Listening to Music with Headphones: An Assessment of Noise Exposure and Hearing Damage

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Title:

Headphone Sound Exposure and Hearing

Project period:
ACO-8
5. Febrary - 7. June 2007

Projectgroup:
1066

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Number of copies: 4

Report – number of pages: 59

Appendix – number of pages: 87

Total number of pages: 146

Abstract:

Many studies suggest that music players used with headphones can emitt sound pressure levels as high as the noises emitted in some industries and working places. Both exposures might be harmful to hearing in prolongate use. Moreover the degree of damage produced by listening to music with headphones is not clearly defined. This has been the motivation for this project which is to investigate the posible presence of a permanent hearing damage due to headphone sound exposure.

In order to fullfil this aim, two populations (control and target) which differ significantly in their habits when listening to music from headphones are compared using a headphone sound exposure evaluation an a hearing assessment. This is carried out by testing 20 selected subjects in a listening test.

This test consists of a pure tone audiometry, a DPOAE measurement and an analisis of the exposure level of the subjects in different environments.

It is concluded that the results obtained could not describe a potential damage by listening to music from a MP with headphones. Moreover, the environment around a person affects the preferred volume setting that this person select in his MP specially when the environment becomes noisy. However, users of MPs with headphones tent to listen to music at higher volume settings than the non users.

PREFACE

This report was written by group 1066 of the 10th semester as the documentation of the Thesis of the international Master of Science programme in Acoustics at the Institute of Electronic Systems at Aalborg University.

The report is primarily addressed to students and staff of the Department of Acoustics at Aalborg University, and anyone interested in the possible noise inductive hearing loss due to the exposure to music from music players with headphones.

The report is divided in two parts; main report and appendix. The main report is divided into the next several chapters:

- **Chapter 1** gives an introduction to the reader and sets the framework for project focus.
- **Chapter 2** presents an overview of the background theory related to the topic of the project.
- **Chapter 3** introduces an analysis describing the most important considerations of the project.
- **Chapter 4** exposes a pilot test carried out to define some parameters used for a listening test.
- **Chapter 5** exposes the listening test carried out to investigate the topic of the project.
- **Chapter 6** presents the results obtained from the listening test and their analysis.
- **Chapter 7** summaries the work done in the project and the results obtained.

The appendix part includes descriptions of measurements, supplementary documentation and important issues regarding the project.

A CD-ROM is enclosed. It contains the report in PDF-file format, the data obtained during the experiment, the Matlab code, the sample files, articles and data sheets.

We would like to thank Miguel Angel Aranda de Toro and Juan Luis Mateo, for all the help given to us during the project; Claus Vestergaard Skipper for their technical assistance and all the subjects that participated in the experiment for their patience and good will.

Aalborg University, June 7, 2007

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Part I

Report

CHAPTER 1

INTRODUCTION

Over time, many scientific studies have investigated the potentially harmful effects of noise and its consequences. Many of them are focus on the hearing damage caused on adults that are exposed to a noisy environment at their working places [4][29][8]. Nevertheless, there are also leisure time activities that can produce hazardous noise levels as well [9][30][39]. These leisure exposures are for example: the sound emitted by some electronic devices such as toys or mobile phones, the sound in cinemas, the music in concerts etc.

Music players (MPs) used with headphones is other of these leisure activities. The use of these devices offer a convenient way to listen to music as high listening level as the user likes without disturbing others. Some of these MPs are portables, for instance MP3 players or pocket computers. Nevertheless there are many others which are not, such as televisions or Hi-Fi equipments.

One of the main reasons of the increasing of users of MPs with headphones is the popularity of MP3 players in the last years. The reason of this success is its portability. Moreover, as technology improves, with greater music storage and longer battery life, it is possible that people will choose to listen for longer periods of time than ever before.

Scientific studies suggest that these MPs, portable or not, may cause hearing damage if they are not used with a degree of caution [10][41]. The exposure time (how often, how long) and the listening level are the main factors that may influence the possible hearing damage [42]. Moreover, it seems that the acoustic environment around a person may affect the listening level that a person sets in his MP [10][11].

Investigations about the possible hazardous effects of headphone sound exposure have been made before, however they have yielded to different results [9]. Some researchers conclude that personal stereo systems pose a risk [9] whereas others claim that their effect is not so harmful [44][3]. In general, it is agreed that there is some level of possible risk to hearing in certain conditions. This leads to the aim of the project.

1.1 The Aim of the Project

The aim of the project is to investigate the possible hearing damage due to the use of MPs with headphones. In order to do that, two groups of subjects which differ significantly in their listening habits are analyzed by means of an evaluation of headphone sound exposure and a hearing assessment.

1.2 Scope of the Project

The scope of the project is to:

- Describe the needed theory in order to fulfill the aim of the project. This includes theory regarding the human hearing, hearing disorders and hearing assessment.
- Identify two groups of subjects denoted as control and target population. The target population is characterized by an exposure to music from MPs with headphones at high listening levels and during long periods of time. By contrast, the control population is defined as a group which do not use, or use MPs with headphones at not risky levels during very short periods of time.
- Design and carry out a listening test that consists of a hearing assessment and a headphone sound exposure evaluation of the populations defined before. Different environments to which these populations are exposed to when using MPs with headphones are considered.
- Carry out the acoustic measurements of different MPs used with headphones in terms of their ability to produce sound pressure levels.

CHAPTER 2

HEARING AND SOUND EXPOSURE

This chapter reviews basic information about sound, human hearing, and how sound exposure affects to the human hearing. Moreover some techniques to assess the ability to hear sounds are explained. The chapter is concluded with the decisions made for the project based on the theory explained.

2.1 Hearing and Sound

Sound can be defined as pressure variations in the air created by vibrating objects and propagated through a medium from one location to another. These pressure vibrations are called sound pressure waves. The hearing process occurs when sound pressure waves reach the ears of a listener. The auditory system is the responsible of this hearing process, which is based on a conversion of the sound pressure waves to impulse signals. Then these impulsive signals are transmitted to the brain where the sound is perceived.

In terms of amplitude, the hearing of a person is limited by the next two definitions: the threshold of hearing and the threshold of pain. The smallest intensity of a sound that a person needs to detect its presence is called hearing threshold [13], whereas the threshold of pain refers to the intensity of a sound stimulus at which it becomes interpreted as painful.

In terms of frequency range, a person is able to hear frequencies from 16 to 20 kHz [7]. However, a person is not equally sensitive at all frequencies, thus the threshold of hearing varies from one frequency to another. Different hearing thresholds are expected if the acoustics environment or the technique used to measure the threshold are modified.

Furthermore, people is not equally sensitive, which means that the threshold of hearing varies among persons. However, standard thresholds values can be derived from a group of otologically normal persons. This concept is defined in the standard ISO 8253-1(1989)[26] as: *a person who is free from all signs or symptoms of ear desiase and from obstructing wax in the ear canal, and who has no history of undued exposure to noise*.

Figure 2.1 shows the standard thresholds values presented in ISO 389-7 [24]. It is observed that the frequencies where the ear is more sensitive is at middle frequencies, between 500 and 5000 Hz [37].

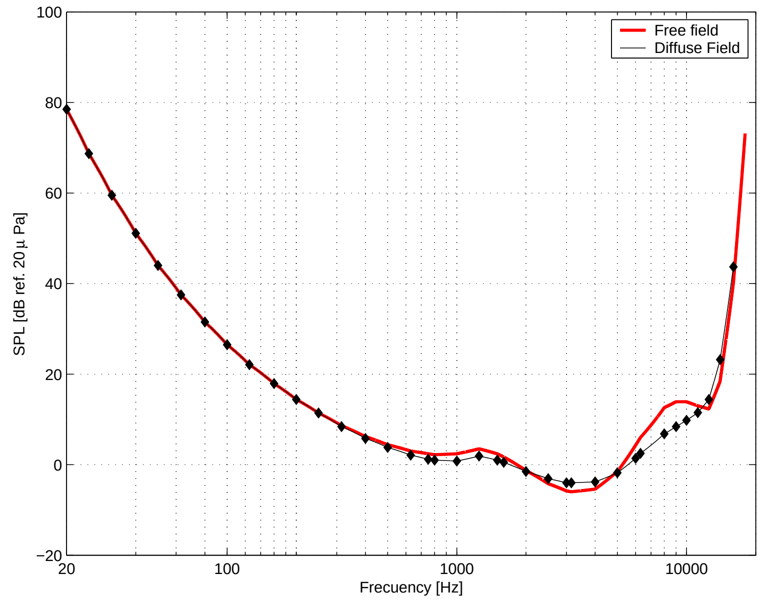

Figure 2.1: Minimum audible sound pressure level (thresholds values) presented in the standard ISO 389-7 [24] in free field and diffuse field of an otologically normal person in the age range from 18 years to 25 years. The data is plotted as a function of frequency. The procedure used for obtaining this data is defined in the standard ISO 8253-1 [26].

It can be observed in Figure 2.1 that the minimum sound pressure level that a person can detect at 1000 Hz corresponds to 20 μPa. All the sound pressure levels expressed in decibels (dB) in this report are referenced to this value.

The sounds that a person is exposed to, may modify his hearing threshold under certain circumstances. This sound exposure level is denoted by $L_{EX,To}$ according to ISO 1999 [23], which is applied for determination of occupational noise exposure. $L_{EX,To}$ combines the listening level and the exposure time to which a person is exposed during a reference time of To hours.

In order to analyze how sound exposure can affect the hearing, some aspects related to the anatomy and physiology of the auditory system are explained in the next section.

2.2 Hearing System anatomy

The auditory system is divided into three main parts: the outer ear, the middle ear and the inner ear, as it is shown in Figure 2.2. The outer ear is composed of the pinna, the ear canal and the tympanic membrane. The pinna is the external cartilaginous part with asymmetrical and irregular shape. The middle ear is an air-filled cavity that is composed of three small bones, the ossicles. This part of the auditory system is connected via the Eustachian tube to the nasal part of the pharynx. Finally, the inner ear comprise the cochlea and the auditory nerve through which the impulse signals are sent to the brain.

2.2.1 Hearing process

The hearing process takes place in the three main parts that it is made up:

Outer ear

The incoming sound waves are filtered by the pinna together with the head and torso. Then the sound travels along the ear canal to reach the eardrum which starts to vibrate as the membrane of a microphone would do. These vibrations are transmitted though the middle ear to the cochlea by the ossicles.

Middle ear

The major function of the middle ear is to ensure the efficient transfer of sound from the air to the incompressible fluids that are inside the cochlea. If the incoming sounds were applied directly on the entrance of the cochlea, which is named oval window, most of them would be simple reflected back instead of enter into the cochlea. It happens because there is a difference in acoustical impedance between the low impedance of the air in the eardrum and the high impedance of the fluid inside the cochlea. The main function of the ossicles is to act as an impedance adaptor, coupling the two different acoustical impedances. Thus, this function together with the difference in area between of the eardrum and the oval window, improve the sound transmission. Moreover the amount of reflected sound is also reduced.

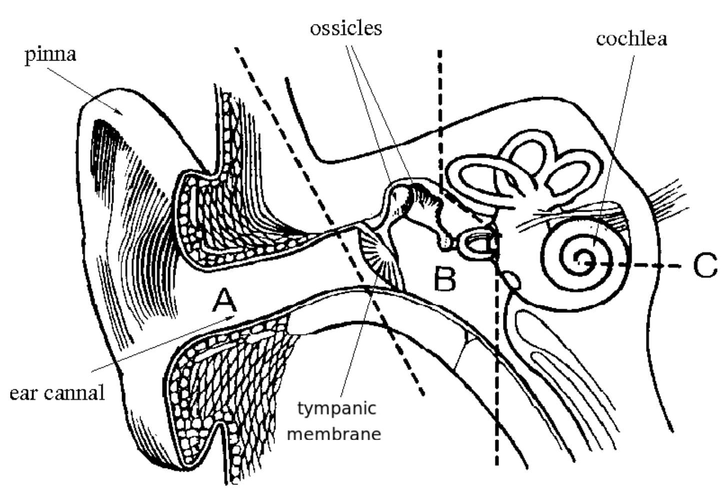

Figure 2.2: *Decomposition of the hearing organ in three main sections: the outer ear (A), the middle ear (B) and the inner ear (C). Figure adapted from [13].*

Transmission of sound through the middle ear is most efficient at middle frequencies. In addition, at low frequencies the sound transmission through the middle ear is reduced due to some contraction caused by the minute muscles attached to the ossicles. This contraction is known as middle ear reflex and it helps to prevent damage to the delicate structures of the cochlea. However this reflex is too slow to provide any protection against impulsive sounds, such as gun shots or hammer blows.

Inner ear

Once the sound is transmitted through the middle ear, it reaches the cochlea via the oval window. The cochlea is a bony structure shaped like the spiral shell of a snail. Within of it there is the incomprehensible fluid which acts as a medium to conduct the mechanical vibrations into pressure waves.

The colchea is divided into three cavities: the Scala vestibuli, the Scala media and the Scala tympani. The Scala media is bounded by two membranes: Reissnert's membrane and Basilar Membrane (BM).

The start of the cochlea where the oval window is situated is known as base while the other end is named apex. When the oval window is set into motion, a pressure difference is applied across the BM. As a consequence of this effect, a wave traveling from the narrow base toward the wide apex of the BM is formed. The amplitude of the sound wave created in the BM increases at first, then when the maximum peak is reached, the sound wave decreases abruptly.

The localization of the maximum peak depends on the frequency content of the incoming sound wave. High frequency sounds produces the maximum displacement of the BM close to the base. By contrast, low frequency sounds set the whole membrane into motion and reaches the maximum near the apex. The BM is behaving as a frequency analyzer, each place on it, is sensitive to a narrow frequency range. It can be appreciated in Figure 2.3 the shape of the traveling wave and the location of its maximum according to the frequency content.

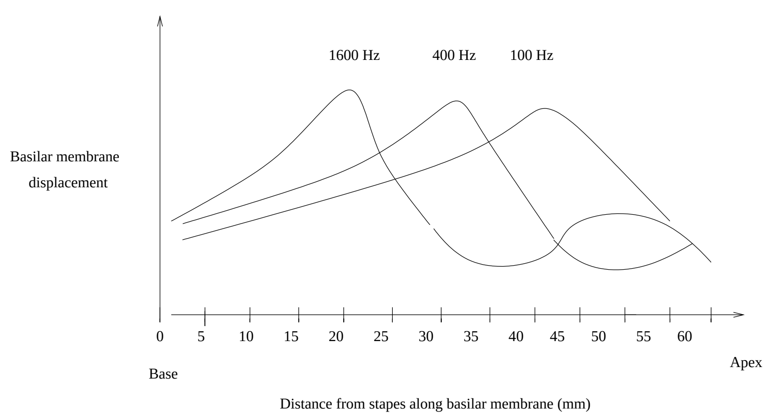

Figure 2.3: *Displacement along the BM for three different frequencies.*

2.2.2 The role of the hair cells

Inside the Scala media, all along the BM are hair cells which form part of a structure named the Organ of Corti. Figure 2.4 shows a cross section of the Organ of Corti, where two types of auditory cells can be appreciated: the inner hair cells and the outer hair cells.

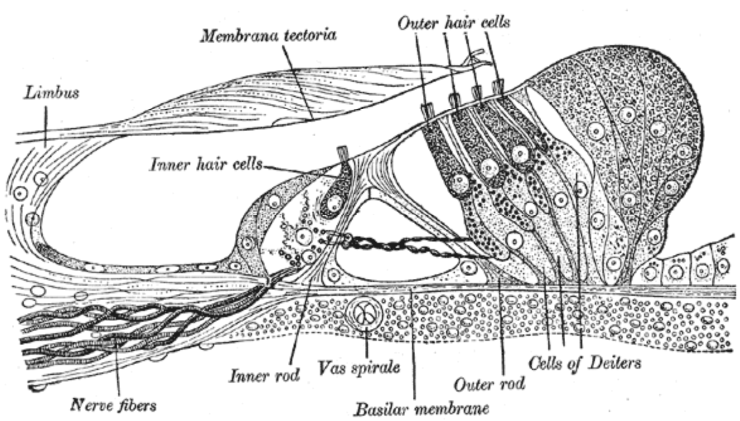

Figure 2.4: Cross section of the Organ of Corti which contains the inner and outer hair cells. Figure obtained from [1].

The inner hair cells are responsible for the transduction of mechanical movements into neural activity. These cells are connected to afferent neurons which carry informations from the cochlea to high levels of the auditory system [37].

The outer hair cells are connected to efferent neurons, which carry information from the brain to the cochlea. The main role of the outer hair cells is to enhance the frequency selectivity and also to produce a non-linear amplification process at low levels in the BM [37]. However, practically no reaction is produced at more intense sounds. This non-linear function is easily damage by noise. Next section explains this type of hearing disorder.

2.3 Noise Inductive Hearing Loss (NIHL)

Noise-Inductive Hearing Loss (NIHL) is a sensorineural hearing disorder referred to as permanent damage, cause by noise, to the outer hair cells resulting in a decreasing of the amplification ability of the cochlea [8]. Anatomical changes such as the fusion or disappearance of the hair cells are the main effects that causes this decreasing[8].

The outer hair cells are generally more susceptible to damage than the inner hair cells. Mainly, the ones corresponding to the frequencies between 3 to 6 kHz are affected [13]. Nevertheless if a person continues being exposed to harmful noises, the hearing damage spreads over other frequencies as well.

NIHL is caused due to an over stimulation of the auditory system produced by an one-time exposure to loud sound, as well as by repeated exposure to sounds at various loud levels over an extended period of time. Therefore, the effects of these over stimulations can be seen slowly over years of continuous exposure, or instantaneously after one-time exposure to loud sound. In the case of an overall year exposure, the full effects of NIHL are generally noticed after ten or more years of noise exposure [8].

Furthermore, there are other reasons that can produce a damage in the hearing cells as an inner ear infection due to external bacteria, an ingestion of ototoxic drugs or inherited conditions.

NIHL is a preventable hearing disorder that affects people of all ages and demographics because it depends mainly of the listening habits, the noisy environments that a person is exposed to, and the characteristics of the noise. One of the possible consequences of noise exposure is tinnitus.

Tinnitus is defined as the abnormal perception of sounds for which there is no external stimulus [13]. It is usually to be perceived in one or both ears or in the head. Some people define it as a ringing noise, a buzzing or a whistling sound. This phenomena can be suffered also by otollogically normal persons after a sound exposure.

It has to be noticed the difference between the NIHL and the hearing loss associated with advancing age, which is called *presbyacusis*. This hearing loss may be due to lesions in the external or middle ear, but the most consistent effect of aging is on the hair cells and neurons [33].

2.3.1 Hearing Loss Descriptors

There are some descriptors associated with the hearing loss explained in this section. These descriptors are combined with the NIHL to give additional information. Some of them are:

- Bilateral versus unilateral hearing loss:
  Bilateral hearing loss occurs when both ears are affected, by contrast unilateral hearing loss means that only one ear is affected.

- Symmetrical versus asymmetrical hearing loss:
  The difference between symmetrical and asymmetrical hearing loss is based on the degree of hearing loss in each ear. If both ears are damaged in the same way, the hearing loss is symmetrical. Otherwise it is asymmetrical.

- Progressive versus sudden hearing loss:
  A hearing loss is progressive when the damage produced in the ear increased over time. However, a sudden hearing loss is a ear damage that occurs in a very short period of time.

- Temporary versus permanent hearing loss:

> A temporary hearing loss or temporary threshold shift is defined as a change in the hearing thresholds that disappears within a period of time after the exposure. By contrast, a permanent hearing loss is a hearing disorder that does not vary over the time.

These descriptors of the NIHL can be identify using different methods. Next section explains the methods utilized for hearing assessment in this project.

2.4 Hearing Assessment

The purpose of hearing assessment is to quantify the ability to hear sounds. A variety of methods can be used, such as audiometry and OtoAcoustic Emissions (OAE).

2.5 Audiometry

This test measures hearing thresholds by means of behavioral feedback from the subject. The person taking the test is instructed to give some type of response when a sound stimuli presented is heard. There are different possibilities for the subject to express if the sound is perceived such as pressing a button or raising a finger. The response given by the subject is caused by the sensory impression of the sound stimuli, but also the interpretation based on the experience and knowledge of the test subject influences in the decision of hearing or not a sound [34].

During this test, headphones are usually used. Thus sound travels through the air in the ear canal to stimulate the eardrum and then the auditory nerve. This procedure, which is specified in the standard ISO 8253-1 [26], is called air conduction audiometry.

Thresholds are measured for different frequencies in each ear. The responses are recorded on a graph called audiogram that provides the Hearing Level (HL) for each frequency tested. The HL expresses the difference in decibels between a measured hearing threshold and the thresholds values derived from an otologically normal population at a particular frequency [25]. A straight horizontal line at 0 dB HL in the audiogram represents the hearing derived from these thresholds values. For example if a person has a hearing threshold of 25 dB HL at a specific frequency, it means that the hearing threshold is 25 dB higher than the threshold of hearing obtained from a population considered otologically normal at that specific frequency.

Types of Audiometries

There are many different types of audiometries for threshold determination. For instance the method of limits, the Békésy method, the method of constant stimuli, forced choice methods, audioscan method, the method of adjustment etc.

Many of them gradually converge on the threshold by presenting sound stimuli at levels that depend on the response to previous trials, considering a trial as the answer given by the subject in each stimuli presentation. After several trials of one subject, the hearing threshold is determinated according to a stop criteria.

The methods to be analyzed in detail for this project are the method of Limits and the Bekesy method. Both methods are standardized in ISO 8253-1 [26].

Method of Limits

There are different versions of this method: Ascending, Descending and Bracketing. They all are based on the same principle: several pure tones at specific frequencies are presented to the subject, so by means of a variation in the level of these pure tones the hearing threshold is determined.

