	2	0.22	-0.14
3	No Noise	0.46	0.71	0.25	5	3	0.79	0.33	4	3	0.79	0.33
3	High Frequency	0.32	0.12	-0.20	5	5	0.34	0.02	5	4	0.35	0.03
3	Traffic	0.20	0.09	-0.11	5	5	0.34	0.14	5	4	0.34	0.14
3	Music	0.07	0.16	0.09	5	5	0.36	0.29	4	3	0.36	0.29
3	Restaurant	0.36	0.04	-0.32	5	2	0.32	-0.04	4	3	0.32	-0.04
4	No Noise	0.75	0.85	0.10	4	2	0.80	0.05	5	3	0.80	0.05
4	High Frequency	0.32	0.12	-0.20	5	4	0.30	-0.02	5	4	0.32	0.00
4	Traffic	0.20	0.09	-0.11	5	5	0.29	0.09	5	2	0.28	0.08
4	Music	0.07	0.17	0.10	6	2	0.29	0.22	5	2	0.25	0.18
4	Restaurant	0.40	0.04	-0.36	6	2	0.27	-0.13	5	2	0.21	-0.19

		Unprocessed	**A_NLC**					**FS**			
Subject	**Noise**	**SII**	**SF**	**CF**	**WF**	**SII**	**IMP**	**SF**	**SA**	**SII**	**IMP**
1	No Noise	0.62	1	4	0.7	0.76	0.14	4	3	0.77	0.15
1	High Frequency	0.02	3	6	0.3	0.30	0.28	6	3	0.24	0.22
1	Traffic	0.04	2	4	0.3	0.28	0.24	6	5	0.25	0.21
1	Music	0.09	1	4	0.3	0.29	0.20	6	5	0.33	0.24
1	Restaurant	0.01	1	5	0.7	0.25	0.24	6	5	0.25	0.24
2	No Noise	0.49	1	4	0.7	0.76	0.27	5	2	0.80	0.31
2	High Frequency	0.32	3	6	0.3	0.30	-0.02	6	3	0.24	-0.08
2	Traffic	0.20	2	4	0.3	0.28	0.08	6	5	0.25	0.05
2	Music	0.07	3	4	0.3	0.29	0.22	6	5	0.34	0.27
2	Restaurant	0.36	1	4	0.3	0.26	-0.10	5	4	0.25	-0.11
3	No Noise	0.46	3	4	0.7	0.79	0.33	6	2	0.79	0.33
3	High Frequency	0.32	2	4	0.3	0.32	0.00	6	3	0.24	-0.08
3	Traffic	0.20	2	4	0.5	0.32	0.12	6	5	0.25	0.05
3	Music	0.07	3	4	0.5	0.35	0.28	6	5	0.34	0.27
3	Restaurant	0.36	1	4	0.5	0.31	-0.05	5	4	0.25	-0.11
4	No Noise	0.75	1	4	0.7	0.77	0.02	4	2	0.82	0.07
4	High Frequency	0.32	3	6	0.3	0.30	-0.02	6	3	0.24	-0.08
4	Traffic	0.20	2	4	0.3	0.28	0.08	6	5	0.25	0.05
4	Music	0.07	1	4	0.3	0.30	0.23	6	5	0.35	0.28
4	Restaurant	0.40	1	5	0.3	0.25	-0.15	5	4	0.25	-0.15

		Unprocessed	**FT**				**NLC**			
Subject	**Noise**	**SII**	**SF**	**SA**	**SII**	**IMP**	**CF**	**WF**	**SII**	**IMP**
1	No Noise	0.62	6	3	0.76	0.14	4	0.7	0.74	0.12
1	High Frequency	0.02	4	3	0.25	0.23	4	0.7	0.31	0.29
1	Traffic	0.04	5	4	0.21	0.17	7	0.3	0.29	0.25
1	Music	0.09	4	3.850	0.25	0.16	6	0.3	0.41	0.32
1	Restaurant	0.01	5	4.850	0.18	0.17	4	0.3	0.32	0.31
2	No Noise	0.49	6	2	0.79	0.30	4	0.7	0.77	0.28
2	High Frequency	0.32	4	3	0.25	-0.07	4	0.7	0.31	-0.01
2	Traffic	0.20	5	4	0.21	0.01	7	0.3	0.29	0.09
2	Music	0.07	5	4.850	0.26	0.19	6	0.3	0.42	0.35
2	Restaurant	0.36	5	4.850	0.18	-0.18	4	0.3	0.33	-0.03
3	No Noise	0.46	5	2	0.79	0.33	4	0.7	0.77	0.31
3	High Frequency	0.32	4	3	0.25	-0.07	4	0.7	0.31	-0.01
3	Traffic	0.20	5	4	0.21	0.01	7	0.3	0.29	0.09
3	Music	0.07	5	4.850	0.26	0.19	6	0.3	0.42	0.35
3	Restaurant	0.36	5	4.850	0.18	-0.18	4	0.3	0.33	-0.03
4	No Noise	0.75	6	2	0.81	0.06	4	0.7	0.77	0.02
4	High Frequency	0.32	4	3	0.25	-0.07	4	0.7	0.31	-0.01
4	Traffic	0.20	5	4	0.21	0.01	7	0.3	0.30	0.10
4	Music	0.07	5	4.850	0.26	0.19	6	0.3	0.42	0.35
4	Restaurant	0.40	5	4.850	0.18	-0.22	4	0.3	0.33	-0.07