- Descending Method
  It consists of a presentation of several pure tones starting from a level which is above to the threshold of hearing. Then the subject must show if the sound was heard or not. Since the starting level is above enough to the threshold of hearing, a positive answer is expected. Then the level of the pure tone is decreased and presented again to the subject. This process is repeated until the subject is not able to perceive the sound. Every time that the subject finishes a descending from an audible to an inaudible stimuli is called a run [14]. Several runs are performed, so the threshold of the subject is obtained according to the threshold levels across runs [14]. This is made for each frequency.

- Ascending Method
  The ascending method differs to the descending method in the starting level of the pure tones. In this case the sound that is first presented is set to a level quite below to the threshold of hearing. Then the level of the presented pure tones is increased until the subject hears the sound. Again several runs are performed and the threshold is calculated.

- Bracketing Method
  This method combined the ascending and descending methods. Starting from a level above the threshold of hearing, the stimuli is decreasing until the subject can not perceived. Then the stimuli is increased again until the subject shows that can hear the sound. Therefore a combination of increasing and decreasing runs are performed when using this method. This process is repeated a certain number of times for each frequency. Then from the values obtained in the descending and ascending runs, the threshold is calculated.

The drawbacks of this method are the anticipation and habituation of the subject to the task. Sometimes subjects anticipate hearing the stimulus and sometimes anticipate not to hear it.

Other disadvantage is that is very dependent on the amount of decibels when increasing or decreasing the levels. A big increasing or decreasing in the runs can lead to inaccurate results.

An advantage of this method is that a full range of performance levels can be estimated. However, if only hearing threshold determination is desired, many trials will be presented until reach the hearing threshold.

Békésy Method

In this method the stimulus is controlled by the test subject who adjusts the level continuously over the time to reach the hearing threshold. The sound stimuli are pure tones as well as in the method of Limits, but the task of the subject is different. In this case the pure tone is presented and the subject has to press a button when the tone is heard and to release it when the signal is inaudible. When the subject release the button, then the level of the tone increases automatically in a certain step size. Therefore the level is increased and decreased several times depending on the answers of the subject. This will produce some sort of valleys and peaks around the minimum audible level. The hearing threshold is calculated according to certain number of peaks and valleys.

A disadvantage of the Békésy method is that the measurements depends on the reaction time of the subject. If the stimulus are decreasing or increasing so fast that the subject does not have time enough to press or depress the button according to his perception of the sounds, then the thresholds obtained are not reliable. This can be avoided using reasonably slower attenuation rates.

On the other hand, this method is fast an has the advantages of speed and reasonable precision. because of the tracking used to achieve the hearing threshold.

2.6 OtoAcustic Emissions (OAE)

Besides the hearing process, a healthy human ear is able to produce inaudible sounds emitted by the cochlea which are known as OAEs. They can be produced either spontaneously or by means of a stimulation of the ear with one or several specific sound signals.

The OAEs are produced in a non damage cochlea by its own activity and reflect the activity of the outer hair cells. The sounds emitted by the ear are in fact produced due to a mechanical motion of the outer hair cells of the cochlea that is transmitted to the basilar membrane [31].

This active mechanical process is consequence of natural imperfections of the cochlea amplifier mechanism [43]. The motion of the hair cells creates a vibration which is driven by the cochlea, passing through the oscicles and finally reaches the tympanic membrane. Then a vibration of the tympanic membrane occurs and a sound wave is emitted by the ear. If a probe microphone is placed into the ear canal closing it, then this sound wave can be recorded.

Although the position of the probe microphone the amplitude of the OAEs may vary slightly [45], some studies have investigated how the amplitude of the OAE varies depending on the degree of hearing loss[43][28][8][12] [31][32]. Most of them conclude that for a population the presence of OAEs is related to normal hearing thresholds, whereas reduced OAE levels can be associated with hearing loss.

Types of OAEs

The OAEs can be classified as evoked or spontaneous OAEs. Evoked OAEs are inaudible sounds emitted by the cochlea when the cochlea is stimulated by a sound signal. When this sound reaches the ear, it is transmitted through the ear canal and the oscicles until the cochlea. Then the outer hair cells vibrate creating an inaudible sound that echoes back into the middle ear again, which is the Evoked OAEs. By contrast, if the ear produces the vibration of the hair cells by itself in the absence of any know stimulus, then the OAEs are called spontaneous OAEs.

Among the evoked OAEs, there are different types depending on the acoustic stimuli used. They are transient evoked, stimulus frequency and distortion product OAEs.

Transient Evoked OAEs (TEOAEs)

These OAEs are produced when a broadband signal is presented as stimuli, for example a click or a tone burst. The whole cochlea is activated from the apex to the base, so a broadband frequency region is tested when measuring TEOAEs. The response of the ear to this stimuli is long and complex because responses from different parts of the cochlea arrive at the ear canal at different times and at different frequencies [31].

Stimulus Frequency OAEs (SFOAEs)

In this case a narrow band stimulus is applied, for example a pure tone. This type of stimuli activates a narrow zone in the cochlea. To excite a wider zone successive stimulations are needed.

Distortion Product Otoacoustic Emissions (DPOAEs)

If the sound stimuli used is based on a multi-tone stimuli, for example two sinusoids of different frequencies f_1 and f_2 $(f_2 > f_1)$ and levels L_1 and L_2 , then the cochlea generates several new acoustic frequency components besides the frequencies f_1 and f_2. These new frequency components, called distortion products, are due to a non-linear intermodulation between the two stimulus tones along the basilar membrane. In the case of the two sinusoids, the distortion products are $2f_1 - f_2$, $3f_1 - 2f_2$, $2f_2 - f_1$ etc. They are obtained according to Equation 2.1

$$fdp = f_1 + N(f_2 - f_1) \tag{2.1}$$

where N is any positive or negative whole number [31].

It is shown that the intermodulation distortion produced at the frequency $2f_1 - f_2$ is the DPOAE which can be measured easily due to its amplitude, although the cochlea also produces DPOAEs at other frequencies, as it was mentioned before. In order to have a good response at that frequency, the levels and the frequencies of the tones must be selected adequately. An f_1/f_2 ratio at 1.2 and a intensity of 65 and 55 dB sound pressure level for L_1 and L_2 respectively yields the greatest DPOAEs [31].

Figure 2.5 shows the development of the traveling waves f_1 and f_2 along the BM. In graph a) corresponds to a dead cochlea. It can be seen that the cochlea does not respond to most of the stimulus energy. In graph b) a cochlea with a linear amplification of the outer hair cells is shown. However the outer hair cells do not have a linear behavior, and this results in intermodulation distortion products ($2f_1 - f_2$ and $2f_2 - f_1$) which then travel to their frequency places at points 3 and 4 and generate the backward traveling waves. This can be seen in graph c). Therefore the DPOAEs generation is based on a two-source model: The first source is the initial non-linear interaction of the primaries and the second source comes from the re-emission site at the characteristic place of the distortion product frequency. If a decreased DPOAE is measured, it may not necessarily mean that the damage area of the BM corresponds to the place where the $2f_1 - f_2$ and $2f_2 - f_1$ are generated. It could be by a BM damage in the overlap area between f_1 and f_2 for example.

By modifying the frequency of f_1 and f_2, the distortion product $2f_1 - f_2$ varies, therefore different frequencies can be tested. If the ratio between f_1 and f_2 or the intensity of the tones changes, the DPOAEs can not be compared among them in terms of amplitude. For this reason, these two parameters have to be maintained constant all along the frequency range.

Depending on the frequency variation when changing f_1 and f_2 along the frequency range, different resolutions can be obtained. For example, if a frequency variation of 15 Hz is used, many values are obtained for a specific range of frequencies. In this range peaks and valleys are detected when measuring the DPOAEs because of the high resolution. Nevertheless, if the frequency variation is selected for giving DPOAEs values each 1000 Hz, then these peaks and valleys do not appear and a curve without abrupt changes is obtained. This small variations detected at high resolution are called DPOAEs fine structures.

Figure 2.6 shows an example of a clinical DPOAE analysis and illustrates its measurement results. In the figure on the left, it can be seen the sound spectrum measured in a healthy human ear canal during stimulation of the pure tones f_1 (at 1425 Hz) and f_2 (at 1500 Hz) with

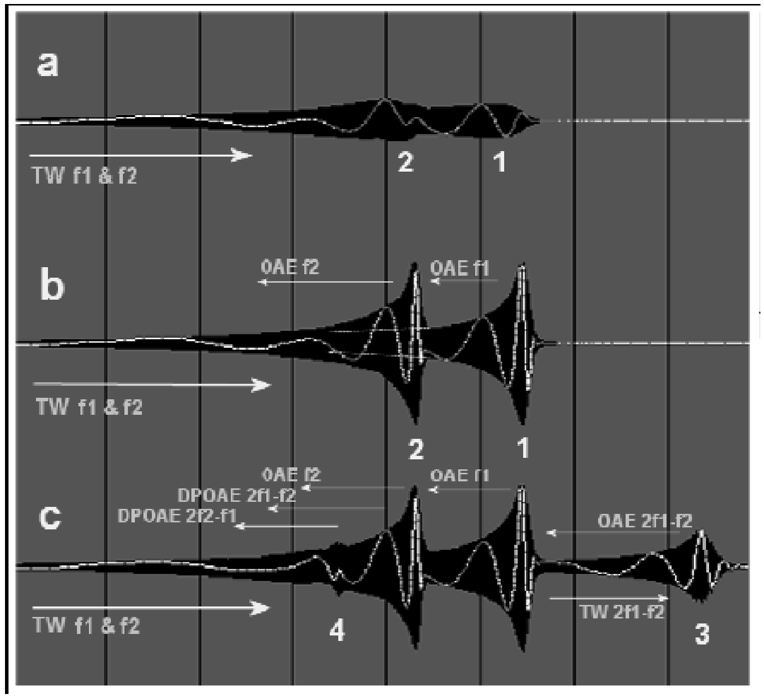

Figure 2.5: Development of the traveling waves along the BM in three cases. Graph a) shows the effect in a dead cochlea. Graph b) shows the effect of a linear amplification of the outer hair cells. Graph c) ilustrates the effects of the non-linear effect of the outer hair cells. Taken from D.T Kemp [31].

an amplitude of 70 dB SPL both. The rest of the spectral lines that appears are due to the intermodulation tones produces by the cochlea. The figure on the right shows the result of the measurements after the presentation of the signals f_1 and f_2 at different frequencies. This is call a DP-gram. The data of the spectrum of the left figure corresponds to the value shown in the right figure with an arrow. The shaded portion indicates the noise level during the measurement. The data is plotted as a function of f_2.

2.7 Selection of the Assessment Techniques for NIHL

A description of the procedures selected in order to analyze the NIHL and the final decision are presented next.

2.7.1 Selection of the Audiometry Method for NIHL

In this section the audiometric method is selected from the different audiometric methods presented in Section 2.5. Before deciding the audiometry method, the following requirements are taken into account:

1. The audiometry method select has to be accurate. The accuracy in this method can be

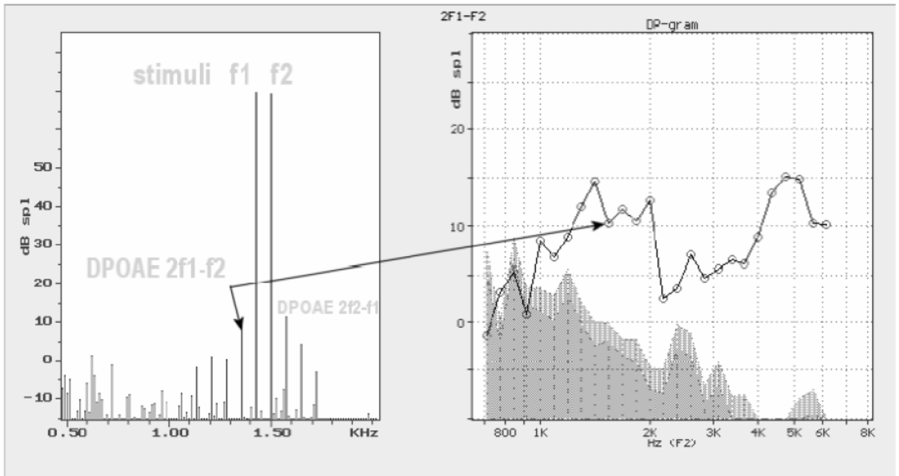

Figure 2.6: *The figure on the left shows the sound spectrum in a healthy human ear canal during stimulation by two pure tones, f_1 (at 1425 Hz) and f_2 (at 1500 Hz), both at 70 dB SPL. The figure on the righ ilustrates the complete DP-gram obtained after the measurements.*

measured by means of the standard deviation within subjects, which means how vary the hearing threshold among subjects, being these subjects from a group of otologically normal persons. In theory all the subjects must have a hearing threshold close to 0 dB HL, therefore by means of an observation of the mean threshold value averaged across subjects an estimation of the precision of the audiometry method can be done.

2. The time for each audiometry is in principle not an important factor but a reasonable time consumption is desired.

3. Conformity with the standard ISO 8253-1 [26] is also desired. Non standardized method are neglected for this project.

From all the audiometric methods mentioned in Section 2.5 for threshold determination, only the three standardized methods in ISO 8253-1 [26] are chosen to be analyzed. These are the Békésy method and the method of Limits using its Ascending and Bracketing versions.

In order to select which one of the three methods mentioned before (Ascending, Bracketing or Békésy) is more appropriate, an investigation made by Lydolf [34] is used. This author compares different methods in terms of accuracy and time consumption of the measurements. Table 2.1 shows an overview of these parameters. Mean and standard deviation of the used time and the threshold accuracy for each method are presented. It is observed that the Bracketing method has the highest mean duration value with 127 seconds and a standard deviation of 12 seconds. On the other hand in terms of accuracy, the Bracketing method seems to be very precise, although it has a relatively large standard deviation accuracy.

	Ascending	Bracketing	Békésy
Accuracy (dB HL)	0.8±2	0.2±1.9	1.5±1.7
Time consumption (seconds)	73± 6	127±12	62±12

Table 2.1: *Mean and standard deviation of the time used and the HL accuracy in the threshold determination of Ascending, Bracketing and Békésy method. This data is obtained from a investigation of Lydolf in his Ph.D.Thesis [34].*

For a simple and a reasonable accurate method, the Bracketing method is chosen. Moreover this method can be used according to the facilities available for the development of this project.

The sound stimuli used are discrete pure tones at 250, 500,750, 1000,1500, 2000,4000, 6000 and 8000 Hz. The time duration of each pure tone presentation is selected to be 300 ms for all the pure tones presentations along the frequency range. It was decided to choose this time to let the subject time enough to hear and to create the response pressing or not pressing when the sound is respectively heard or not heard [15].

Other parameter is the attenuation step size that indicates how the sounds decrease or increase in level from one presentation of the signal to the next presentation. This parameter is desired to be small to give a precise audiometry. If the subject answers that the sound was heard, a decreasing of 10 dB is performed. However if the subject does not hear the sound an increasing of 5 dB is performed.

The calculation of the threshold in the standard ISO 8253-1 [26] for the Bracketing method requires that three runs in series occur at the same level out of a maximum of five runs. Two ascending-descending runs are chosen in this project instead of three because when using three, the time consumption of the audiometry with all the frequencies becomes very large.

In the beginning of the audiometry an initial familiarization is carried out to be assure that the subject has understood how to perform during the test. This familiarizations consist on a pure tone at an audible level, which decreases until a certain level when the subject is not able to hear it. If the subject responds correctly to this first descent, the threshold determination goes on. In this part the attenuation step is the same specified before.

When changing from one frequency to another, the next frequency presented to the subject is played higher than the level recorded when the push button was not pressed in the last threshold determination.

2.7.2 Selection of Otoacoustic Emissions for NIHL

Many researchers [38][43][28][42] used OAEs for audiologic evaluation in their investigation about NIHL.

Evoked OAEs are frequently used instead of spontaneous OAEs for hearing assessment because not all the healthy ears produce spontaneous OAEs. Table 2.2 shows the prevalence of the different types of OAEs in human healthy ears which is defined as no cochlear pathology and hearing threshold of 15 dB HL or better. According with this table, TEOAEs and DPOAEs are the possible evoked OAEs selected for this project.

Type of OAEs	Stimulus	Prevalence in normal ears
Spontaneous OAEs	No stimulus required	approximately 60%
Transient Evoked OAEs (TEOAEs)	Click or tone burst	99%
Stimulus Frequency OAEs (SFOAEs)	Continuous pure tone	unknown
Distortion Product OAEs (DPOAEs)	Two pure tones	99%

Table 2.2: *Classification of the different types of OAEs according to the stimulus applied to excite them and with their prevalence in normal ears (no cochlear pathology and hearing threshold of* 15 dB *HL or better). The data is obtained from [16].*

The broad band nature of the TEOAE does not permit a deeper analysis of the hearing due to its highly non-linearity. Moreover, the frequency analysis of the TEOAEs can not be related to a specific site of the BM, since the TEOAE level at any given frequency is a result of combined sources [42]. By contrast, DPOAE allows to associate each DPOAE level with certain areas of the BM derived from the frequency of the emission signals [42]. Therefore DPOAEs are preferable to TEOAEs for this project.
DPOAEs allow to into account.
quantify the degree of

DPOAEs are measured at the frequencies $2f_1 - f_2$, ranging from 635 to 3943 kHz. Two sinusoids with frequencies f_1 and f_2 are selected to be presented to the subject to excite the OAEs. The distortion product is obtained varying the frequency f_2 from 1001 to 6165 Hz. Fixed levels of 65 and 45 dB for L_1 and L_2 respectively and a fixed frequency ratio of $f_2/f_1 = 1.22$ are selected for the pure tones. Regarding the resolution of the measurements, eight DPOAE values per octave band are chosen.

2.8 Chapter Conclusions

Though this chapter, it has been described the hearing assessment in order to detect a possible hearing damage due to a sound exposure. As stated in the Introduction (Chapter 1), this project involves the analysis of a specific situation: a headphone sound exposure by MPs.

Headphone sound exposure, as a sound exposure in itself, may leads to NIHL. This NIHL is diagnosed in this project by means of DPOAE measurements and pure tone audiometry. These techniques are chosen since the DPOAEs measurements have the potential to indicate a mild

NIHL before it is observed audiometrically [43][8].
A summary of the parameters selected in these assessment methods are shown in Appendix A.

In addition, in next chapter a detail description of the sound exposure produced by MPs with headphones is presented. Furthermore a explanation about how the Lex,To is used to evaluate this exposure is made.

CHAPTER 3

HEADPHONE SOUND EXPOSURE

Headphone sound exposure is a difficult and subjective exposure where many variables play an important role. This chapter defines in detail how all these variables are considered in this project for the analysis of a possible NIHL in a population.

3.1 Listening Devices: Music Players and Headphones

A MP is defined in this project as any kind of device which is able to play music files through headphones. The sound signal is produced by the MP, however the headphones are the transducers responsible to convert the output signal in sound pressure level.

There are different types of MPs that can be considered for headphone sound exposure, nevertheless, only the following devices are taken into account:

- Laptop computers or desk computers.
- Portable MPs: MP3 players, mobile phones, portable DVD, CD players, portable radios, pocket computer etc.
- Televisions or games console.
- Hi-Fi equipment, mini-stereo systems, professional stereo systems or similar.
- Mixer table or similar.

All the MP mentioned above must have a common point: They all must have the possibility to be used with headphones.

Regarding to the headphones, there are five different categories, according to the standard ITU-T-1993 [27], that are considered. An explanation of each type can be seen in Appendix B. The different types of headphones are the following:

- Intra-concha.
- Supra-concha.
- Supra-aural.

- Circum-aural.
- Insert.

In general, headphones do not incorporate acoustic insulation to protect from external noises. However some headphones in itself provide some attenuation due to their structural properties. This insulation varies among the different types and among the different models of headphones. Therefore the exposure level can be modified slightly depending on the type of headphones. This consideration is not taken into account in this project because it is treated as an uncontrollable variable because even though some headphones can provide greater attenuation compare to others, this fact is a consequence of the particular exposure of each person. Thus, it can not be corrected, because then the real sound exposure will be distorted.

3.2 Listening Source: Music

The source of sound exposure through the headphones that is considered for this project is music.When dealing with noises such as the machinery noisy, the sounds used to be more predictable, so it is easier to analyze. However, in the case of music, the temporal variations, the frequency content and the average to peak level can vary among different types of music or even within a same song.

Some investigations [10] have concluded that depending on the type of music, the MP users adjust the volume of their MP to different levels. It means that the type of music is a parameter which may affect on the headphone sound exposure. Therefore depending on the music preferences, people can be more or less exposed. Moreover people is not used to listen to only one type of music. Thus an estimation of the exposure time per each type of music is needed for each person in order to compare the headphone sound exposure as a function of the music.

An analysis of the headphone sound exposure depending on the type of music is considered beyond of the objectives of the project.

3.3 Headphone Sound Exposure Evaluation

In this project the headphone sound exposure is calculated as $L_{EX,To}$ which is defined in the standard ISO 1999 [23] and mentioned in Chapter 2. Equation C.4 shows the expression.

$$L_{EX,8h} = L_{eq,Te} + 10\log\left(\frac{Te}{To}\right) \tag{3.1}$$

Te is the effective duration that the person is exposed to the noise in hours per day and *To* corresponds to a reference duration of 8 hours. It is named **exposure time**. Information about *Te* is obtained by means of a questionnaire.