		Unprocessed	**A_NLC_FT**					**NLC_FT**				
Subject	**Noise**	**SII**	**EF**	**CF**	**WF**	**SII**	**IMP**	**EF**	**CF**	**WF**	**SII**	**IMP**
1	No Noise	0.62	4	6	0.3	0.79	0.17	4	7	0.3	0.84	0.22
1	High Frequency	0.02	5	4	0.7	0.30	0.28	2	4	0.7	0.35	0.33
1	Traffic	0.04	6	7	0.3	0.28	0.24	3	4	0.7	0.31	0.27
1	Music	0.09	6	7	0.3	0.29	0.20	5	6	0.3	0.49	0.40
1	Restaurant	0.01	6	7	0.3	0.28	0.27	2	4	0.7	0.20	0.19
2	No Noise	0.49	5	5	0.7	0.82	0.33	3	7	0.3	0.88	0.39
2	High Frequency	0.32	5	4	0.7	0.30	-0.02	2	4	0.7	0.36	0.04
2	Traffic	0.20	6	7	0.3	0.27	0.07	4	4	0.7	0.32	0.12
2	Music	0.07	6	7	0.3	0.27	0.20	5	6	0.3	0.49	0.42
2	Restaurant	0.36	6	7	0.3	0.28	-0.08	5	6	0.3	0.33	-0.03
3	No Noise	0.46	6	6	0.7	0.79	0.33	3	7	0.3	0.87	0.41
3	High Frequency	0.32	6	5	0.5	0.34	0.02	2	4	0.7	0.36	0.04
3	Traffic	0.20	6	7	0.7	0.33	0.13	4	4	0.7	0.32	0.12
3	Music	0.07	5	7	0.3	0.35	0.28	5	6	0.3	0.49	0.42
3	Restaurant	0.36	5	7	0.3	0.31	-0.05	5	6	0.3	0.33	-0.03
4	No Noise	0.75	4	4	0.5	0.86	0.11	2	7	0.3	0.90	0.15
4	High Frequency	0.32	5	4	0.7	0.30	-0.02	2	4	0.7	0.36	0.04
4	Traffic	0.20	6	6	0.3	0.27	0.07	4	4	0.7	0.32	0.12
4	Music	0.07	6	7	0.3	0.30	0.23	5	6	0.3	0.49	0.42
4	Restaurant	0.40	6	7	0.3	0.28	-0.12	5	6	0.3	0.33	-0.07

APPENDIX G: Ethical Forms for Subjects

1. Information Form for Subjects

O.D.T.Ü. ENFORMATİK ENSTİTÜSÜ TIP BİLİŞİMİ AD
UMUT ARIÖZ DOKTORA TEZ ÇALIŞMASI
KATILIMCI BİLGİ FORMU

Adınız :
Soyadınız:
Cinsiyetiniz:
Yaşınız:
Eğitim Durumunuz:

İşitme Kaybınız Var mı? :
Var ise;
Hangi kulağınızda işitme kaybı var? :

İşitme kaybının oluşma nedeni:

İşitme kaybınız ne kadar süreden beri var ? :

Kulaklık Cihazı kullanıyor musunuz?