$L_{eq,Te}$ correspond to the level that a person set in its MP. This is defined as the equivalent continuous sound pressure level which is the steady sound pressure level obtained from an integration over a period of time of a fluctuating sound pressure level. It is recorded from the sound produced by the headphones. The expression of the $L_{eq,Te}$ can be seen in Equation 3.2. During all the project the time of integration of all the measurements of $L_{eq,Te}$ is fixed to 60 seconds.

$$L_{eq,Te} = 10 \log \frac{1}{Te} \int_0^{Te} \left(\frac{p(t)}{p_0} \right)^2 \tag{3.2}$$

where Te is the time of integration, $p(t)$ is the instantaneous sound pressure level and p_0 is the reference sound pressure which is 20 μPa.

3.3.1 Sound Levels Generated by the Headphones

The measurements of the $L_{eq,60s}$ produced by the headphones of a MP within the ear can be measured with the MANIKIN technique and the MIRE technique stated in the standard ISO 11904-2 and ISO 11904-1 respectively [22][21]. MANIKIN technique uses a standardised artificial ear including microphones, whereas the MIRE technique uses a probe microphone inserted in the ears of human subjects.

This last technique can not be used when measuring the sound produced by intra-concha and insert headphones because the placement of the probe microphone with this type of headphones is not possible with the correct fit. Furthermore the probe microphones are very delicate, sensitive to environmental conditions and difficult to calibrate [42].

On the other hand, the MANIKIN technique permits to use any king of headphones, and allows repeated measurements in a short period of time [42]. A disadvantage is the difficulty to use it outside of the laboratory due to its weight and size. Moreover the pinna of the manikin does not have the same properties than a human ear, so placement in the ear may not be exactly the same than in a human being. However this technique is applied in this project since it provides a simpler and more robust manner of measurement.

The acoustic field produced in the headphone cup can not be compared with a source that creates a sound field which is propagated in an open space. Therefore a conversion from $L_{eq,60s}$ measured in the ear canal to a field level un-disturbed by the presence of a manikin is needed. This level is named as free-field related equivalent continuous A-weighted sound pressure level and it is denoted as $L_{FF,Aeq}$. Moreover for this project this level is called **listening level**. Appendix C explains in detail the procedure to measure and calculate the $L_{eq,60s}$, the $L_{FF,Aeq}$ and the $L_{EX,8h}$.

3.4 Headphone Sound Exposure Parameters

The parameters to take into account in order to perform a precise headphone sound exposure evaluation are explained in this chapter.

3.4.1 Environments

It seems that the acoustic environment around a person may affect the preferred sound level that a person set in his MP [10].

People use MPs in many different situations. Therefore it is necessary to define precisely the places and the characteristics of the environments where MPs are used. For instance it can not be considered the same exposure to utilise a MP with headphones in a very quiet street or a park, or to use it in a cafeteria. Furthermore in the same environments different background levels are possible. For example to use a MP while walking in a street can be considered depending on the street as a very noisy or quiet environment.

The environments that are considered for the headphone sound exposure evaluation are:

- Quiet.
- Moderate.
- Noisy.

3.4.2 Other Sound Exposures

If a NIHL is diagnosed in a person who is exposed to another excessive sound apart from headphone sound exposure by MPs, it is impossible to define which exposure is the responsible of the hearing damage.

All those persons who do not have any other exposure than the headphone sound exposure besides not having other complication in his hearing, are considered as individuals who do not have any **previous hearing condition**.

For this project a previous hearing condition is presented when a person:

- Suffers from a cold or has taken any medicine or another type of drugs that might influence on his hearing.
- Has very often hearing problems as infections, ear noises, tinnitus, drainage etc.
- Has a know history of hearing damage diagnosed by a medical doctor.
- Has been exposed to impulsive or loud sounds for long periods of time without hearing protectors i.e. explosions, fireworks, shootings etc.

- Has been working in a job were the use of headphones was needed for at least two years full time.
- Has been working in a noisy environment for at least two years full time without using hearing protectors.
- Is a musician or is professionally involved.
- Used to play an instrument or attend to concerts/discos very often without using hearing protectors.

3.4.3 Gender and Age Differences

Among MP with headphones users, there are people of different ages. This project investigates the age range of the potential users of MPs with headphones in a population. However whether the age within the potential users is a parameter that affects the headphone sound exposure is not an issue analysed in this project.

In addition, whether a gender difference exist when assessing noise exposure through the headphones is not an issue to be investigated.

3.5 Chapter Conclusions

In the headphone sound exposure evaluation carried out for this project, different types of headphones and MPs are selected to be analysed when music is played. Moreover quiet, moderate and noisy are the three environments considered.

In order to assess the influence that MPs with headphones produces on the hearing, a selection of MP users according to their $L_{EX,8h}$ and their previous hearing condition is made.

Next chapter explains the classification of subjects in two groups, defined as control and target population:

- The **control population** is a group of persons that do not present any previous hearing condition besides not being potential MP users.
- The **target population** is formed by persons who do not present any previous hearing condition besides listening to MP with headphones for long periods of time and at high volume settings.

CHAPTER 4

PILOT TEST

The pilot test is performed in order to select the subjects that belong to control and target population for the purposes of this project. First a preliminary survey is described, and afterwards the pilot test design is explained.

4.1 Preliminary Survey

The purpose of this part is to define the age of MPs users that utilize headphones. This survey is conducted to 80 subjects randomly selected asking them the next question: "Do you listen to music using MP with headphones?" The important parameters that are taken into account are the age, the gender, and the answer to the question formulated.

The data collected is shown in Table 4.1. From these results, it can be seen that the highest percentage of MP with headphones users is 83,3% which corresponds to an age ranged from 19-30. In consequence it is stated that the age range of the target and control population that will be tested in this project has to be from 19 to 30 years old.

Number of subjects		Age Range	% of persons who use MP with headphones	% of persons who do not use MP with headphones
Women	Men			
10	10	19-30	83.3	16.6
10	10	31-38	63.3	36.6
10	10	42-48	33.3	66.6
10	10	51-57	26.6	73.3

Table 4.1: *Percentage of the population that use or do not use MP with headphones.*

4.2 Pilot Test Design

In this section the previous hearing condition, the listening habits and the $L_{EX,8h}$ are studied. It has to be noticed that the subjects who performed the pilot test are not the same subjects who participated in the preliminary survey. The only requirement for the new subjects is to be ranged in age from 19 to 30, as it was concluded in the results of the preliminary survey.

4.2.1 Goals of the Pilot Test

The goals of the pilot test are:

- To identify two groups of subjects: target and control population
- To define the most typical places where MPs are used.

This is done by means of

- Analysis of the previous hearing condition and the environments where MPs with headphones are used. The subjects could select among the next environments: Bus, train, bike, motor-bike, car, street, home, university or at work. This is done with a questionnaire.
- An evaluation of the headphone sound exposure of the subjects testing the listening level and the exposure time.

In addition, some other parameters are investigated in order to verify some of the decisions that were taken in the pilot test design. These are:

- The use of MP with headphones among the next devices: Portable MP, computer, television/DVD, HIFI equipment or mixer table.
- The type of headphones preferred by users among the next types: Intra-concha, supra-concha or circum-aural headphones.

4.2.2 Method

It is decided to carry out this pilot test in Aalborg university offices which is a quiet environment where the background noise can not vary suddenly from low to high levels. The instructions given to the subjects are shown in Appendix E.

This pilot test is divided in two steps:

1. It consists of testing the volume listening preferences of the subjects when using MP with headphones. The purpose is to obtain the sound exposure level of each subject. In order to do that, two different types of headphones and one portable MP are presented to every subject. They can be seen in Table 4.2. Each person must select the type of headphones that would choose in case of listening to music with headphones. Then, the task of the subject will be to adjust the preferred volume control of one from seven different music samples of 60 seconds that are stored in the portable MP. Table 4.3 shows title, author and type of the music samples. A normalization of all the music samples is done to assure that they all have the same energy content. The music samples are popular and well known songs in order to allow the subjects to focus on the volume selection instead of another not important details i.e. the lyrics or the rhythm of the music.

Appendix D describes the selection of the portable MP and the headphones as well as the music samples used. The normalization performed in the music samples is also detailed in this appendix.

Device	Model	LAB-Nr
Headphone	Sony MDR	-
Headphone	Creative MuVo V200	2157-41
MP	Creative MuVo V200	2157-41

Table 4.2: *Devices used in the pilot test*

2. It is based on a paper questionnaire inspired by the one used by Mattila & Zacharov [35]. This questionnaire is formulated in order to identify those subjects who do not have any previous hearing condition and to get some information related to their listening habits. The entire questionnaire can be seen in the Appendix F.

Music Author	Music Title	Music Type
The Beetles	Help	Pop
Milk Inc.	In my eyes	Dance
Fugees	Ready or not	Hip-hop
Woody Allen	Come On and Stomp	Jazz
Shakira	Hips dont't lie	Pop
U2	Sunday Bloody Sunday	Rock
Vivaldi	The Four Seasons	Classical

Table 4.3: *Music samples presented to the subjects. The duration of all the music samples is 60 seconds*

4.2.3 Evaluation and Results

A total of 61 persons, 40 males and 21 females, ranged in aged from 21 to 33 (median=23) took part of this study. Appendix G shows the results in detail.

Previous Hearing Condition

Firstly, the subjects that do not present any previous hearing condition are selected and the rest are rejected.

Regarding to the results collected from the questionnaire, any significant problem related to hearing infections or medicine that might have influence on the hearing was revealed by the subjects. Five candidates showed a diagnosed hearing problem and one of them was suffering a cold, therefore these six subjects, that correspond to a 9.83% of the tested population were rejected.

There was not relevant case affected by impulsive or loud sounds as explosions, shootings or firearms. The most common cases correspond to persons exposed to fireworks once or twice per year. In addition there was a 8% of subjects that declared that they have been working in a noisy environments i.e. machinery noises in a factory. However it was during short periods of time and in the most of cases hearing protectors were used.

A 32% of the subjects play some musical instrument as piano, guitar, drums, saxophone or electrical guitar. The 11.76% of these subjects play in a band in their free time and 88,24% play at home. There is only one subject who used to play around 80 hours per month, therefore this participant is rejected. The rest of the subjects are accepted because any of them was professionally involved in music and the exposure time was less than 32 hours.

A 82,69% of the subjects assists to discos or pop/rock concerts however since any subject attends regularly and the average is 2 times per month, then it is considered that any subject is severely affected.

Thus, it can be concluded that 54 subjects, that corresponds to 88.52% of the population, are considered do not present any previous hearing condition. From these subjects the headphone sound exposure is analyzed.

Headphone Sound Exposure

The next step is to calculate the headphone sound exposure to identify the subjects of the target and control population using the data collected from the control level setting and the time exposure marked in the questionnaire. This is done by means of the calculation of the $L_{EX,8h}$ as it was explained in Section 3.3 in Chapter 3.

The levels that correspond to each control level setting are measured beforehand, so they were known before the performance of the pilot test. This can be seen in Appendix E.

The $L_{EX,8h}$ of all the subject can be seen in Table G.1 in Appendix G. Figure G.1 presents the $L_{EX,8h}$ sorted from the minimum to the maximum $L_{EX,8h}$. There are 11 subjects that are not MP users, therefore the exposure time is zero and consequently the corresponding $L_{EX,8h}$ is zero.

This data is evaluated according to the Danish legislation [5] which states that no person may be subjected to noise with a level higher than 85 dBA in an eight hour working day. Therefore those persons who are exposed to levels above 85 dBA are considered subjects of the target population. On the other hand, all the subjects who performed a $L_{EX,8h}$ of less than 75 dBA are considered control population.

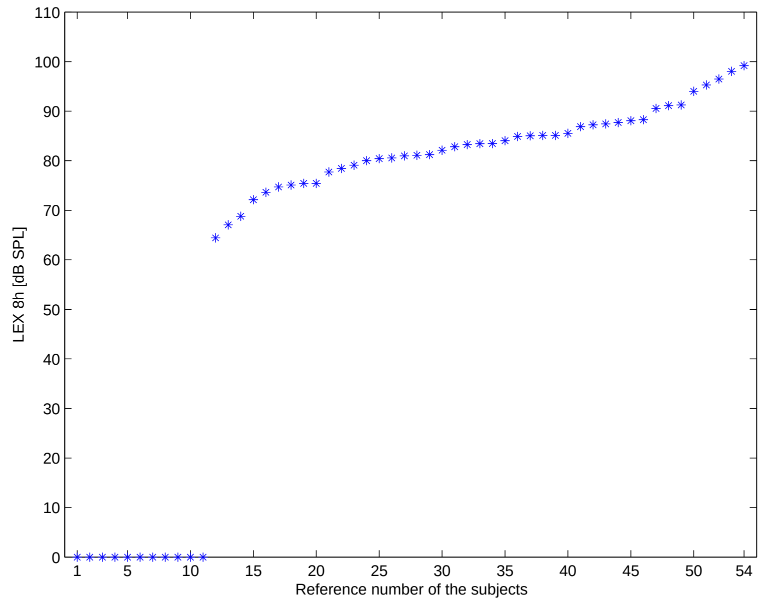

Figure 4.1: *$L_{EX,8h}$ calculated from the data collected in the pilot test. The $L_{EX,8h}$ of the subjects is sorted from the minimum to the maximum $L_{EX,8h}$*

The difference between the $L_{EX,8h}$ in the population would be desired to be bigger, but due to lack of subjects interested to participate in the complete investigation, this range was reduced to be only 10 dB difference between populations.

Parameters Analysis

This last step evaluates the parameters mentioned in Section 4.2.1 using the data collected from the questionnaire.

Regarding to the environments where MPs with headphones are used, the subjects were asked about how often they used to listen to their MPs (rarely, often or very often) and the type of environment that corresponds to the place selected (quiet, moderate or noisy).

The analysis is made according to a 3-stage analysis system that is invented. A point scale from 1 to 3 corresponding 1 to the weakest stage and 3 to the strongest as it can be seen in the questionnaire is used. Figure 4.2 shows the results plot as a function of the number of points get in each environment. It can be seen that the two environments that get the highest number of points were bus and street.

A representation of the number of MPs users for each type of MP devices is shown in Figure 4.3. The participants display a high use of MP devices when headphones are used, especially

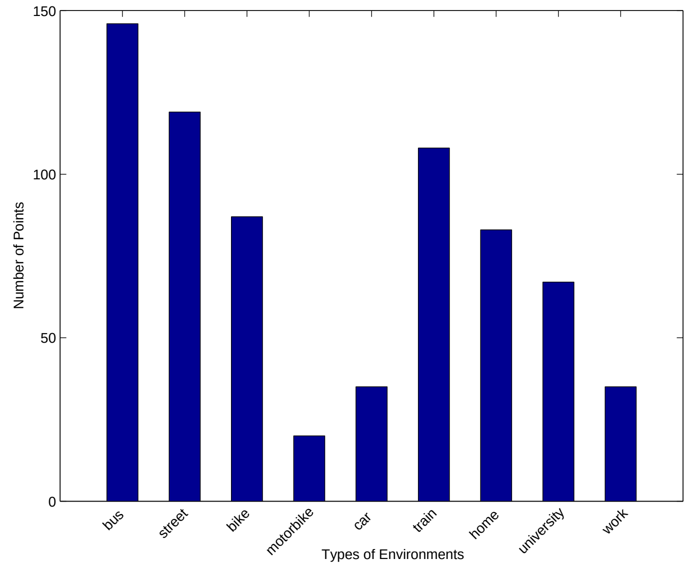

Figure 4.2: *Environments where MPs with headphones are used. Each subject could choose more than one environment.*

portable MP and personal computers or laptops are the MP most used by the population tested. Therefore it is consistent with the decision taken of using a portable MP as reference device in order to measure the headphone sound exposure.

Regarding the type of headphones that the population uses, it can be concluded that 71.11% use intra-concha headphones, 8.89% use supra-concha headphones and 20% use circum-aural headphones. Therefore the headphones selected in Appendix D for this pilot test are according to the preferences of the people that use headphones for listening to MPs.

4.3 Chapter Conclusions

When calculating the headphone sound exposure for each subject, the same exposure level was considered for the total exposure time. This assumption is only an approximation because it is not proved that the MP users listen to the music at the same level all the time.

The users may modify the control volume position of the MP depending on the environment where they are listening to music. Due to this, another headphone sound exposure evaluation taken into account different environments is performed in a listening test that is explained in next chapter. Bus and street, which are the most common places to use the MP as it was concluded in this pilot test, are used as references to evaluate the $L_{EX,8h}$ in a quiet/moderate and noisy environment respectively.

Furthermore, subjects did not use their MPs or their headphones in this pilot test. This may

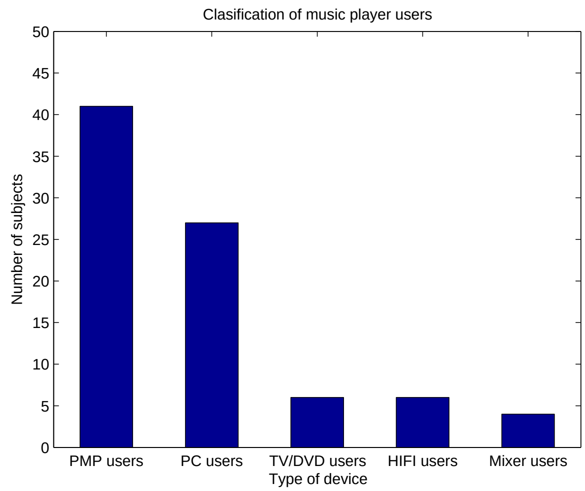

Figure 4.3: *Use of MPs with headphones as a function of the users preferences. Each subject had the possibility to select more than one device*

change the control level setting somehow for a lower or higher setting. Therefore it is asked to the subjects to bring their own MP, headphones and music in the listening test. Thus, a more accurate evaluation of the real headphone sound exposure can be made.

From the total of persons that took part of this pilot test, 18 subjects (28%) are selected as control population and 26 subjects (33%)as target population. These subjects are called to participate in a hearing assessment and a headphone sound exposure evaluation, which is carry out in different environments.

CHAPTER 5

LISTENING TEST

This chapter describes the design of the listening test. First the method and the goals of the listening test are described. Then, a detail description of each part is explained. The results of this listening test will be given in detail in Appendix. K.

5.1 Goals of the Listening Test

The goals of the listening test are:

- To measure the listening level, $L_{FF,Aeq}$, in three environments: very quiet, quiet/moderate and noisy for the control and the target population.
- To calculate the $L_{EX,8h}$ for both populations taken into account two environments: quiet, quiet/moderate and noisy.
- To test the hearing thresholds and the DPOAEs for both populations.

5.2 Listening Test Design

The test is made as it explained in the following lines:

First the subject is conducted to a room where an instruction paper is given. It can be seen in Appendix H. Then the subject must fill out a short questionnaire. After this, the subject is conducted to an audiometer cabin where DPOAEs measurements and a pure tone audiometry are performed. Then, a break is given to the subject to be ensure that he does not get tired and lose focus. After the break, the subject is conducted to a listening room. A control volume adjustment of his MP using his headphones and music is performed in different environments several times. Between each volume adjustment the subject come out of the room during 1 or 2 minutes.

The paper instructions given to the subjects can be seen in Appendix H. In addition, the conducted guidelines followed by the instructor can be found in Appendix I.

5.3 Listening Test Subjects

To perform this listening test, 26 and 18 subjects selected from the pilot test as target and control population respectively are invited to participate in this second part of the investigation. From these subjects, 12 and 10 subjects of the target and control population respectively agreed to participate.

Table K.2 and K.1 in Appendix K shows reference number, age and sex of all the subjects of control and target population who participate in the listening test respectively.

5.4 First Part: Listening Test Questionnaire

The first task is to fill out a questionnaire. This questionnaire can be seen in Appendix J.

The objective is to estimate the exposure time when using headphones for listening to music with a MP in a quiet/moderate and noisy environment for all the subjects. The results can be seen in Figure K.2 of Appendix K.

In this questionnaire, as well as in the pilot test, the subjects who suffer from a cold or take any medicine or another type of drugs are rejected. Any subject was in this situation, therefore no subject was rejected.

Moreover there are some specific questions asked to have a better overview of the hearing state of the subjects. The answers given by the subjects can be seen in Figure K.9 in Appendix K.

5.5 Second Part: Hearing Assessment

An audiometry test and DPOAEs are carried out. Appendix L describes these measurements and presents the results.

From the target population, two subjects are neglected after the performance of these two tests. Subject EDR is neglected because a deep hearing loss at high frequency in his right hear was detected. This audiometry was repeated twice and the results obtained were approximately the same. The results of his audiometry can be observed in Table L.2 in Appendix L. This hearing loss is considered to be produced by other reasons not related to the use of MPs with headphones, therefore this subject is neglected. Moreover, there was a problem conducting the DPOAE measurement to the subject JLS. It was seen that after the DPOAE measurement of the right ear, the measurement system was blocked. It was due to an accumulation of wax that was stuck in the microphone probe of the measurement system. Then, the wax was removed and the measurement finished. Observing his results, it can be seen that there is a strong asymmetrical difference between the right and left ear of both tests. After this examination, it is decided not to take into account this subject because there are some signs that this subject had an excessive amount of wax in his right ear. His audiometry and DPOAE measurements can be seen in Table L.2 and Figure L.17 respectively in Appendix L.

5.6 Third Part: MP Volume Adjustment

One of the goals of this listening test is to analyze the $L_{EX,8h}$ of both population. This parameter is calculated following the same procedure used in the pilot test. Therefore, first the subject must adjust the volume of his MP, then $L_{FF,Aeq}$ is measured, and finally with this level and the exposure time,$L_{EX,8h}$ is obtained.

The main considerations in this listening test are:

- The subjects are asked to bring their own MP, headphones and music. Since not all the MPs are portable, computers and MPs easily transported are recommended. Moreover the devices used in the pilot test are available just in case that the subjects can not bring their own devices.