2. Voluntary Participation Form

Gönüllü Katılım Formu

Bu çalışma, Öğr.Gör.Dr. Banu Günel danışmanlığında yürütülen Umut ARIÖZ'e ait bir doktora tez çalışmadır. Çalışmanın amacı, işitme kaybına sahip insanların nasıl duyduklarının modellenerek simule edilmesi ve bu kayıplarının iyileştirilmesine yönelik yeni algoritmaların geliştirilmesidir. Çalışmaya katılım tamimiyle gönüllülük temelinde olmalıdır. Formlarda, sizden kimlik belirleyici hiçbir bilgi istenmemektedir. Cevaplarınız tamimiyle gizli tutulacak ve sadece araştırmacılar tarafından değerlendirilecektir; elde edilecek bilgiler bilimsel yayımlarda kullanılacaktır.

Uygulama, kulaklıklardan ses dinletilmesi şeklinde gerçekleştirilecek olup sizden duyduğunuz kelimeleri size verilen listeden işaretlemekten ibaret olacaktır. Genel olarak kişisel rahatsızlık verecek derecede yüksek bir ses seviyesi uygulamada kullanılmayacaktır. Ancak, katılım sırasında seslerden ya da herhangi başka bir nedenden ötürü kendinizi rahatsız hissederseniz cevaplama işini yarıda bırakıp çıkmakta serbestsiniz. Böyle bir durumda uygulamadaki sorumlu kişiye, cevaplama işini tamamlamadığınızı söylemek yeterli olacaktır. Anket sonunda, bu çalışmayla ilgili sorularınız cevaplanacaktır. Bu çalışmaya katıldığınız için şimdiden teşekkür ederiz. Çalışma hakkında daha fazla bilgi almak için Enformatik Enstitüsü Bilişim Sistemleri Bölümü öğretim üyelerinden, Öğr.Gör.Dr. Banu Günel (Oda: B220; Tel: 210 7866; E-posta: bgunel@ii.metu.edu.tr) ya da doktora öğrencisi Umut Arıöz (Tel: 0 505 231 8360; E-posta: umutarioz@gmail.com) ile iletişim kurabilirsiniz.

Bu çalışmaya tamamen gönüllü olarak katılıyorum ve istediğim zaman yarıda kesip çıkabileceğimi biliyorum. Verdiğim bilgilerin bilimsel amaçlı yayımlarda kullanılmasını kabul ediyorum. (Formu doldurup imzaladıktan sonra uygulayıcıya geri veriniz).

İsim Soyad Tarih İmza

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3. Information Form after the Test for Subjects

KATILIM SONRASI BİLGİ FORMU

Bu çalışma, Öğr.Gör.Dr. Banu Günel danışmanlığında yürütülen Umut ARIÖZ'e ait bir doktora tez çalışmadır. Çalışmanın amacı, işitme kaybına sahip insanların nasıl duyduklarının modellenerek simule edilmesi ve bu kayıplarının iyileştirilmesine yönelik yeni algoritmaların geliştirilmesidir.

Bu çalışma sayesinde ilk olarak işitme kaybına sahip bir insanın kulağının nasıl duyduğuna dair bir modelleme simülasyonu gerçekleştirilecektir. Geliştirilen yeni metodlara dair kodlamalar sayesinde farklı işitme kaybı sorunlarına yönelik (özellikle yüksek frekans işitme kayıpları) bir iyileştirme algoritması gerçekleştirilmiş olacaktır. Bu algoritma bir anlamda yeni bir işitme cihazı yazılımı görevi görecektir.

Çalışma sadece kulaklıktan sen dinletmeden ibaret olacağı için herhangi bir fiziksel ve/ya ruhsal sağlığını tehdit edici ya da katılımcılar için stres kaynağı olabilecek unsur içermemektedir. Çalışmalarımız sessiz ve sakin bir ortamdan gerçekleştirileceği için ayrıca bir rahatlık hissi uyandıracağı düşünülmektedir.

Bu çalışma sayesinde insan kulağının etkilerinin de göz önüne alınarak bir modelleme simülasyonunun gerçekleştirilmesi ve bunun güvenilirliğinin denenmesi literatürdeki benzerlerine göre daha çok geliştirilmiş ve farklı kombinasyonlar denenerek farklı uygulama alanlarının ortaya konulmasına sebep olacaktır. Çalışma kapsamında geliştirilecek olan iyileştirme algoritmaları (yükseltme, frekans sıkıştırma ve frekans kaydırma) kendi alanlarında yeni uygulamalar olacaktır.

Bu çalışma sayesinde işitme kaybına sahip özellikle günümüz cihazlarından en çok memnuniyetsizlik yaşayan yüksek frekans işitme kaybına sahip insanların daha iyi ve net bir şekilde duymasına ve anlaması sebep olacaktır.