- Bus and street, which are the most common places to use the MP as it was concluded in the pilot test in Chapter 4, are used as references environments to evaluate the $L_{EX,8h}$ in a quiet/moderate and noisy environment respectively. Moreover the subject is asked to adjust the MP when there is not environment being simulated. The environments are presented to the subjects randomly. Furthermore, two repetitions of each environment are simulated. Appendix M explains in detail the listening test setup and the simulations of the environments.

- For the calculation of the $L_{EX,8h}$, only the quiet/moderate and the noisy environment are considered since a very quiet situation is considered as an unrealistic environment.

- A familiarisation process is performed before starting this part of the listening test. It consist of an adjustment in one of the environments. This adjustment is not taken into account for the results.

The $L_{EX,8h}$ obtained for all the subjects is shown in Figure 5.1. Figures and tables of the exposure level and the exposure time can be found in Appendix K.

5.7 Chapter Conclusions

The data from 10 subjects of the control and 10 subjects of the target population are collected to be analyzed in next chapter.

From the pure tone audiometry and DPOAE measurements, 10 hearing threshold levels (HL) and 22 DPOAE levels are obtained respectively per subject and per ear. These values are according to the frequencies selected in section 2.7 in Chapter 2.

From the headphone sound exposure evaluation, for each subject, two exposure levels ($L_{EX,8h}$) and three listening levels ($L_{FF,Aeq}$) are calculated. The exposure levels corresponds to a quiet/-moderate and a noisy environment. Moreover, the listening levels corresponds to a very quiet, quiet/moderate and noisy environment.

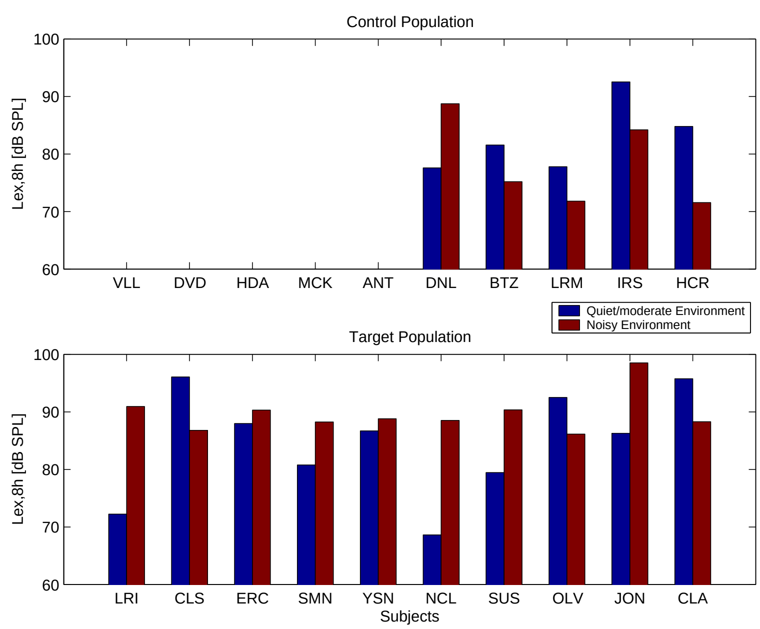

Figure 5.1: *$L_{EX,8h}$ calculated for the subjects of the target and control population according to the data obtained in the listening test for a quiet/moderate and a noisy environment.*

CHAPTER 6

LISTENING TEST RESULTS

This chapter contains an evaluation of the conducted listening test in order to analyze the data collected using an statistical tool.

6.1 Listening Test Analysis

There are four parameters tested: exposure level ($L_{EX,8h}$), listening level ($L_{FF,Aeq}$), hearing threshold level (HL) and DPOAE level. Moreover, there are some factors that are controlled in the listening test. Each factor contains a number of treatments. All factors and treatments used in this analysis are list below:

- Factor: Populations
  - Treatment: Control population
  - Treatment: Target population
- Factor: Ears
  - Treatment: Left ear control population (LC)
  - Treatment: Right ear target population (RC)
  - Treatment: Left ear control population (LT)
  - Treatment: Right ear target population (RT)
- Factor: Environments
  - very quiet
  - quiet/moderate
  - noisy
- Factor: Frequencies
  - Treatment: f_i
    where:
    i=1,2,...,10 for the HL statistical analysis.
    i=1,2,...,22 for the DPOAE statistical analysis.

In order to perform this statistical study an ANalysis Of VAriance test (ANOVA) and an Independent Sample T-test are applied using the Program SPSS 14.0. For further reading on the method, reference is made to [36]. In Appendix N and Appendix O a further explanation about the ANOVA and the T-test analysis is described.

6.2 Analysis of Listening Level

The aim of this section is to determine if the listening level differs among the populations and the environments.

In this study, the parameter analyzed is the $L_{FF,Aeq}$. The factors and the treatments defined are the followings:

- Factor A: Population
  - Treatment μ_{A1}: Control population
  - Treatment μ_{A2}: Target population
- Factor B: Environments
  - Treatment μ_{B1}: Very quiet environment
  - Treatment μ_{B2}: Quiet/moderate environment
  - Treatment μ_{B3}: Noisy environment

All the subjects, regardless of the type of population that they belong to, are introduced to the three environments simulated.

The analysis of the listening level is done to answer the next questions:

- Do control and target population differ significantly on their performance on the $L_{FF,Aeq}$?
- Second, is there any significant difference in listening level among very quiet, quiet/moderate and noisy environment?
- Finally, how do the two factors: populations and the environments interact in their effect on $L_{FF,Aeq}$?

6.2.1 Method

Since this test has two factors, it is analyzed using a two-way ANOVA test. Therefore, it is possible to evaluate the influence of the two factors as well as the influence of a possible interaction between them. In order to evaluate this statistical significance the next hypotheses are formulated:

- For factor A: Populations.
  - The null hypothesis, $H_{0,A}$: It states that there is not significant difference between the $L_{FF,Aeq}$ means of the two populations. It is noted as:

$$H_{0,A} : \mu_{A_1} = \mu_{A_2}.$$

  - The alternative hypothesis, $H_{1,A}$: It states that there is a significant difference between the $L_{FF,Aeq}$ means of the two populations.

$$H_{1,A} : \mu_{A_1} \neq \mu_{A_2}.$$

- For factor B: Environments.
  - The null hypothesis, $H_{0,B}$: It states that there are not significant differences among $L_{FF,Aeq}$ means of the three environments.

$$H_{0,B} : \mu_{B_1} = \mu_{B_2} = \mu_{B_3}.$$

  - The alternative hypothesis, H_1, B: It states that at least one of the three $L_{FF,Aeq}$ means is different from the others.

- For interaction between factors population and environments.
  - The null hypothesis, $H_{0,AB}$: It states that the interaction between factor populations and environments has a significant effect on $L_{FF,Aeq}$.
  - The alternative hypothesis, $H_{1,AB}$: It states that the interaction between factor populations and environments has not a significant effect on $L_{FF,Aeq}$.

6.2.2 Results

Table 6.1 presents the $L_{FF,Aeq}$ means across subjects for the treatments and factors defined in this section. Moreover the two-way ANOVA test results are presented in Table 6.2. Figure 6.1 illustrates the Confidence Interval (IC) and the estimated $L_{FF,Aeq}$ means for the two factors: populations (left) and environments (right).

Factor B	Mean $L_{FF,Aeq}$ (dB)		Standard Deviation		Number of Subjects		Mean for
Environment	Control	Target	Control	Target	Control	Target	environment (dB)
very quiet	87.82	97.29	9.99	5.75	10	10	92.96
quite/moderate	94.11	98.83	5.10	4.47	10	10	96.98
noisy	97.52	101.39	3.38	4.42	10	10	99.76
Mean for population (dB)	93.15	99.17					

Table 6.1: *Data collected from the listening test for the $L_{FF,Aeq}$ analysis.*

	Sum of Squares	Degrees of Freedom	Mean Squares	F-value	p-value
Factor A: Population	388,524	1,000	388,524	11,460	0,001
Factor B: Environment	483,794	2,000	241,897	7,135	0,002
Interaction AxB	72,408	2,000	36,204	1,068	0,351
Error	1830,744	54,000	33,903		
Total	571229,936	60,000			

Table 6.2: *Results of the $L_{FF,Aeq}$ analysis using two-way ANOVA statistical method.*

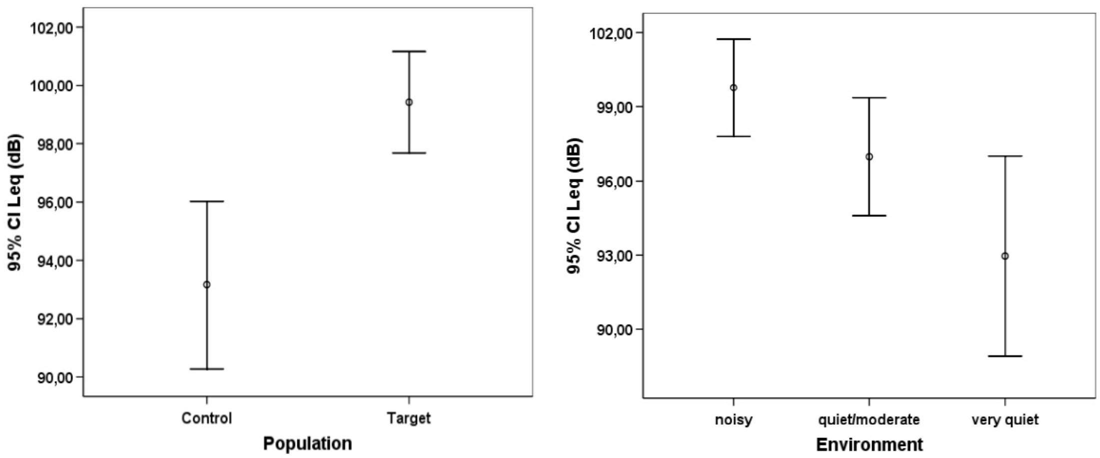

Figure 6.1: *Representation of the listening level as a function of the population (left) and the environment (right). The Null hypothesis can be rejected if the variances lines do not overlap in the horizontal direction.*

6.2.3 Conclusions

In this project the level of significance used is equal to 0.05. Then, to reject a null hypothesis, the p-value in the ANOVA table must be lower than 0.05.

From Table 6.1 it can be seen that the two factors present differences among the $L_{FF,Aeq}$ means. Furthermore, it is shown in Table 6.2 that the p-value in both cases is lower than 0.05. Then, the null hypotheses $H_{0,A}$ and $H_{0,B}$ can be rejected. This means that there is a significant difference between the performance of both populations. In addition, it also can be concluded that the listening level varies significantly among the three environments.

Since the p-value from factor population and environment interaction is higher than 0.05. It can be concluded that the interaction between these factors has not significant effect on the listening level performance.

The same conclusions can be observed from Figure 6.1. If the variance lines that represents the IC from the estimated $L_{FF,Aeq}$ does not overlap in the horizontal direction, two means are considered significantly different. In this case, the variance lines does not overlap, then the populations and the environments means are considered significantly different.

In order to analyze in detail the effect of $L_{FF,Aeq}$ among the three environments an Independent Sample T-test is performed. The T-test design and the results obtained are presented in Appendix O.

From the T-test results shown in Tables O.1, O.2 and O.3, the next conclusions are made. There is not a significant difference on $L_{FF,Aeq}$ performance between very quiet and quiet environment and between quiet/moderate and noisy environment. However, there exists a difference between very quiet and noisy environment $L_{FF,Aeq}$ performance.

6.3 Analysis of Exposure Level

The goal of this section is to determine if the $L_{EX,8h}$ of the control and the target population would differ among the environments.

This study is similar to the sound exposure level analysis described in Section 6.2. However, in this case the parameter analyzed is the $L_{EX,8h}$. The factors and the treatments are:

- Factor A: Population
  - Treatment μ_{A1}: Control population
  - Treatment μ_{A2}: Target population
- Factor B: Environment
  - Treatment μ_{B1}: Quiet/moderate environment
  - Treatment μ_{B2}: Noisy environment

Those subjects who belong either to the control or target population are introduced to all the treatments defined by the factor environments. Notice that now factor B has two treatments.

Since the $L_{EX,8h}$ of the subjects that do not use MP with headphones is equal to zero. These subjects are not taken in account in this study.

The analysis of the exposure level is done to answer the next questions:

- First, do control and target population differ significantly on their performance on $L_{EX,8h}$?
- Second, is there any significant difference in $L_{EX,8h}$ between quiet/moderate and noisy environment?

- Finally, how do the two factors: populations and the environments interact in their effect on $L_{EX,8h}$?

6.3.1 Method

To evaluate the influence of factor populations, environments and the interaction between them a two-way ANOVA analysis is applied. Thus, the hypotheses formulated are:

- For factor A: Populations.
  - The null hypothesis, $H_{0,A}$: It states that there is not significant difference between the $L_{EX,8h}$ means of the two populations. It is noted as:

$$H_{0,A} : \mu_{A_1} = \mu_{A_2}.$$

  - The alternative hypothesis, $H_{1,A}$: It states that there is a significant difference between the $L_{EX,8h}$ means of the two populations.

$$H_{1,A} : \mu_{A_1} \neq \mu_{A_2}.$$

- For factor B: Environments.
  - The null hypothesis, $H_{0,B}$: It states that there is not a significant difference between the $L_{EX,8h}$ means of the two environments.

$$H_{0,B} : \mu_{B_1} = \mu_{B_2}.$$

  - The alternative hypothesis, $H_{1,B}$: It states that there is a significant difference between the $L_{EX,8h}$ means of the two environments.

$$H_{1,B} : \mu_{B_1} \neq \mu_{B_2}.$$

- For interaction between factor populations and environments.
  - The null hypothesis, $H_{0,AB}$: It states that the interaction between factor populations and environments has a significant effect on $L_{EX,8h}$.
  - The alternative hypothesis, H_1: It states that the interaction between factor populations and environments has not a significant effect on $L_{EX,8h}$.

6.3.2 Results

Table 6.3 shows the mean $L_{EX,8h}$ for the treatments and factors considered. In addition, in Table 6.4 the results from the ANOVA analysis are presented.

A comparison of the mean listening levels and the IC of the two treatments of factor population(left) and environment (right) can be shown in Figure 6.2.

Factor B	Mean $L_{EX,8h}$ (dB)		Standard Deviation		Number of Subjects		Mean for
Environment	Control	Target	Control	Target	Control	Target	environments (dB)
quite/moderate	82.86	89.68	6.17	3.58	5	10	86.27
noisy	78.31	88.33	7.76	9.55	5	10	83.32
Mean for population (dB)	77.58	89.00					

Table 6.3: *Data collected from the listening test for the $L_{EX,8h}$ analysis. The subjects that do not use MP are nor included in this study.*

	Sum of Squares	Degrees of Freedom	Mean Squares	F-value	p-value
Factor A: Population	432,944	1,000	432,944	8,439	0,007
Factor B: Environment	0,872	1,000	0,872	0,017	0,897
Interaction AxB	124,639	1,000	124,639	2,429	0,130
Error	1539,139	30,000	51,305		
Total	254214,503	34,000			

Table 6.4: *Results of the L_{EX8h} analysis using two-way ANOVA statistical method*

6.3.3 Conclusions

Regarding the data exposed in Table 6.3 and Figure 6.2 (left), it can be seen that the L_{EX8h} means of factor populations are significantly different. Moreover the p-value of this factor, shown in Table 6.4, is equal to 0.007. This means that H_0, A can be rejected. Therefore the L_{EX8h} varies depending on the population.

The means of the factor environments are also different. However Figure 6.2 (right) shows that the IC are almost overlapped. Since the p-value is significantly higher than 0.05, H_0, B is not rejected. Then it can be concluded that $L_{EX,8h}$ do not depend on the environment.

From Table 6.4, it can be appreciate that the interaction effect between factor environments and populations is not present since the p-value is equal to 0.130.

6.4 Analysis of Hearing Thresholds and DPOAEs

In this section the data obtained from the audiometric tests and the DPOAE measurements is analyzed. Since the procedure followed is similar, both analysis are explained in the following lines.

The purposes of this section are:

- To analyze if the HL differs for both populations and for the 10 frequencies tested.
- To analyze if the DPOAE level differs for both populations and for the 22 frequencies

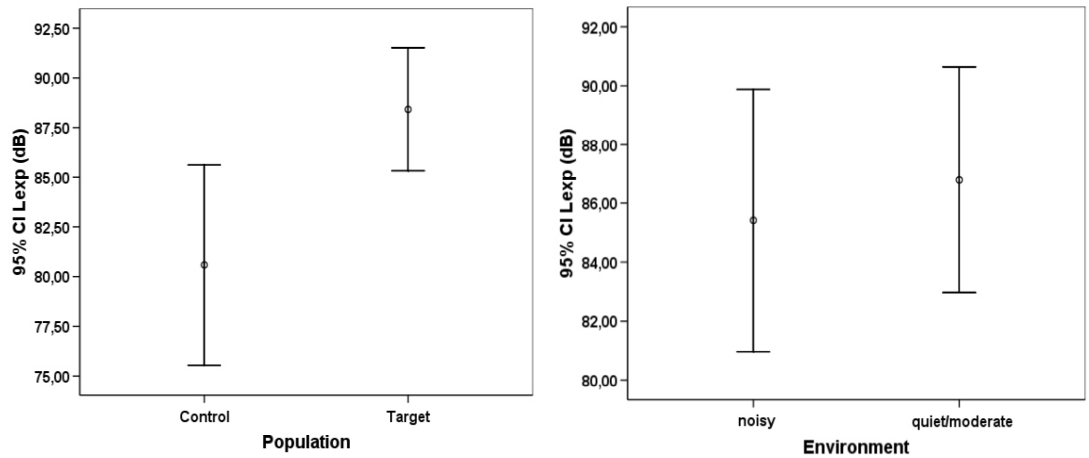

Figure 6.2: *Representation of $L_{EX,8h}$ in function of the population (left) and the environment (right). The null hypothesis can be rejected if the variances lines do not overlap in the horizontal direction.*

tested.

There are two factors: ears and frequencies. The parameter analyzed is HL or DPOAE level depending on the test. The treatments contained by the two factors are listed below:

- Factor A: Ears
  - Treatment μ_{A1}: LC
  - Treatment μ_{A2}: RC
  - Treatment μ_{A3}: LT
  - Treatment μ_{A4}: RT
- Factor B: Frequencies
  - Treatment μ_{Bi}: f_i
    where:
    i=1,2,...,10 for the HL statistical analysis.
    i=1,2,...,22 for the DPOAE statistical analysis.

It should be noticed that the range of frequencies tested is different in the audiometric test than in the DPOAE measurements.

Figures 6.3 and 6.4 present the HL mean and the standard deviation of the two ears of both populations along the frequencies.

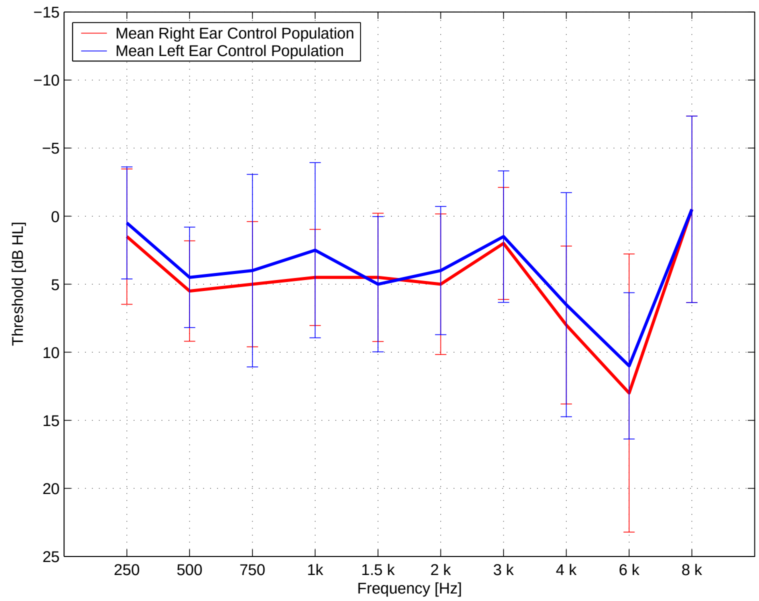

Figure 6.3: *Representation of the HL mean and the standard deviation of left and right ear of control population.*

The data collected from the DPOAE test is presented in Figures 6.5 and 6.6. It represents the DPOAE levels of left and right ear of both populations and for the frequencies defined as $\sqrt{f1.f2}$.

All these data is calculated by averaging across the ears of 10 subjects of control population and 10 subjects of target population. All these values are shown in Table P.1 and P.2 of Appendix P.

From an analysis of the data presented above, the next questions can be stated:

- First, do LC, RC, LT and RT ears differ significantly on their HL performance? Do they differ on DPOAE level performance?.
- Second, is there any significant difference in HL among the frequencies tested? Is there any difference in DPOAE level?
- Third, how do the two factors: ears and frequencies interact in their effect on HL? How do they interact in their effect on DPOAE level?

6.4.1 Method

It is desired to analyze the performance of the parameter HL or DPOAE level on the factors ears and frequencies. Thus, a two-way ANOVA test is applied individually for HL and DPOAE level data.
In next lines the hypotheses that corresponds to the hearing thresholds analysis are enunciated:

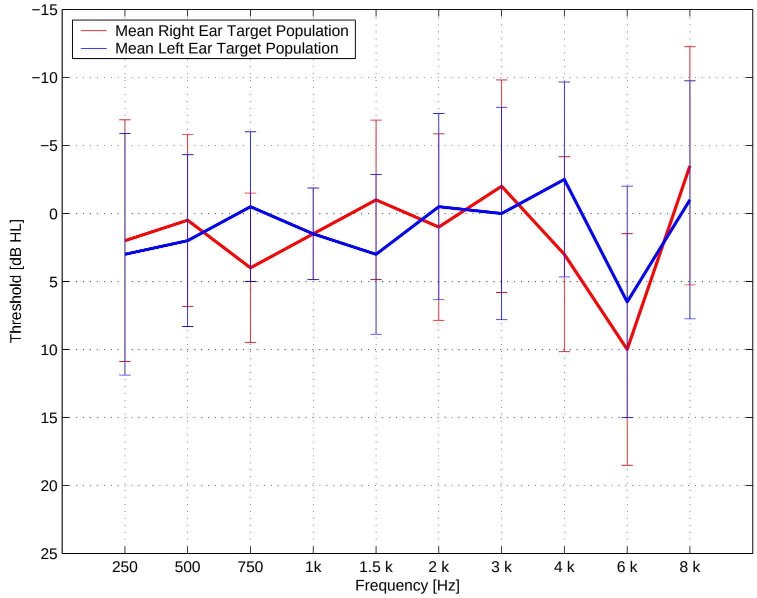

***Figure 6.4:** Representation of the HL mean and the standard deviation of left and right ear of target population.*

- For factor A: Ears.
  - The null hypothesis, $H_{0,A}$: It states that there are not significant differences among the HL means of the four ears. It is noted as:

$$H_{0,A} : \mu_{A_1} = \mu_{A_2} = \mu_{A_3} = \mu_{A_4}.$$

  - The alternative hypothesis, $H_{1,A}$: It states that at least one of the ears means is different from the others.
- For factor B: Frequencies.
  - The null hypothesis, $H_{0,B}$: It states that there are not significant differences among the HL means of the ten frequencies.

$$H_{0,B} : \mu_{B_1} = \mu_{B_2} = \mu_{B_i}. \quad \text{where i is the number of frequencies.}$$

  - The alternative hypothesis, H_1, B: It states that at least one of the HL means of the ten frequencies is different from the others.
- For interaction between factor ears and frequencies.
  - The null hypothesis, $H_{0,AB}$: It states that the interaction between factor ears and frequencies has a significant effect on HL.
  - The alternative hypothesis, $H_{1,AB}$: It states that the interaction between factor ears and frequencies has not a significant effect on HL.

Since the hypotheses of DPOAE analysis are similar, they are not described in this report.

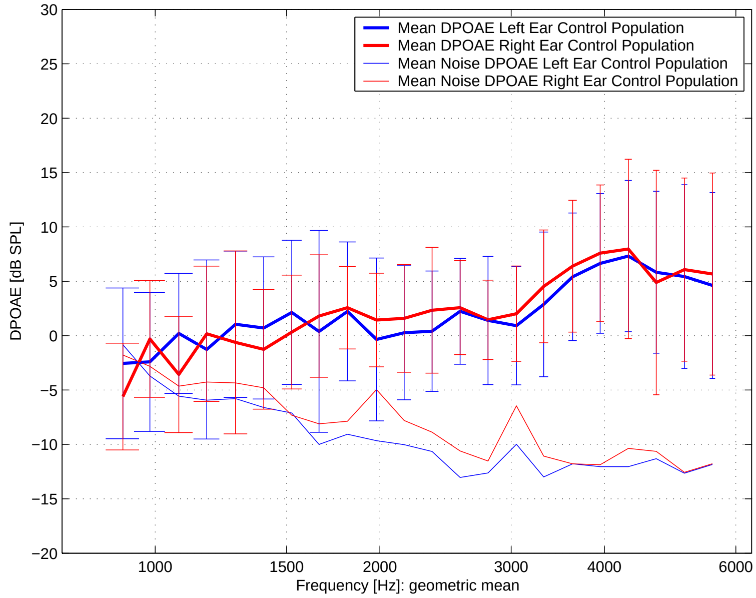

Figure 6.5: *Representation of the DPOAE mean and the standard deviation for left and right ear of control population.*

6.4.2 Results

In the following lines the results obtained from the two-way ANOVA test are presented for hearing thresholds and DPOAE analysis.

Hearing Thresholds results

In Table P.1 of Appendix P it is shown the HL means for the four ears and for the ten frequencies tested. Moreover, Table 6.5 presents the two way ANOVA test results obtained. The HL means and the IC of the factors ears and frequencies are shown in Figure 6.7.

	Sum of Squares	Degrees of Freedom	Mean Squares	F-value	p-value
Factor A: population	934,000	3,000	311,333	8,367	0,000
Factor B: frequency	2942,750	9,000	326,972	8,788	0,000
Interaction AxB	1047,250	27,000	38,787	1,042	0,410
Error	13395,000	360,000	37,208		
Total	21800,000	400,000			

Table 6.5: *Results of the HL analysis using two-way ANOVA statistical method*

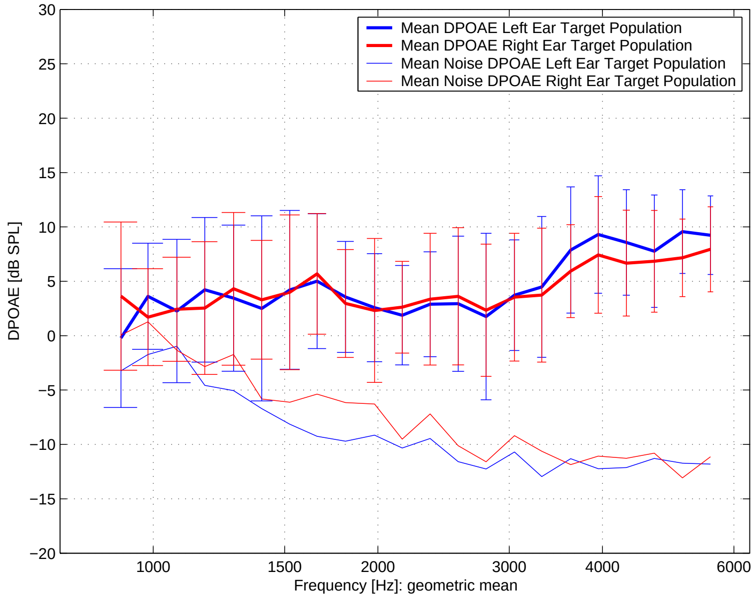

Figure 6.6: *Representation of the DPOAE mean and the standard deviation for left and right ear of target population.*

DPOAE results

Table P.2 of Appendix P shows the DPOAE means of the four populations and for the 22 frequencies tested. In addition, Table 6.6 presents the two way ANOVA test results obtained. A representation of the DPOAE means and the IC of the two factors analyzed is presented in Figure 6.8.

	Sum of Squares	Degrees of Freedom	Mean Squares	F-value	p-value
Factor A: ears	1387,206	3,000	462,402	11,803	0,000
Factor B: frequencies	5359,802	21,000	255,229	6,515	0,000
Interaction AxB	1088,462	63,000	17,277	0,441	1,000
Error	31026,891	792,000	39,175		
Total	47890,850	880,000			

Table 6.6: *Results of DPOAE level analysis using two-way ANOVA statistical method*

6.4.3 Conclusions

This section presents the conclusions obtained from the HL and DPOAE analysis.

HL Conclusions

From Table 6.5 it can be seen that the p-value for factor ears is less than 0.05. Then, the null hypothesis $H_{0,A}$ can be rejected. This means that at least one of the four treatments of factor

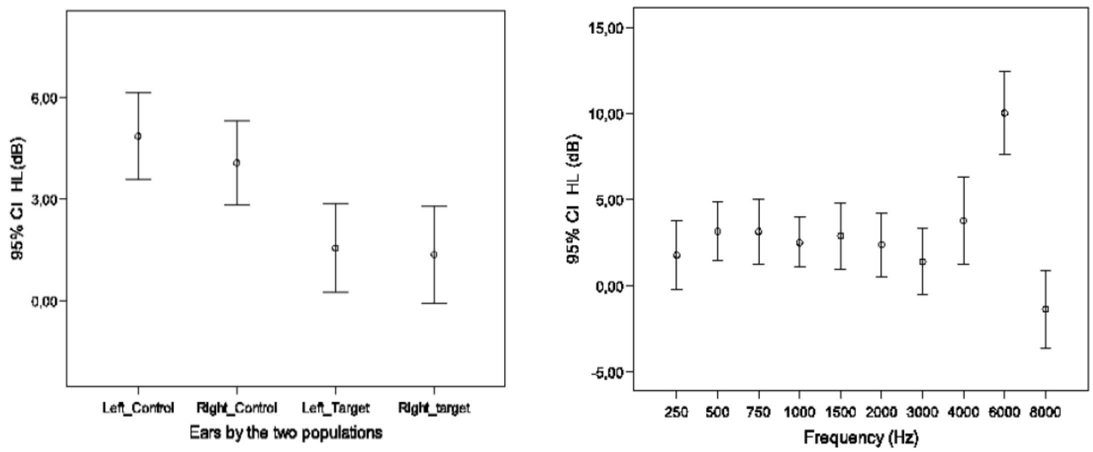

Figure 6.7: *Representation of HL mean in function of the ears of both populations (left) and the frequencies (right)*

ears performs different from the rest. There is at least a significant difference among the four treatments analyzed.

In case of factor frequencies, the null hypothesis $H_{0,B}$ can also be rejected as the p-value is lower than 0.05. Therefore, a significant difference among frequencies can also be found.

Nevertheless, the null hypothesis $H_{0,AB}$ can not be rejected. Then it can be concluded that there is not interaction effect between factor ears and frequencies.

Because $H_{0,A}$ and $H_{0,B}$ are rejected, it is known that at least a treatment performs different than the others. In order to study in detail the differences among the treatments of the factor ears and the factor frequencies, a T-test is performed for each factor:

- The T-test results for the factor ears are presented in Table O.4 of Appendix O. It can be concluded that there is a dependence on HL between the left and the right ear of the control population. This dependence is also found in the target population. There is not dependence in the HL performance between left and right ears of different populations. For instance, LC performs different than LT and RT.

- The T-test results for the factor frequencies are shown in Table O.5 of Appendix O. It can be appreciated a significant difference on HL performance between 6000 and 8000 Hz frequencies and the others.

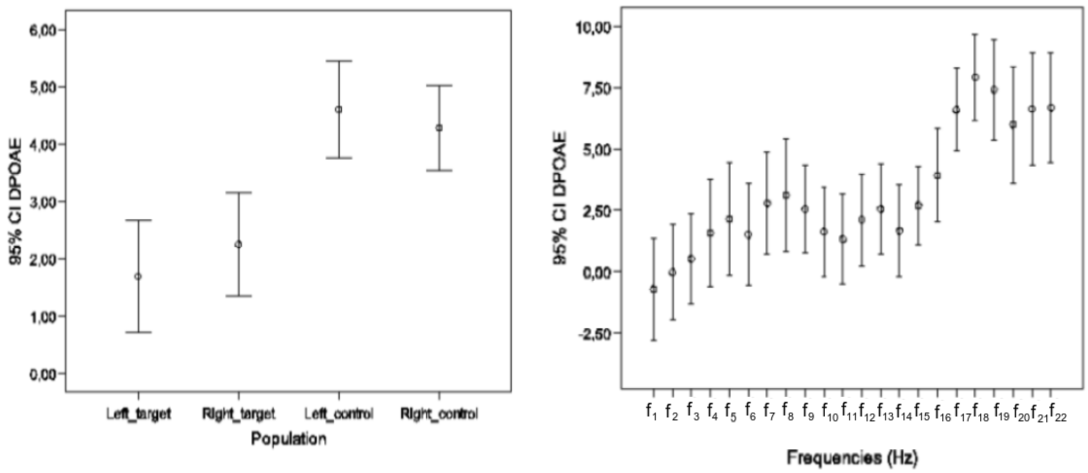

Figure 6.8: *Representation of DPOAE level mean in function of the ears of both populations (left) and the frequencies (right).*

DPOAE Conclusions

The p-values shown in Table 6.6 for factor ears and frequencies are less than 0.05. This means that there is at least a difference among the treatments of factor ears. This is also the same situation for factor frequencies. However, the interaction between them is not significant since the p-value is higher than 0.05.

In order to study in detail the differences among the treatments of the factor ears and factor frequencies, a T-test is performed for each factor:

- The T-test results calculated to analyze the differences of DPOAE level performance among the treatments of the factor ears, are shown in table O.6 of appendix O. A significant dependence between the left and the right ear of both populations is also appreciated.
- The T-test results for the factor frequencies are shown in Table O.7 of Appendix O. It can be appreciated a significant difference on DPOAE level performance in a range between 3626.17 and 5584.93 Hz, compared to the rest.

6.5 Chapter Conclusion

This section discusses the main conclusions derived from the research made in this project. With the results of the data collected from the listening test, conclusions related to headphones sound exposure and hearing assessment are presented next.

The number of subjects tested was 20, which is not considered a number high enough to conclude definitive assumptions regarding either the headphone sound exposure or the hearing assessment.

6.5.1 Conclusions of Headphone Sound Exposure

It was observed that the subjects of both populations adjusted the listening level depending on the environment. In general terms, a clear progression to higher volume settings is seen when increasing the external noise to which they are exposed to.

A significant difference was found in the listening level between a very quiet and a noisy environment. However, this difference was not between a very quiet and a moderate, or between a moderate and a noisy environment.

Nevertheless, it has to be noticed that not all the subjects responds in the same manner. Control population presents volume settings significantly higher than the target population for each environment. This difference can be appreciated specially in a very quiet environment, where the control population differs 10 dB from the target population.

Related to exposure levels, it can be concluded that the target population is sightly more exposed than the control. A difference in the exposure time is not clearly observed. In fact, only one subject, which is YSN, showed a exposure time representative higher compare to the control population. Therefore, the listening level is the parameter which makes the difference between both populations in terms of exposure level.

6.5.2 Validity and Conclusions of Hearing Assessment

Regarding the results from the listening test it can be said that the resolution of the methods used for the hearing assessment implies not very precise results due mainly to two reasons: First, the number of subjects tested for the investigation, and second the resolution of the audiometry test and DPOAEs measurements. Selecting a higher precision, better results could be expected.

The accuracy of the Bracketing method presented in Chapter 2 for the pure tone audiometry is 0.2 dB, but this accuracy does not correspond exactly to the method applied in this project. In that study [34], the attenuation step size varies during the threshold determination from 5 dB to 2.5 dB. By contrast, in this project a fixed step size of 5 dB is selected. It leads to a non so good accuracy. The effects of this step size can be reflected in the standard deviation of the audiometry data. Nevertheless, the right ear of the control population presents at 6 KHz higher standard deviation compare to the rest of frequencies of that ear. Therefore the performance of the subjects of that population at 6 KHz is not as homogeneous as for the rest of frequencies.

By the analysis of the audiometries it is seen that a mild hearing damage is appreciated at 6 KHz for both populations. However it can not be concluded that it is due to the use of MPs with headphones because it is present in both populations. For the rest of frequencies, there is not any high variation respect to the reference 0 dB HL.

It is seems that the hearing threshold of the different populations tend to follow similar frequency patterns giving representative results. By contrast, a DPOAEs mean of a population can not be representative due to the big differences between the DPOAE levels of subjects within a same population. This fact can be appreciated in the standard deviation values. Moreover, some investigations [8] state that a DPOAE is considered present when it is at least 6 dB above the noise floor. If this criteria is applied to the DPOAEs mean of the populations, DPOAEs are present. However, this should be applied to each individual instead to an average population. Therefore observations of the average across the DPOAE values of the ten subjects of each population does not give a clear picture of the effects of the exposure. To have representative results a large number of subject should be tested.

From the statistical analysis of DPOAE, its is concluded that there is a significant difference between both populations. Moreover the results show that at high and low frequencies the DPOAEs levels of the subjects are significantly different. This conclusion is expected since the DPOAEs have different amplitudes in different frequencies. Specially DPOAEs are not reliable at low frequencies since the noise of the measurement becomes higher at low frequency overlapping the DPOAEs.

CHAPTER 7

CONCLUSIONS

The aim of the project is to investigate the possible hearing damage due to the use of MPs with headphones when listening to music. In order to achieve this goal, two groups of subjects denoted as control and target populations were classified. This was done in a pilot test, where the headphone sound exposure level was calculated by means of the exposure time and the listening level.

A 33% of the subjects tested, were users highly exposed according to 85 dB exposure level stated in the Danish legislation. This group was defined as the target population. Moreover, a 47% of the subjects reported a moderate exposure, whereas a 20% were non exposed. From these two last groups, either the subjects whose exposure was lower than 75 dB, or the subjects who were not users of MPs with headphones, are named as the control population.

After this, a listening test was performed for the two populations to analyze the headphone sound exposure in a more accurately way. In this case, an individual study of the exposure level in different environments is performed. Moreover a hearing assessment is carried out.

The headphone sound exposure of the listening test consist of a questionnaire and a control volume adjustment test. From this part, the listening habits, the listening level and the exposure time are obtained. This was done in three different environments which are very quiet, quiet/moderate and noisy. Concerning to the hearing assessment, an pure tone audiometry and DPOAE measurements were carried out.

All the data collected from target and control population were compared to investigate the possible differences regarding to the parameters measured. The final conclusions obtained are:

- The contribution of headphone sound exposure to a possible hearing loss (NIHL) is as important as the contribution of occupational noise exposure, because the sound pressure levels produced by the listening devices tested can reach values considerably high. These listening devices were able to produce sound pressure levels range from 91 dB to 109 dB.
- The environment around a person affects the preferred volume setting that this person select in his MP specially when the environment becomes noisy. Moreover, users of MPs with headphones tent to listen to music at higher volume settings than the non users.

- Potential users of MPs with headphones are more exposed than the non potential users mainly because they set higher volume settings, although their exposure times are similar.
- A mild hearing loss was found in the subjects at 6 kHz, however it can not be concluded that this damage is due to the use of MPs with headphones, because it is present for exposed and non exposed populations.

For all the reasons stated in this chapter, it is concluded that this study only represents a hearing state from a group which could be considered in terms of hearing, as being within an average population with a slight hearing loss in the frequency of 6 KHz. Although the subjects, the exposure times and noise levels measured may not be fully representative of an average study, there is no reason to believe that the values obtained are atypical for young people.

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Part II

Appendix

APPENDIX A

ASSESSMENT TECHNIQUES PARAMETERS

This appendix shows a summary of the parameters selected for both hearing assessment methods selected in Chapter 2.

A.1 Audiometry

- Method: Fixed discrete pure tone audiometry where, for each frequency, the sound is presented monaurally through headphones to the subject.

- Sound stimuli: Pure tones of a time length of 300 ms are presented at 250,750, 500, 1000, 1500, 2000, 3000, 4000, 6000 and 8000 Hz.

- Patient instructions: The subject is instructed to press the button when hearing the sound stimulus, and to not press it when do not hear it.

- Familiarization process: A familiarization is carried out to let the subject get used to the task. This is done by means of a threshold determination using a pure tone of 40 dB. After the familiarization, the first tone presented is played at higher level than the level recorded when the button was not pressed in the last threshold determination.

- Attenuation step size: The sound stimulus is presented at an audible level of 40 dB. Then, if the subject is able to hear the stimulus, a descent by steps of 10 dB is performed until the subject does not hear it. Then an increasing of 5 dB is performed.

- Threshold determination: The threshold is determined when the subject responds twice in a row the same level before he does not hear the signal.

A.2 DPOAE Measurements

- OAEs: DPOAEs are selected, where the distortion product at $2f_1 - f_2$ due to the intermodulation between two tones along the basilar membrane are measured.

- A fixed frequency ratio of $f_2/f_1 = 1.22$ is set for all the measurements.

- The level of the two pure tones was 65 and 45 dB SPL for L_1 and L_2 respectively. This values are kept constant for all the measurements.
- The equipment is able to test frequencies from 635 to 3943 . The frequencies are obtained from f_2 = 1001-6165 Hz. This allows to test the state of the hearing at 635, 696, 769, 830, 903, 1001, 1074, 1172, 1270, 1404, 1526, 1648, 1807, 1965, 2148, 2344, 2563, 2795, 3027, 3308, 3625, and 3493 kHz.

APPENDIX B

TYPES OF HEADPHONES

This appendix present a classification of the different types of headphones according to the standard ITU-T-1993 [27].

B.1 Introduction

Headphones (also known as earphones, stereo phones or headsets) are a pair of transducers that receive an electrical signal from a MP or receiver and use speakers placed in close proximity to the ears to convert the signal into audible sound waves [19].

Important advantages of these devices are their privacy and portability characteristics. Moreover headphones do not excite room resonances, therefore it gives a more accurate acoustic sense.

Transducers commonly used in headphones are isodynamic, dynamic for example moving-coil, electrostatic and electret. A more deep explanation of the mechanical and electrical properties of headphones and transducers can be found in Poldy [40] but it is not examined in this appendix.

B.2 Headphone Categories

Headphones can be divided in five categories based on their structural properties as it is explained in the standard ITU-T-1993 [27].

Likewise, headphones can be classified as open or closed headphones.

Open headphone refers to an intentional leakage built in the back of the headphone cup. Therefore this kind of headphones are provided of an intentionally acoustic path between the external environment and the ear canal [27]. By contrast, closed earphones are characterized because they prevent any acoustic coupling between the external environment and the ear canal [27]. Although they are not completely airtight they can be considered nominally sealed. This kind of headphones are very good at containing the sound away from others and insulating the listener from outside sounds.

Standard ITU-T-93 [27] states that circum-aural, supra-aural, intra-concha and insert headphones can be open and closed, whereas supra-concha headphones can only be open.

Circum-aural Headphones

Circum-aural headphones are defined as those headphones which enclose the pinna and seat on the surrounding surface of the head. Contact to the head is normally maintained by compliant cushions. This kind of headphones may touch, but not significantly compress the pinna [27].