Bu çalışmadan alınacak ilk verilerin Aralık 2011 sonunda elde edilmesi amaçlanmaktadır. Elde edilen bilgiler sadece bilimsel araştırma ve yazılarda kullanılacaktır. Çalışmanın sonuçlarını öğrenmek ya da bu araştırma hakkında daha fazla bilgi almak için aşağıdaki isimlere başvurabilirsiniz. Bu araştırmaya katıldığınız için tekrar çok teşekkür ederiz.

Öğr.Gör.Dr. Banu Günel (Oda: B220; Tel: 210 7866;
E-posta: bgunel@ii.metu.edu.tr)

Doktora öğrencisi Umut Arıöz (Tel: 0 505 231 8360;
E-posta: umutarioz@gmail.com)

CURRICULUM VITAE

Date of Birth & Place: 1979, Ankara

Education:
Dokuz Eylül University Dep. of Electrical & Electronics Engineering, 1997-2001
Hacettepe University Graduate School of Natural and Applied Sciences, Dep. of Electrical & Electronics Engineering, Biomedical, M.S., 2001-2004
Middle East Technical University Graduate School of Informatics, Medical Informatics, Ph.D., 2004-2012

Spoken Languages: Turkish and English

Work Experiences:

- Research Assistant, Medical Education and Informatics, Hacettepe Unv. (2001-2010)
- Expert, Project Coordination Implementation and Research Center, Gazi Unv. (2010-)

Certificates :

- The 4th FMRI (Functional Magnetic Resonance Imaging) analysis with AFNI (Analysis of Functional Neuroimaging) and SUMA (Surface Mapping) course, Pisa, Italy, June 2006. (Photos)
- Project Cycle Management, 2005
- Microsoft Certified Professioal, 2002

Affiliations:

- Organization for Human Brain Mapping, Student Member
- IEEE Student Member
- Informatics Association Of Turkey
- Medical Informatics Association
- Chamber of Electrical Engineers

Project Experiences:

- Contact person of Hacettepe University and member of Project Management group of finished TOI Project (2008-1-TR1-LEO05-03140, “Virtual Learning Environment For Rational Drug Use”)

- Contact person of Gazi University and member of Project Management group of finished Ankara Development Agency Project (TR51-10-DFD-0093, “Feasibility Report of Competition Analysis For Ankara Province”)

- Contact person of Gazi University and member of Project Management group of finished Ankara Development Agency Project (TR51/11/DFD/0058, “Feasibility Report of Innovation Center For Ankara Province”)

- Independent Project Assessor

    - Turkish National Agency - Youth Programmes (2007 - cont)
    - Turkish National Agency - Leonardo Da Vinci Programmes (2010)
    - Ankara Development Agency - Innovative Implemantations Programme (2011 - cont)
    - Turkish Republic Ministry of Development - Social Support Programme (2011 - cont)
    - United Nations Development Programme - Sustainable Development and Green Growth Best Practices in Turkey Applications (2012)

Publications :

Thesis :

- Development Of An Off-Line Software Program To Process 3 Tesla MRI Data To Obtain Human Brain Perfusion Maps, M.S. Thesis, Hacettepe University, 2004.

Papers:

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YAZARIN

Soyadı : ARIÖZ

Adı : UMUT

Bölümü : TIP BİLİŞİMİ

TEZİN ADI (İngilizce): DEVELOPING SUBJECT-SPECIFIC HEARING LOSS SIMULATION TO APPLY DIFFERENT FREQUENCY LOWERING ALGORITHMS FOR THE ENHANCEMENT OF SENSORINEURAL HEARING LOSSES

TEZİN TÜRÜ: Yüksek Lisans ☐ Doktora ☒

1. Tezimin tamamı dünya çapında erişime açılsın ve kaynak gösterilmek şartıyla tezimin bir kısmı veya tamamının fotokopisi alınsın. ☒
2. Tezimin tamamı yalnızca Orta Doğu Teknik Üniversitesi kullanıcılarının erişimine açılsın. (Bu seçenekle tezinizin fotokopisi ya da elektronik kopyası Kütüphane aracılığı ile ODTÜ dışına dağıtılmayacaktır. ☐
3. Tezim bir (1) yıl süreyle erişime kapalı olsun. (Bu seçenekle tezinizin fotokopisi ya da elektronik kopyası Kütüphane aracılığı ile ODTÜ dışına dağıtılmayacaktır.) ☐

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