So long as the seal is effective, the frequency response is essentially flat down to a low frequency which is dependent only on the degree of sealing. A poor seal due to inadequate headband pressure can cause modifications in the headphone response.

The main disadvantage of this type of headphones is that they tent to be heavier and required greater headband pressure. Moreover they also can make the ears hot and uncomfortable [6]

Supra-aural Headphones

Supra-aural headphones are defined according to the standard ITU-T-1993 [27] as headphones which rest upon the pinna and have an external diameter or maximum dimension of at least 45 mm.

Compare to circum-aural headphones, supra-aural models are lighter, with smaller cushions, and do not surround the whole ear. They only cover the concha. The cushion is flat and it is placed on top of the ear. Therefore supra-aural headphones are more comfortable than circum-aural headphones. However the frequency response of a supra-aural headphone is more dependent on the headphone placement than in the case of circum-aural headphones [40].

Intra-concha headphones

Intra-concha headphones are intended to rest within the concha cavity of the ear. They have an external diameter (or maximum dimension) of less than 25 mm but are not made to enter the ear canal [27].

This kind of headphones are inserted at the entrance of the ear canal and are supported by the cartilage of the concha. Compared to the previous types this model is very smaller and portable. Nevertheless they can be uncomfortable to some people and due to the size.

Insert headphones

Insert headphones are those headphones designed to enter partially or completely into the ear canal [27], thus the sound is almost conducted directly into the ear canal. These models provide a good insulation from external sound. They are characterized because the small size of their transducers. This type of headphones are usually needed for professional issues.

APPENDIX C

EXPOSURE LEVEL CALCULATION

This appendix shows how to calculate the $L_{EX,8h}$ from the headphones of a MP using a manikin (head and torso simulator). Standards ISO 11904-2 [22] is followed to calculate the $L_{FF,Aeq}$ produced by the headphones. Moreover the standard ISO-1999 [23] is also applied to calculate the $L_{EX,8h}$. All these values are in dB SPL.

C.1 Method

The calculation of the $L_{EX,8h}$ can be divided in the next three steps:

- **Measurement of $\mathbf{L_{eq,Te}}$ in Third Octave Bands**:

  For each of the ear simulators integrated in the manikin, the $L_{eq,Te}$ is measured in one-third octave frequency bands when the manikin is exposed to the sound played through the headphones.

- **Free Field Correction**:

  Each of the band levels measured before with the manikin is corrected to convert the $L_{eq,Te}$ inside of the ear, to $L_{FF,eq}$. In order to do this correction the values show in Figure C.5 are subtracted from the $L_{eq,Te}$ as it shows in the Equation C.1.

$$L_{FF,eq} = L_{eq,Te} - \Delta L_{FF} \tag{C.1}$$

- **A-weighted Correction**:

  After the free field correction, an A-weighted correction is performed to obtain the equivalent continuous A-weighted sound pressure level. It is denoted as $L_{FF,Aeq}$. Equation C.2 shows the expression of the correction and Figure C.6 shows the values that are added.

$$L_{FF,Aeq} = L_{FF,eq} + A_f \tag{C.2}$$

- **Calculation of $\mathbf{L_{FF,Aeq}}$**:

  Since the $L_{FF,Aeq}$ is obtained in third octave bands, a conversion to a value which does not depend on the frequency is needed. This is done by means of the expression shown in Equation C.3.

$$L_{FF,Aeq} = 10\log\sum_{f} 10^{L_{FF,Aeq}} \tag{C.3}$$

- **Calculation of $\mathbf{L_{EX,8h}}$:**

  In order to calculate the sound exposure $L_{EX,8h}$, Equation C.4 has to be applied

  $$L_{EX,8h} = L_{FF,Aeq} + 10\log\left(\frac{Te}{To}\right) \tag{C.4}$$

  where Te is the time that the person is exposed to his headphones in hours per day and To corresponds to 8 hours.

As an example, the effect of these different steps has been applied to a measurement carried out with a portable MP and its headphones. Next sections show the equipment, the setup and the results.

C.2 Setup and Equipment

Table C.1 lists the equipment used in these measurements and Figure C.1 illustrates the setup.

The measurements are done using the control volume position 19 of the portable MP, with the music sample “Help” from “The Beetles” and with an integration time for $L_{eq,Te}$ measurement of 60 seconds. Furthermore a exposure time of 4 hours per day is used to calculate the $L_{EX,8h}$.

C.3 Results

Since the data of $L_{eq,Te}$, $L_{FF,eq}$, $L_{FF,Aeq}$ are frequency-dependent, the results are shown in third octave bands. Moreover an average between the measurements obtained from right and left ear is done for each plot.

Figure C.2 shows the $L_{eq,Te}$ measured by the microphones placed on the ears of the manikin. Figure C.3 illustrates the $L_{FF,eq}$ after the free field correction. Figure C.4 shows the $L_{FF,Aeq}$ after the A-weighted correction.

Finally, the calculated value of the $L_{FF,Aeq}$ is 103.16 dB SPL, and the $L_{EX,8h}$ is 100.15 dB SPL.

Item	Model	LAB-Nr:
Head and Torso Simulator	B&K 4128	08453060
Portable MP	Creative MuVo V200	215741
Headphones	Creative MuVo V200	215741
Measurement System	0.1 dB Harmonie	33964
PC	Fujitsu (laptop) -1600MB RAM, Intel M 760MHz	33964

Table C.1: *Equipment used for the measurements of the* $L_{eq,Te}$

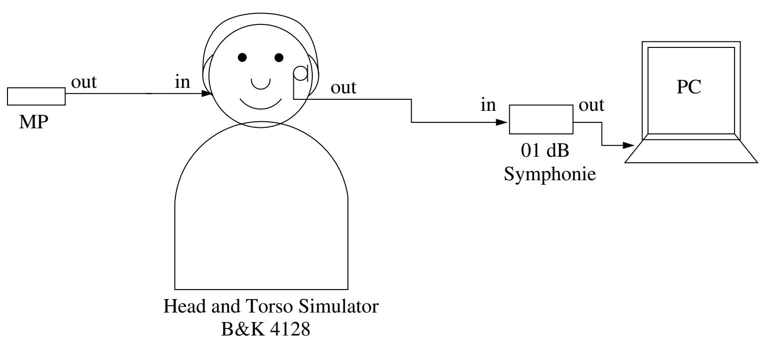

Figure C.1: *Setup used for the measurements of the* $L_{eq,Te}$

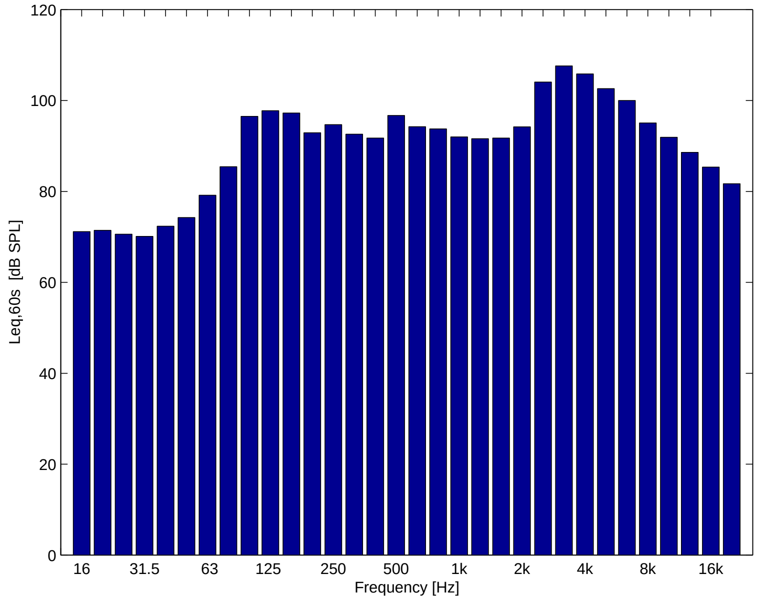

Figure C.2: *$L_{eq,60s}$ in third octave bands measured by the microphones placed on the ears of the manikin with the Creative MuVo V200 portable MP and its headphones. The control volume position selected for the measurement is 19 and the integration time is* 60 seconds*. The data show in this graph is an average of the right and left ear.*

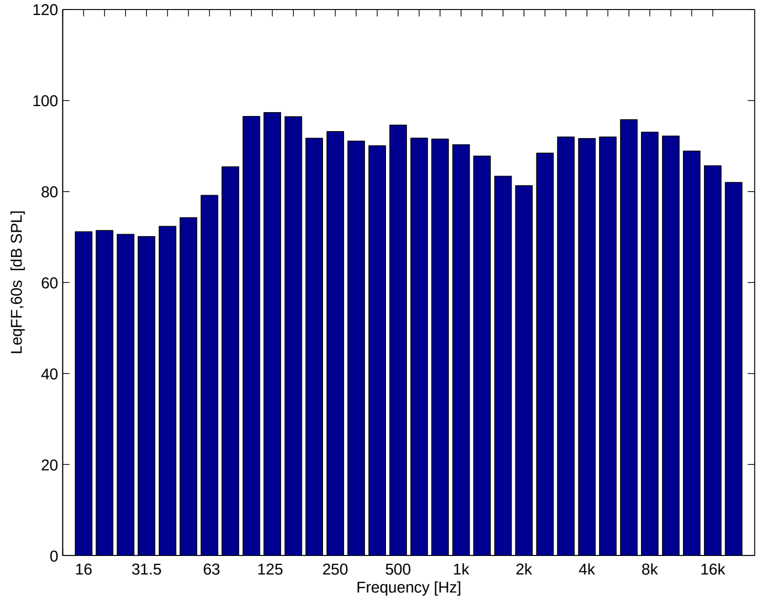

Figure C.3: *$L_{eqFF,60s}$ in third octave bands calculated after the free field correction. The data after the free field correction is shown in Figure C.2. The data show in this graph is an average of the right and left ear.*

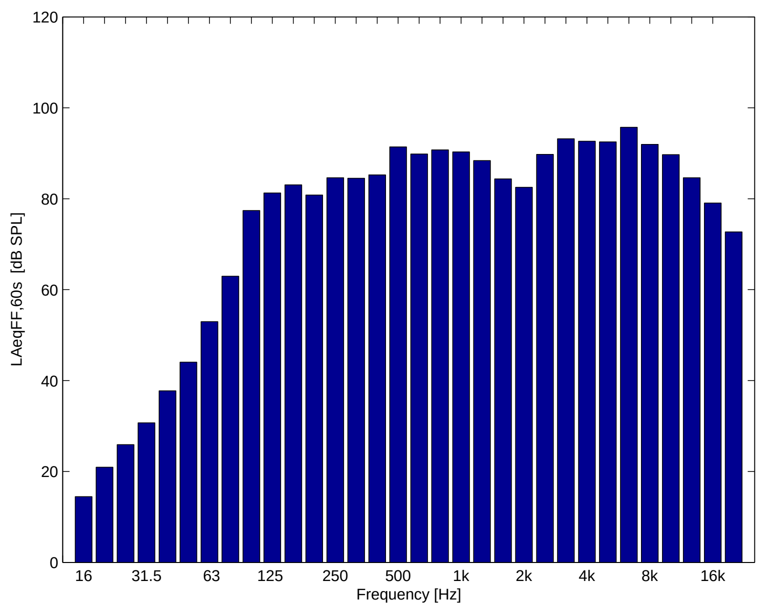

Figure C.4: *$L_{AeqFF,60s}$ in third octave bands calculated after the free field correction and the A-weighted correction. The data after the A-weighted correction is shown in Figure C.3. The data show in this graph is an average of the right and left ear.*

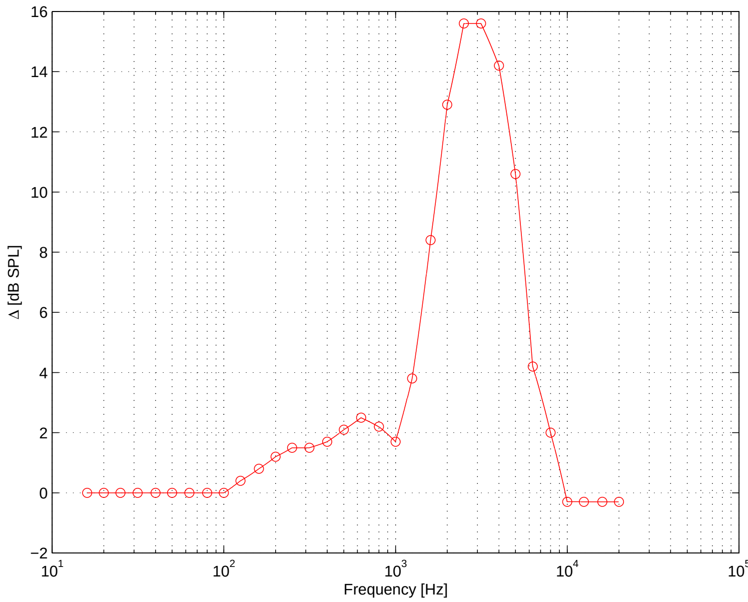

Figure C.5: *Standardized values of the free field correction for ear measurements of the manikin. The values that are subtracted are those which correspond with the third octave bands frequencies.*

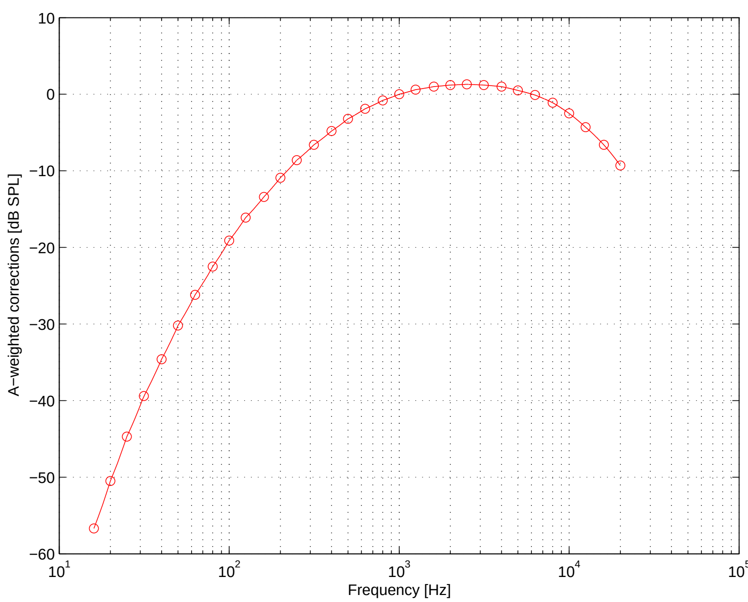

Figure C.6: *Standardized values of the A-weighted correction for ear measurements of the manikin. The values that are subtracted are those which correspond with the third octave bands frequencies. These values are obtained from the standard IEC 61672-1 [20].*

APPENDIX D

PILOT TEST MEASUREMENTS

This appendix describes the measurements needed for the pilot test described in Chapter 4. The normalization of the music samples and the measurements for the selection of the portable MP and the two headphones used in the pilot test are explained. Finally, the $L_{FF,Aeq}$ produced by the selected MP with both headphones when the portable MP is set to different volume settings is carried out.

D.1 Method

The measurements are divided in three different parts:

- Measurements related to the normalization of the music samples selected for the pilot test.
- Measurements in order to select a portable MP and a pair of headphones.
- Measurements of the $L_{FF,Aeq}$ produced at the different volume control positions of the portable MP and the headphones selected.

D.2 Setup and Equipment

The measurements are carried out in the listening room A at Aalborg University. Figure D.1 illustrates the setup and Table D.1 lists the equipment. The same setup and equipment is used for all the measurements described in this appendix.

The measurements are performed using a head and torso simulator. This device is equipped with a set of soft artificial pinnas, an artificial ear canal and an occluded artificial ear which allows to simulate the sound pressure level in the inner part of a real human ear. The pinnas have a hardness very close to that of a real human ear, therefore the head and torso simulator enables easy and realistic mounting of headphones [17]. In addition headphones evaluation can be performed because the artificial ear provides the correct acoustic loading [17].

The portable MP is connected to an adapter that splits the signal in two. One of its outputs is connected to the headphones and other is connected to a voltmeter for measuring the output voltage of the MP. The headphones are placed on the head and torso simulator, thus the microphone of the artificial ear measures the sound pressure level. The measurements are recorded in the time domain with the 0.1 dB Harmonie Measurement System and later they are proccessed in MATLAB in order to obtain the $L_{Aeq,60s}$. The integration time is set to 60 seconds which is the time duration of all the music samples.

The head and torso simulator has two artificial ear inserted in the right and left side of the head, therefore two measurements were obtained in each recording.

Item	Model	LAB-Nr:
Head and Torso Simulator	B&K 4128	08453060
PMP	Creative MuVo V200	215741
	Supratech JazzFree	-
Headphones	Creative	215741
	Super PowerBass CBX-15	-
	Supratech JazzFree	-
	Miniheadphones a11P1	-
	Sony MDR	2741
Measurement System	0.1 dB Harmonie	33964
PC	Fujitsu (laptop) -1600MB RAM, Intel M 760MHz	33964
Voltmeter	-	-

Table D.1: *Equipment used for the pilot test measurements.*

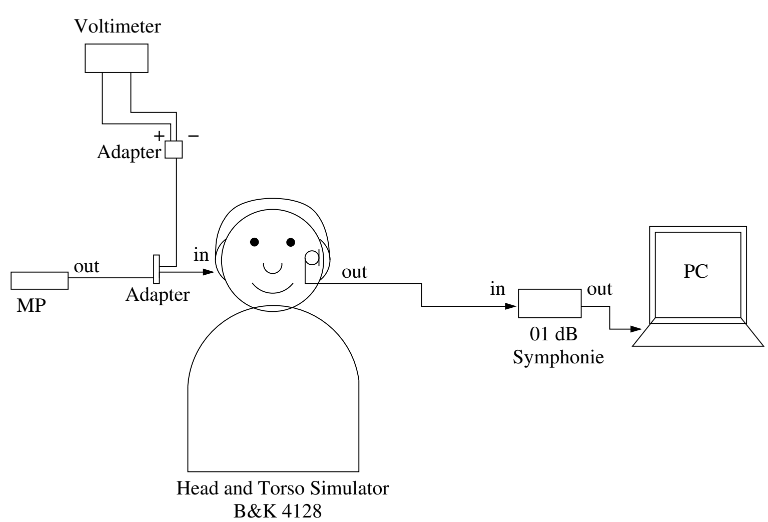

Figure D.1: *Setup used for the pilot test measurements.*

D.3 Results

D.3.1 Normalization of the Music Samples

The different selected music samples that are presented to the subject in the pilot test were collected from different information sources. All the music samples are single-channel WAVE files, with a sample frequency of 44.1 kHz, 16 bits per sample and 60 seconds of duration. The problem with these stimuli was the deficiency to control the level of the recordings beforehand. Due to this, when a music sample is played in the portable MP with the same volume control position, the equivalent level of the sound produced at the headphones is different depending on the level used when the recordings of the songs were made. Therefore a normalization of the music samples used in the pilot test is needed. For example Figure D.2 shows 30 seconds of two different samples before the normalization. It is observed that the energy content of these two signals is different.

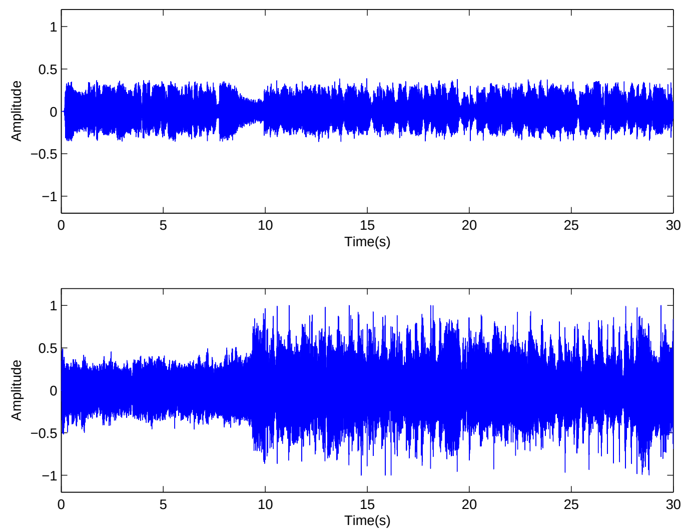

Figure D.2: *The upper figure corresponds to first 30 seconds of the music sample "Help" from "The Beetles" and the lower figure corresponds to the first 30 seconds of the music sample "Hips don't lie" from "Shakira". Both figures show the time signals before the normalization.*

The normalization is applied to all the music samples to get the same $L_{Aeq,60s}$. This is done following the definition of $L_{Aeq,T}$ stated in the standard ISO 1999 [23]. Equation D.1 shows the expression where T is the duration of the recording, $P_A(t)$ is the instantaneous sound pressure (A-weighted) at time t in Pascals, and P_0 is the standard reference pressure which is $20\mu Pa$. The A-weighted is performed in order to get the signal as perceived by the ear.

$$L_{Aeq,T} = 10 \log \left[\frac{1}{T} \int_0^T \frac{P_A^2(t)}{P_0^2} dt \right] \tag{D.1}$$

The procedure to normalize all the music samples is based on the calculation of the $L_{Aeq,60s}$ of one of the samples, and then adjust the rest to have the same $L_{Aeq,T}$ than this first sample, which is the reference. This is implemented in MATLAB.

From Equation D.1, an expression for the normalization can be derived by means of a level difference dB_{diff} (in dB) between two equivalent continuous A-weighted sound pressure levels, $L_{Aeq1,T}$ and $L_{Aeq2,T}$. This is show in Equation D.2 where $P_2(t)$ is the time function (instantaneous pressure values) of the signal to be normalized and $P_1(t)$ is the time function of the reference signal. Both, $P_1(t)$ and $P_2(t)$ are in Pascals.

$$dB_{diff} = L_{Aeq1,T} - L_{Aeq2,T} = 20\log \int_0^T \frac{P_1(t)}{P_2(t)} \tag{D.2}$$

Thus, the equation that describes the normalization can be obtained solving $P_2(t)$ from Equation D.2. The solution is described in Equation D.3.

$$P_2(t) = P_1(t).10^{-\frac{dB_{diff}}{20}} \tag{D.3}$$

The reference signal chosen is the music sample “Help” from the “The Beetles” which has a $L_{Aeq,60}$ of 96.03 dB. Therefore, by applying Equation D.3 to all the music samples, they all are adjusted to this equivalent continuous A-weighted sound pressure level.

In order to test the normalization, the $L_{Aeq,60s}$ of the stimuli is calculated in MATLAB after and before the normalization. Figure D.3 shows 30 seconds of the two stimuli shown in Figure D.2, but after the normalization.

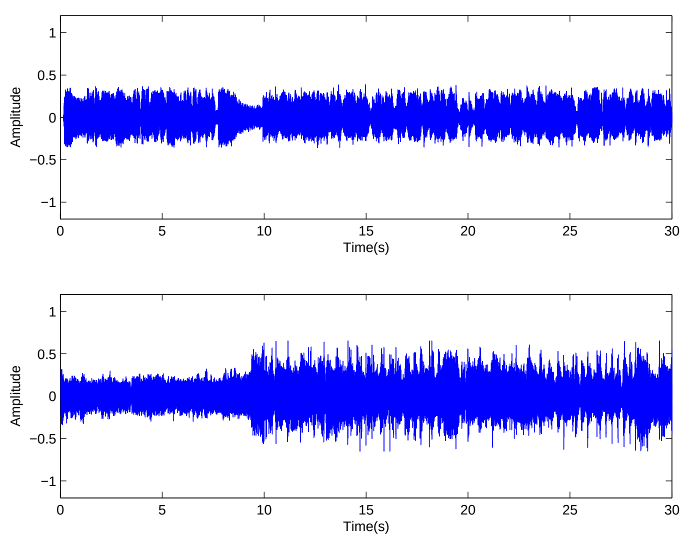

Figure D.3: *The upper figure corresponds to first 30 seconds of the sound stimulus “Help” from “The Beatles” and the lower figure corresponds to the first 30 seconds of the sound stimulus “Hips don’t lie” from “Shakira”. Both figures show the time signals after the normalization. The* $L_{Aeq,60s}$ *in both cases is* 96.03 dB

D.3.2 Measurements for the Selection of the MP and the Headphones

In order to fairly select a portable MP and a pair of headphones, all possible combinations between the two portable MP and the five sets of headphones shown in Table D.1 are tested. Each combination is identified by a reference name as it can be seen in Table D.2. For instance LD3 would correspond to the Listening device (LD) formed by the Creative MuVo V200 portable MP and the Super PowerBass CBX-15 headphones.

A requirement for the portable MPs that are tested is that they must have a digital volume setting for a easier control of the volume set by each subject.

Regarding the headphones, they must be portable, comfortable and easy to place. The types of headphones selected to be tested are supra-concha and intra-concha earphones. It is decided not to use circum-aural headphones because they are not considered portable. In addition, insert earphones are neither used because they are not comfortable enough furthermore, these devices are associated with professional issues [18].

Item	PMP	Types of Headphone
LD1	Creative MuVo V200	Creative
LD2	Creative MuVo V200	Supratech JazzFree
LD3	Creative MuVo V200	Super PowerBass CBX-15
LD4	Creative MuVo V200	Miniheadphones a11P1
LD5	Creative MuVo V200	Sony MDR
LD6	Supratech JazzFree	Creative
LD7	Supratech JazzFree	Supratech JazzFree
LD8	Supratech JazzFree	Super PowerBass CBX-15
LD9	Supratech JazzFree	Miniheadphones a11P1
LD10	Supratech JazzFree	Sony MDR

Table D.2: *Possible combinations between the two MP and the four headphones with their corresponding assigned name. The measurements are done according to these combinations for the pilot test measurements.*

Two LDs are selected according to the next requirements.

- First, the selected LDs must produce the highest sound pressure level among all the possible LDs.
- Second, the two LDs chosen must have different types of headphones.

The selection is made according to the results of the next measurements.

- Sensitivity of the headphones.
- Maximum $L_{FF,Aeq}$ delivered by the LDs.

Sensitivity of the Headphones:

The sensitivity of the headphones is measured playing in the portable MP a pure tone signal at 1000 Hz. Then, the sound pressure level is directly measured by means of the software of the Symphonie system and the voltage is measured in the voltmeter. From these two measurements a sensitivity value can be derived. This is done for all the headphones and for both cups of each headphone. Since it is a headphone measurement, either the Supratech JazzFree MP or the Creative MuVo V200 MP can be used as a sound source because it does not change the results.

In Table D.3 the values of the sensitivities measured for the different headphones are shown.

Headphones Type	Voltage (V_{rms})	SPL right cup (dB)	SPL left cup (dB)	Sensitivity right cup (dB/V)	Sensitivity left cup (dB/V)
Creative	0.268	101.7	102.5	113.93	113.13
Supratech JazzFree	0.271	87.0	86.5	97.84	98.34
Super PowerBass CBX-15	0.246	90.7	91.5	103.68	102.88
Miniheadphones a11P1	0.270	76.7	81.3	92.67	88.07
Sony MDR	0.251	101.6	103.0	115.00	113.60

Table D.3: *Measured sensitivity of the different headphones. The measurements are performed for both cups playing a pure tone at* 1000 Hz *using the Supratech JazzFree MP. The sound pressure level is measured only at that frequency.*

Maximum $L_{FF,Aeq}$ delivered by the LDs:

The music sample used is the song "The Beetles" which is one of the stimuli signals presented to the subject as it is explained in the design of the pilot test in Chapter 4. However any of the music samples could be used because they are all normalized. The integration time for the calculation of $L_{FF,Aeq}$ is set to the duration of the music sample which is 60 seconds.

Listening Device	$L_{FF,Aeq}$ (dB) left cup	$L_{FF,Aeq}$ (dB) right cup
LD1	109.77	107.60
LD2	104.57	104.92
LD3	105.31	101.96
LD4	97.29	90.78
LD5	105.80	104.38
LD6	109.43	106.24
LD7	103.47	98.25
LD8	102.43	97.45
LD9	96.47	91.90
LD10	104.60	103.73

Table D.4: *Maximum $L_{FF,Aeq}$ when the volume is set to the maximum for the different LDs. The music sample used is the song titled "Help" from "The Beetles".*

Final Selection
From the results showed in table D.4 it can be concluded that LD1, which gives 109.77 dB and 107.60 dB for the right and left cup respectively, are the devices that produce the highest $L_{FF,Aeq}$. Taking in account that the other LD selected must have different type of headphones, the next LD that gives a high $L_{FF,Aeq}$ is LD5. It produces 105.80 dB and 101.96 dB for right and left cup respectively. In addition, the headphones of LD1 and LD5 are the ones with the highest sensitivity, therefore they provide the highest sound pressure level among all the headphones. It can be appreciated in table D.3.

In conclusion, even though no big different among LD is seen, LD1 and LD2 are selected according these measurements.

D.3.3 Volume Setting Measurements

With the two LDs selected in the last section, a measurement of the $L_{FF,Aeq}$ for different control volume positions is done. The measurements are performed moving the digital control position from the minimum to the maximum volume. The signal used is again the musical excerpt from "The Beetles" and titled "Help" and the integration time for the calculation of $L_{FF,Aeq}$ is the duration of the music sample (60 seconds).

The data obtained in the volume setting measurements is shown in Tables D.5 and D.6 for the two LDs. Moreover Figure D.4 shows this data in a graph.

Control Volume Position	$L_{FF,Aeq}$ (dB) left cup	$L_{FF,Aeq}$ (dB) right cup	Mean $L_{FF,Aeq}$ (dB)
1	75.54	73.30	74.42
2	75.37	73.75	74.56
3	76.83	75.34	76.08
4	77.57	76.19	76.88
5	79.09	77.83	78.46
6	80.38	79.19	79.79
7	82.06	80.92	81.49
8	83.71	82.64	83.17
9	85.38	84.40	84.9
10	87.16	86.19	86.68
11	89.12	88.18	88.65
12	91.04	90.12	90.58
13	92.97	92.02	92.50
14	94.98	94.03	94.50
15	96.99	96.00	96.50
16	98.86	97.78	98.32
17	100.68	99.45	100.06
18	102.35	101.00	101.67
19	103.91	102.42	103.17
20	105.34	103.71	104.52
21	106.55	104.78	105.66
22	107.66	105.75	106.71
23	108.64	106.57	107.60
24	109.07	106.96	108.02
25	109.77	107.60	108.68

Table D.5: *Maximum $L_{FF,Aeq}$ when the volume is set to different positions for LD1.*

Control Volume Position	$L_{FF,Aeq}$ (dB) left cup	$L_{FF,Aeq}$ (dB) right cup	Mean $L_{FF,Aeq}$ (dB)
1	70.64	66.72	68.68
2	71.03	67.24	69.14
3	71.96	68.71	70.34
4	72.44	69.06	70.75
5	74.43	71.19	72.81
6	74.32	71.27	72.80
7	75.44	72.52	73.98
8	76.67	73.84	75.26
9	78.18	75.42	76.80
10	79.82	77.14	78.48
11	81.58	79.02	80.30
12	83.42	80.82	82.12
13	85.37	82.86	84.12
14	87.25	84.71	85.98
15	89.24	86.68	87.96
16	91.19	88.62	89.91
17	93.21	90.66	91.93
18	95.16	92.61	93.89
19	97.14	94.58	95.86
20	99.03	96.41	97.72
21	100.80	98.15	99.48
22	102.46	99.71	101.08
23	104.06	101.25	102.65
24	104.81	101.97	103.39
25	105.96	105.96	105.96

Table D.6: *Maximum $L_{FF,Aeq}$ when the volume is set to different positions for LD5.*

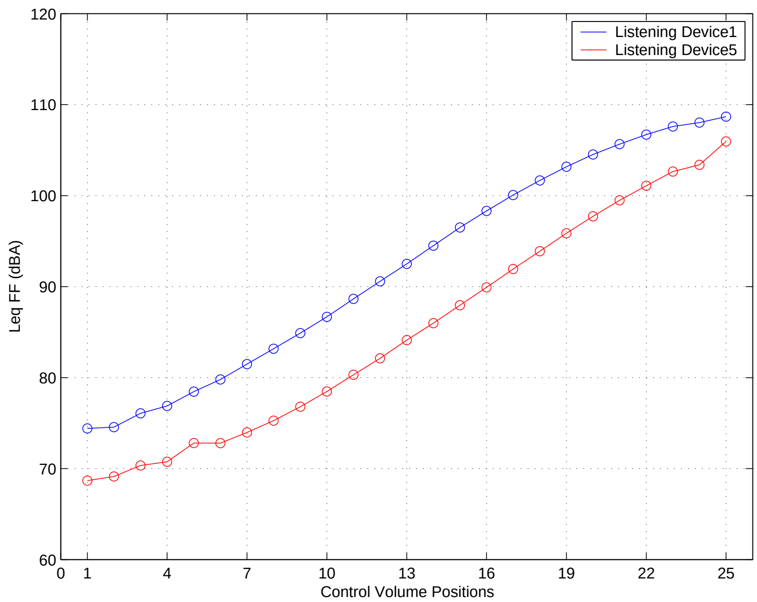

Figure D.4: *Mean $L_{FF,Aeq}$ produced by the LD1 and the LD5 measured at the headphones using an artificial head and torso simulator. Circles represents the measured values and the curve is calculated by interpolation. An average between the measurements of the right and left cup is done. This data can be also seen in Tables D.5 and D.6 respectively*

APPENDIX E

PILOT TEST INSTRUCTIONS

Welcome to our Listening Test. The pilot test you are about to take part in is carried out for the final master thesis project performed by group 1066 of the Acoustic department of AAU. It studies the exposure level and the listening habits when music players with headphones are used.

Task 1: In this task you have to:

- Select one of two different headphones showed.
- Select one of seven music samples presented.
- Adjust the control volume setting of a given portable music player using the headphones and the music sample elected before.

Two different types of headphones are going to be presented. You have to choose the one that looks more similar to the headphone that you use normally. In case that you are not a music player user, you must select that set of headphones that you would use if you were going to listen to music with a music player.
In next table there is a list of music samples of varied styles. You have to choose the sample that you would like to listen to.

Author	Title
The Beetles	Help
Milk Inc.	In my eyes
Fugees	Ready or not
Woody Allen	Come On and Stomp
Shakira	Hips dont't lie
U2	Sunday Bloody Sunday
Vivaldi	The Four Seasons

Table E.1: *Music samples*

Task 2: In this task you have to fill out a questionnaire.

All your data will be stored and treated confidentially.
Thanks for your participation
Acoustics Department. Group 1066

APPENDIX F

PILOT TEST QUESTIONNAIRE

This is a questionnaire carried out for the final master thesis project performed by group 1066 of the Acoustic department of Aalborg University. If you want to participate in this listening experiment, please fill in the form bellow. Your data will be stored and treated confidentially.

F.0.4 Personal data:

- Name and Surname:..
- Age:....................   • Genre: ☐ Woman   ☐ Man

F.0.5 Prior experience:

1 Do you have a known history of hearing damage diagnosed by a medical doctor?
☐ Yes
☐ No
☐ I dont't know
If last answer was Yes, which and when?..
....

2 Have you ever had an ear operation?
☐ Yes
☐ No
☐ I dont't know
If last answer was Yes, which and when?...
....

3 Do you ever had any hearing problem i.e. infections, ear noises, drainage...?
☐ Yes
☐ No
☐ I dont't know
If last answer was Yes, how often?...
....

4 Are you suffering a cold?
☐ Yes

☐ No
☐ I dont't know

5 Have you ever had your hearing tested before?
☐ Yes
☐ No
☐ I don't know
If last answer was Yes, when, where and how did it go?..
....

6 Does/Did anyone in your immediate family have hearing disorder?
☐ Yes
☐ No
☐ I don't know
If last answer was Yes, please explain...
....

7 Have you ever taken any medicine or another type of drugs that might have influence on your hearing?
☐ Yes
☐ No
☐ I don't know
If last answer was Yes, which and when?..
....

8 Have you ever been exposed to loud sounds i.e. explosions, fireworks, shootings, firearms...?
☐ Yes
☐ No
☐ I don't know

9 If last question was Yes:

- Please explain if you felt any pain in your ears or sudden lost of hearing?.........................
....
- Which kind of sound and how often have you been exposed?...
....
- Did you use hearing protectors?
☐ Yes
☐ No
☐ I don't know
If last answer was Yes, for how long?...
....

10 Have you ever had a job where you need to use headphones i.e. call center, dj...?
☐ Yes

☐ No
☐ I dont't know
If last answer was Yes, for how long?..
....

11 Have you ever worked in a very noisy environment where you could not talk easily with other people?
☐ Yes
☐ No
☐ I dont't know

12 If last question was Yes:

- Which kind of noise and in which environment?...
  ....
- How long and how often?..
  ....
- Did you use hearing protectors?
  ☐ Yes
  ☐ No
  ☐ I dont't know
  If last answer was Yes, for how long?...
  ....

F.0.6 Listening habits:

13 Do you listen to music using music players with headphones?
☐ Yes
☐ No
If last answer was No, please go to question number 23

14 If the music player with headphones that you use is a portable music player i.e. mp3, mobile telephone, portable radio, PDA ... please, fill out next table choosing how often and for how long time you have been using it:

How often?	Day	Time in hours per day	**How long?**
	☐ 1	☐ 1 or less	☐ 1 month
☐ weekly	☐ 2	☐ 1-2	☐ 1-6 months
	☐ 3	☐ 2-4	☐ 6-12 months
	☐ 4	☐ 4-6	☐ 1-2 years
	☐ 5	☐ 6-8	☐ 2-5 years
☐ monthly	☐ 6	☐ 8-10	☐ 5-10 years
	☐ 7	☐ more than 10	☐ more than 10 years

15 If the music player with headphones that you use is a personal computer or a laptop please fill out next table choosing how often and for how long time you have been using it:

How often?	Day	Time in hours per day	**How long?**
	☐ 1	☐ 1 or less	☐ 1 month
☐ weekly	☐ 2	☐ 1-2	☐ 1-6 months
	☐ 3	☐ 2-4	☐ 6-12 months
	☐ 4	☐ 4-6	☐ 1-2 years
	☐ 5	☐ 6-8	☐ 2-5 years
☐ monthly	☐ 6	☐ 8-10	☐ 5-10 years
	☐ 7	☐ more than 10	☐ more than 10 years

16 If the music player with headphones that you use is a TV or a DVD, please fill out next table choosing how often and for how long time you have been using it:

How often?	Day	Time in hours per day	**How long?**
	☐ 1	☐ 1 or less	☐ 1 month
☐ weekly	☐ 2	☐ 1-2	☐ 1-6 months
	☐ 3	☐ 2-4	☐ 6-12 months
	☐ 4	☐ 4-6	☐ 1-2 years
	☐ 5	☐ 6-8	☐ 2-5 years
☐ monthly	☐ 6	☐ 8-10	☐ 5-10 years
	☐ 7	☐ more than 10	☐ more than 10 years

17 If the music player with headphones that you use is a Hi-Fi equipment or similar, please fill out next table choosing how often and for how long time you have been using it:

How often?	Day	Time in hours per day	**How long?**
	☐ 1	☐ 1 or less	☐ 1 month
☐ weekly	☐ 2	☐ 1-2	☐ 1-6 months
	☐ 3	☐ 2-4	☐ 6-12 months
	☐ 4	☐ 4-6	☐ 1-2 years
	☐ 5	☐ 6-8	☐ 2-5 years
☐ monthly	☐ 6	☐ 8-10	☐ 5-10 years
	☐ 7	☐ more than 10	☐ more than 10 years

18 If the music player with headphones that you use is a mixer table or similar, please fill next table choosing how often and for how long time have you been using it:

How often?	Day	Time in hours per day	**How long?**
	☐ 1	☐ 1 or less	☐ 1 month
☐ weekly	☐ 2	☐ 1-2	☐ 1-6 months
	☐ 3	☐ 2-4	☐ 6-12 months
	☐ 4	☐ 4-6	☐ 1-2 years
	☐ 5	☐ 6-8	☐ 2-5 years
☐ monthly	☐ 6	☐ 8-10	☐ 5-10 years
	☐ 7	☐ more than 10	☐ more than 10 years

19 Next table contains some places where music players with headphones can be used. Please fill the table marking how often you use to listen to your music player with headphones and the type of environment which corresponds to the place selected. You only have to mark those places where you use your music player.

	how often?			which environment?		
	1 Rarely	2 Often	3 Very often	1 Quiet	2 Moderate	3 Noisy
bus	☐	☐	☐	☐	☐	☐
train	☐	☐	☐	☐	☐	☐
bike	☐	☐	☐	☐	☐	☐
motor-bike	☐	☐	☐	☐	☐	☐
car	☐	☐	☐	☐	☐	☐
street	☐	☐	☐	☐	☐	☐
home	☐	☐	☐	☐	☐	☐
university	☐	☐	☐	☐	☐	☐
at work	☐	☐	☐	☐	☐	☐
another place:...........................	☐	☐	☐	☐	☐	☐

20 Do you use to place the two earphones in your ears when you are listening to music with your music player?
☐ Yes
☐ No

21 If last question was No, which ear do you use to cover?
☐ right
☐ left

22 Which kind of headphones do you use?
☐ Inside the ear
☐ On the ear
☐ Around the ear

23 Are you a musician?
☐ Yes

☐ No
If last question was No, please go to question number 26
If last answer was Yes, which kind of instrument do you play?..

24 Are you playing in a:
☐ Rock band ☐ Orchestra ☐ Jazz band ☐ Big band ☐ At home ☐ pub
☐ studio ☐ at work ☐ Another one: ....

25 Please, fill next table choosing how often do you play and for how long time have you been playing

How often?	Day	Time in hours per day	**How long?**
	☐ 1	☐ 1 or less	☐ 1 month
☐ weekly	☐ 2	☐ 1-2	☐ 1-6 months
	☐ 3	☐ 2-4	☐ 6-12 months
	☐ 4	☐ 4-6	☐ 1-2 years
	☐ 5	☐ 6-8	☐ 2-5 years
☐ monthly	☐ 6	☐ 8-10	☐ 5-10 years
	☐ 7	☐ more than 10	☐ more than 10 years

26 Do you go to discotheques or pop/rock concerts?
☐ Yes
☐ No

27 If last question was Yes, please fill next table choosing how often do you go to discotheques or pop/rock concerts and for how long have you been going to this places.

How often?	Day	Time in hours per day	**How long?**
	☐ 1	☐ 1 or less	☐ 1 month
☐ weekly	☐ 2	☐ 1-2	☐ 1-6 months
	☐ 3	☐ 2-4	☐ 6-12 months
☐ monthly	☐ 4	☐ 4-6	☐ 1-2 years
	☐ 5	☐ 6-8	☐ 2-5 years
☐ yearly	☐ 6	☐ 8-10	☐ 5-10 years
	☐ 7	☐ more than 10	☐ more than 10 years

This questionnaire is a part of a master thesis which study the hearing and the sound exposure level when music players with headphones are used. Do you want to take part of our listening test? In this study your hearing will be tested using common and not risky methods as audiometry and otoacoustic emissions (OAE). Furthermore the sound exposure level when you are using portable music players with headphones will be measured and finally, you will be asked to fill a short questionnaire.

Do you want to participate?
☐ Yes
☐ No

Telephone number:..
e-mail address:..

Thanks for your participation
Acoustics Department. Group 1066

APPENDIX G

PILOT TEST SUBJECTS

This appendix lists the subjects who performed the pilot test and their results.

The reference number, the sex, the age and the volume control level setting of each of the subjects can be seen in Table G.1. Moreover the $L_{FF,Aeq}$, the exposure time in hours per day and the $L_{EX,8h}$ calculated from the data collected in the pilot test are also presented.

It must be noticed that the subjects who present any hearing condition in the pilot test are not listed in this table.

The data of Table G.1 is sorted from the minimum $L_{EX,8h}$ to the maximum $L_{EX,8h}$. Figures G.1 and G.2 plots the data shown in this table. Figure G.1 shows all the subjects whereas figure G.2 shows only the subjects with a $L_{EX,8h}$ different from zero.

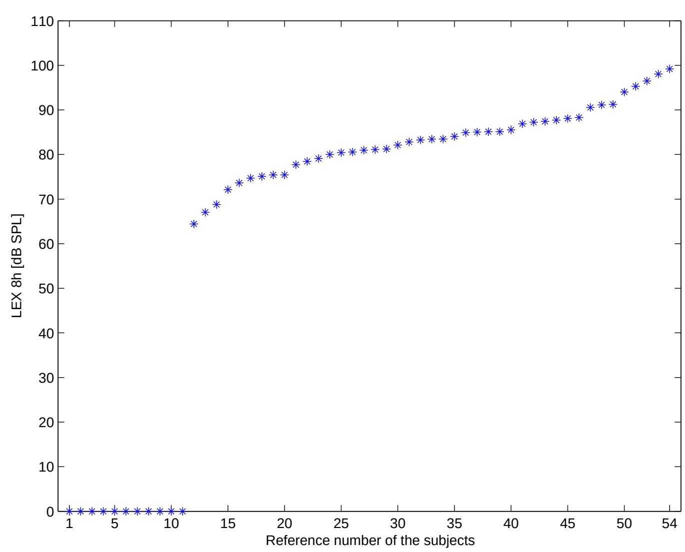

Figure G.1: *$L_{EX,8h}$ calculated from the data collected in the pilot test. The $L_{EX,8h}$ of the subjects is sorted from the minimum to the maximum $L_{EX,8h}$. This data is also shown in Table G.1*

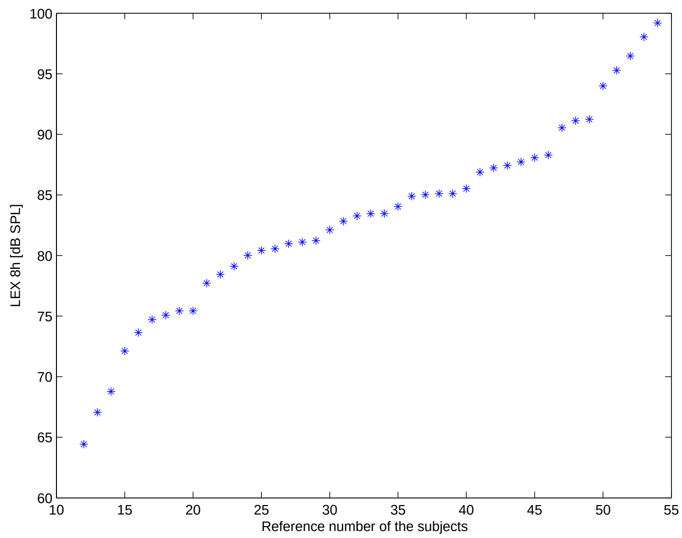

Figure G.2: *$L_{EX,8h}$ calculated from the data collected in the pilot test. The subject with a $L_{EX,8h}$ of $0\,\mathrm{dB}$ are not shown. The $L_{EX,8h}$ of the subjects is sorted from the minimum to the maximum $L_{EX,8h}$. This data is also shown in Table G.1*

Reference Number	Sex	Age	Control Level Setting	$L_{FF,Aeq}$	Hours per Day	$L_{EX,8h}$
1	male	30	16creative	98,32	0	0,00
2	female	22	10sony	78,48	0	0,00
3	male	27	13sony	84,12	0	0,00
4	female	22	18creative	101,67	0	0,00
5	female	24	20sony	97,72	0	0,00
6	female	24	12sony	82,12	0	0,00
7	male	21	15sony	87,96	0	0,00
8	male	24	19creative	103,17	0	0,00
9	female	31	17sony	91,93	0	0,00
10	male	27	8sony	75,26	0	0,00
11	female	22	9creative	84,89	0	0,00
12	female	31	1creative	74,42	0,8	64,42
13	female	25	6sony	72,80	2,13	67,05
14	male	33	10creative	86,68	0,13	68,78
15	male	25	12sony	82,12	0,8	72,12
16	female	23	9creative	84,89	0,6	73,64
17	female	26	13creative	92,50	0,13	74,71
18	male	34	13sony	84,12	1	75,08
19	male	24	10creative	86,68	0,6	75,43
20	male	26	10creative	86,68	0,6	75,43
21	female	21	10creative	86,68	1,2	78,44
22	male	21	12sony	82,12	4	79,11
23	female	23	9creative	84,89	2,6	80,01
24	male	21	16sony	89,91	0,9	80,42
25	female	24	16sony	89,91	0,93	80,56
26	male	24	15sony	87,96	1,6	80,97
27	male	22	13sony	84,12	4	81,11
28	female	25	15sony	87,96	1,7	81,23
29	male	24	16sony	89,91	1,33	82,11
30	female	21	10creative	86,68	3,3	82,83
31	male	29	14creative	94,50	0,6	83,26
32	male	26	19sony	95,86	0,46	83,45
33	male	28	13creative	92,50	1	83,46
34	male	25	17sony	91,93	1,3	84,04
35	male	27	10creative	86,68	5,3	84,89
36	male	24	16sony	89,91	2,6	85,02
37	female	21	18sony	93,89	1,06	85,11
38	male	24	18sony	93,89	1,06	85,11
39	male	25	12creative	90,58	2,5	85,53
40	male	22	20sony	97,72	0,66	86,88
41	female	26	12creative	90,58	3,7	87,23
42	male	22	21sony	99,48	0,5	87,43
43	male	27	15creative	96,50	1,06	87,72
44	male	27	22sony	101,08	0,4	88,07
45	female	24	19creative	103,17	0,26	88,29
46	male	21	18sony	93,89	3,7	90,54
47	male	23	19creative	103,17	0,5	91,13
48	male	26	20sony	97,72	1,8	91,24
49	male	22	15creative	96,50	4,5	94,00
50	male	23	19creative	103,17	1,3	95,28
51	male	22	21sony	99,48	4	96,47
52	female	28	20creative	104,52	1,8	98,05
53	male	25	21creative	105,66	1,8	99,19
54	female	22	22sony	101,08	5,9	99,76

Table G.1: *List of the subjects who performed the pilot test. The subjects who presented any hearing condition in the pilot test are not listed in this table.*

APPENDIX H

LISTENING TEST INSTRUCTIONS

Welcome to our Listening Test!

The listening test you are about to participate is part of a listening experiment that studies the effects of using music players with headphones on the hearing. You have already participated in the first phase and now it comes the second phase. In this paper you will find a short description of the parts of the listening test. Read carefully these instructions and if you have any doubt, do not hesitate to ask us. Feel free to eat cake and drink coffee or soda while you are reading this paper:

- FIRST PART:
  The first part takes around 5 minutes and consist of a questionnaire and several questions about your listening habits. It is quite similar to the questionnaire that you filled out in the first phase of this listening experiment.

- SECOND PART:
  This second part takes around 20 minutes and consist of an audiologic evaluation. Your ears will be tested using two not risky methods which are an audiometric test and otoacoustic emissions measurements. If you are interested on the results of the tests, we can give them to you in the end of the listening test. After this, you will have a break of 5 minutes. During this time you can leave the room, eat more cake and drink coffee or soda.

- THIRD PART:
  This third part will take around 20 minutes. Your task will be to adjust the volume of your own music player using your own headphones in different environments. If you could not bring your own devices, we will provided you the music player and the headphones that you used in the first phase of this experiment.

This is a brief explanation of the listening test. It is very important that you feel relaxed and comfortable during all the experiment. If for any reason you want to quit the experiment, you can do it at any time without any explanation.
Thank you very much for your participation.
Group 1066. Acoustic Department

First Part: Audiometry Test

- DESCRIPTION:
  During this test you will have to wear a pair of headphones. When you place them, be sure that they fit your ears well. Then different sounds will be presented, first on one ear and then in the other.

- YOUR TASK:
  Your task is to press a button that you will have in your hand whenever you hear something. If no sound is heard, you do not have to press the button. In order to be sure that you understand this procedure a trial will be performed in the beginning.

- TIPS:
  It is very important that you feel relax and concentrated during this test because weak sounds are going to be presented.

Second Part: Otoacoustic Emissions Measurements

- DESCRIPTION:
  In this hearing test, a test probe will be inserted in your ear and some sounds will be played through it. All the sounds will be played at comfortable levels.

- YOUR TASK:
  During this test you do not have to do anything, you just have to be relaxed.

- TIPS:
  This measurement is very sensitive to movements of the probe, so you must try to be quiet, do not move and try not to swallow.

Remember that after this test you will have a short break of 10 minutes when you can enjoy our cake and coffee.

Third Part: Adjustment of the Volume of your Music Player using your Headphones in different Environments

- DESCRIPTION:
  You are going to be conducted to a listening room where a street, a bus and a very quiet environment are going to be simulated in different moments.

- TASKS:
  Your task is to set the volume of your music player using your headphones every time that an environment is simulated. It is very important that you select the volume that **you would use** if you would be in these situations.

  You will be sit down in a listening room. The first thing you have to do is to listen to the environment during 20 or 30 seconds without headphones and with the music player off. Then, you must place the headphones on, turn on the music and play the song you would like to listen to. Finally you have to adjust the volume of the music player and let us know that you finished by means of an intercomunicator.

  After the volume setting of each environment, you will have a break of 3 minutes and you will have to leave the room.This procedure will be repeat 9 times.

  It is very important that after each volume setting you do not touch or vary the control volume of the music player.

  The maximum time that you have for the volume settings is 5 minutes per environment. You can choose any song that you have in your music player , but once you chose it, you will have to use that song for all the environments.

  The first time that you adjust the volume of your music player is taken as trial to make you get used to the procedure to follow.

- TIPS:
  In this part of the listening test you have to trust your feelings and try to imagine that you are in a bus, a street or a quiet environment. Feel free to set the volume that you would use, no matter which one it is. Remember that there is not right or wrong settings, so please try to be honest and show your preferences.

APPENDIX I

INSTRUCTIONS FOR THE TEST EXPERIMENTER

This appendix explains the procedure followed by the test experimenter when doing the listening test with a subject. Basic rules and some general issues that should be well known by the test experimenter are described in this appendix.

I.1 Basic Rules for the Test Experimenter

It is important that the subject is feeling well and comfortable doing the complete listening test. In order to do this, different rules that must be followed by the test experimenter are defined in the next lines:

- The test experimenter must be polite all the time, even if the subject is tired, angry, or impolite.
- The test experimenter must act as if he is in control of everything during the experiment.
- It is the experimenters task to welcome the subject by means of guiding the subject and eliminating possible misunderstandings.
- It is the experimenters task to have a good treatment of the subject and explain to him the needed indications in order to do the listening.

I.2 Test Experimenter Instructions

The instructions followed by the test experimenter for the different parts of the listening test are described in this section:

I.2.1 Welcome and Introduction

- Welcome the subject and say that we appreciate to have him/her as a subject.
- Conduct the subject to the waiting room.
- Invite the subject to sit down and offer him soda and cake in the waiting room.

- Hand the instructions paper to the subject and ask him/her to read it thoroughly.
- Ask if they understand what they read and if they have any questions or objections to it.
- Start the listening test.

I.2.2 First Part of the Listening Test: Personal Questionnaire

- Give the questionnaire to the subject.
- Instruct the subject in the procedure of filling it out.
- Take the questionnaire with you and conduct the subject into the audiometry cabin.

I.2.3 Second Part of the Listening Test: Bekesy Audiometry and DPOAEs Measurements

- Instruct the subject where to sit in order to perform the audiometry.
- Give the audiometry instructions to the subject.
- Ask if they understand what they read and if they have any questions or objections to it.
- Be sure that the subject puts on the headphones correctly in terms of left/right.
- Start the familiarization process of the audiometry.
- When finished, ask the subject if everything is all right and if he/she has any questions regarding the method.
- Perform the audiometry for both ears.
- Save the data in the audiometer with the name of the subject.
- Introduce the subject to the DPOAEs measurements.
- Give the DPOAEs measurements instructions to the subject.
- Ask if they understand what they read and if they have any questions or objections to it.
- Put the plastic globes on the hands and place the test probe in the hear of the subject.
- Be sure that the test probe is correctly placed by testing it in the OAEs measurement equipment.
- Perform the DPOAEs measurements per each ear and save the data of each subject in the floppy disc and the hard disc of the computer.
- When the measurement is finished, conduct the subject to the waiting room. Feel free to small talk but do not discuss any technical test related issues. Wait until after the listening test is done with discussing the test in general.

I.2.4 Third Part of the Listening Test: Control Volume Adjustment

- Introduce the subject to the control volume adjustment part.
- Ask to the subjects about the music player and the headphones they brought. Be sure that they wrote correctly the model of the devices in the questionnaire as well as the music sample that they are going to use for this part.
- Give the control volume adjustment instructions to the subject.
- Be sure that the subject understand what he read and ask if he has any questions.
- Conduct the subject to the listening room and show him where to sit.
- Remain to the subject that he has to listen to the environment during 20 or 30 seconds without headphones, and after that he has to place the headphones on and play the music in his music player for the control volume adjustment.
- Remain to the subject to contact with the text experimenter after each control volume adjustment by means of the inter-communicator.
- Explain to the subject how the inter-communicator system works.
- Remain to the subject that the first control volume adjustment does not count as data for the listening test. It is only in order to make him used to the task.
- Tell the subject that there is no wrong answers since we are interested in his/her opinion.
- When the subject finishes each control volume adjustment, go back into the listening room and conduct him to the waiting room.
- Then go into the listening room again and measure the SPL in the head and torso simulator produced by the music player of the subject, using the music sample and the control volume position that he selected. Do not forget to save the data in the measurement system.
- When all the volume adjustments have finished tell the subject that the listening test is over.
- Answer possible questions that the subject can have.
- Say “Thank you”, and show the subject to the entrance.

APPENDIX J

LISTENING TEST QUESTIONNAIRE

J.0.5 Personal data:

- Name and Surname:..
- Music Player:...
- Headphones:..
- Music Sample:..

J.0.6 Prior experience:

- Are you suffering or have you had recently a cold?
  ☐ Yes
  ☐ No
  ☐ I dont't Know

- Have you ever taken any medicine or another type of drugs that might have influence on your hearing?
  ☐ Yes
  ☐ No
  ☐ I dont't Know

- Have you ever had?

	Never	Sometimes	Often	Very often
buzzing noises in your ear	☐	☐	☐	☐
sudden lost of hearing	☐	☐	☐	☐
wax in your ears	☐	☐	☐	☐
pain or headache due to powerful sounds	☐	☐	☐	☐
hearing problems when you are listening TV	☐	☐	☐	☐
hearing problems when you talk by phone	☐	☐	☐	☐
nervous or anxious feeling after being in a noisy area	☐	☐	☐	☐
ringing in the ears after being in a noisy area	☐	☐	☐	☐
pain in your ears when you travel by plane	☐	☐	☐	☐
hearing problems after listening to music				
using portable music players with headphones	☐	☐	☐	☐

J.0.7 Listening habits:

- Please, fill next table with the corresponding time that you use to listen to your music player with headphones in quiet/moderate environments such as the street, the university or at home for example:

How often?	Day	Time in hours per day	**How long?**
	☐ 1	☐ 1 or less	☐ 1 month
☐ weekly	☐ 2	☐ 1-2	☐ 1-6 months
	☐ 3	☐ 2-4	☐ 6-12 months
	☐ 4	☐ 4-6	☐ 1-2 years
	☐ 5	☐ 6-8	☐ 2-5 years
☐ monthly	☐ 6	☐ 8-10	☐ 5-10 years
	☐ 7	☐ more than 10	☐ more than 10 years

- Please, fill next table with the corresponding time that you use to listen to your music player with headphones in noisy environments such as the bus, the train or the bike for example:

How often?	Day	Time in hours per day	**How long?**
	☐ 1	☐ 1 or less	☐ 1 month
☐ weekly	☐ 2	☐ 1-2	☐ 1-6 months
	☐ 3	☐ 2-4	☐ 6-12 months
	☐ 4	☐ 4-6	☐ 1-2 years
	☐ 5	☐ 6-8	☐ 2-5 years
☐ monthly	☐ 6	☐ 8-10	☐ 5-10 years
	☐ 7	☐ more than 10	☐ more than 10 years

Thank you for your participation.
Group 1066. Acoustic Department.

APPENDIX K

LISTENING TEST SUBJECTS

This appendix lists the subjects who performed the listening test and their results.
According to the results of the pilot test, some subjects are classified as target and some as control population.

The subjects of the control and target population who performed the listening test are shown in Table K.1 and K.2 respectively. The reference number and an assigned nickname is specified in this table to differ among subjects. Moreover, this table illustrate the $L_{EX,8h}$ calculated from the listening test data as well as the $L_{FF,Aeq}$ for the different environments tested (very quiet, quiet/moderate, noisy).

Figures K.1 and K.2 show the $L_{FF,Aeq}$ and the exposure time for each subject in both populations and for very quiet, quiet/moderate and noisy environment. The data from these two graph can be combined to obtain the $L_{EX,8h}$, which is show in Figure K.3, for each subject in both populations too.

Figure K.4 shows the mean $L_{FF,Aeq}$ for both populations in the different environments tested (very quiet, quiet/moderate, noisy). Moreover, Figure K.5 shows the mean $L_{EX,8h}$ for a quiet/-moderate and noisy environment.

Figures K.6, K.7 and K.8 illustrate again the data of the $L_{FF,Aeq}$ selected for all the subject in both populations, but as a function of the environments.

Figure K.9 shows the information obtained from the prior experience of the listening test questionnaire.

Reference Number	Nickname	Environment	$L_{FF,Aeq}$	Hours per Day	$L_{EX,8h}$
2	VLL	Very Quiet	73,94		
		Quiet/Moderate	90,21	0,00	0,00
		Noisy	100,80	0,00	0,00
3	DVD	Very Quiet	85,28		
		Quiet/Moderate	93,32	0,00	0,00
		Noisy	99,45	0,00	0,00
5	HDA	Very Quiet	98,13		
		Quiet/Moderate	100,36	0,00	0,00
		Noisy	98,54	0,00	0,00
7	MCK	Very Quiet	88,50		
		Quiet/Moderate	90,78	0,00	0,00
		Noisy	91,86	0,00	0,00
8	ANT	Very Quiet	102,04		
		Quiet/Moderate	98,88	0,00	0,00
		Noisy	102,04	0,00	0,00
12	DNL	Very Quiet	76,95		
		Quiet/Moderate	88,39	0,67	77,60
		Noisy	99,53	0,67	88,74
13	BTZ	Very Quiet	77,56		
		Quiet/Moderate	91,56	0,80	81,56
		Noisy	92,99	0,13	75,21
15	LRM	Very Quiet	83,34		
		Quiet/Moderate	89,56	0,53	77,80
		Noisy	95,61	0,03	71,81
17	IRS	Very Quiet	97,73		
		Quiet/Moderate	103,34	0,67	92,55
		Noisy	98,98	0,27	84,21
18	HCR	Very Quiet	94,80		
		Quiet/Moderate	94,79	0,80	84,79
		Noisy	95,36	0,03	71,56

Table K.1: *$L_{FF,Aeq}$ and $L_{EX,8h}$ calculated for the subjects of the control population according to the data obtained in the listening test for a very quiet, a quiet/moderate and a noisy environment.*

Reference Number	Nickname	Environment	$L_{FF,Aeq}$	Hours per Day	$L_{EX,8h}$
		Very Quiet	90,74		
31	LRI	Quiet/Moderate	96,04	0,03	72,24
		Noisy	103,26	0,47	90,92
		Very Quiet	102,56		
33	CLS	Quiet/Moderate	104,82	1,07	96,07
		Noisy	107,59	0,07	86,79
		Very Quiet	94,80		
34	ERC	Quiet/Moderate	97,30	0,93	87,97
		Noisy	103,32	0,40	90,31
		Very Quiet	99,10		
39	SMN	Quiet/Moderate	91,56	0,67	80,77
		Noisy	97,57	0,93	88,24
		Very Quiet	88,53		
41	YSN	Quiet/Moderate	97,49	0,67	86,70
		Noisy	93,56	2,67	88,79
		Very Quiet	87,86		
42	NCL	Quiet/Moderate	92,43	0,03	68,63
		Noisy	97,27	1,07	88,52
		Very Quiet	100,16		
45	SUS	Quiet/Moderate	103,24	0,03	79,44
		Noisy	105,11	0,27	90,34
		Very Quiet	103,02		
46	OLV	Quiet/Moderate	98,83	1,87	92,51
		Noisy	103,91	0,13	86,13
		Very Quiet	102,07		
50	JON	Quiet/Moderate	103,08	0,17	86,27
		Noisy	106,30	1,33	98,52
		Very Quiet	104,12		
52	CLA	Quiet/Moderate	103,55	1,33	95,76
		Noisy	96,07	1,33	88,28

Table K.2: *$L_{FF,Aeq}$ and $L_{EX,8h}$ measured in dB SPL calculated for the subjects of the target population according to the data obtained in the listening test for a very quiet, a quiet/moderate and a noisy environment.*

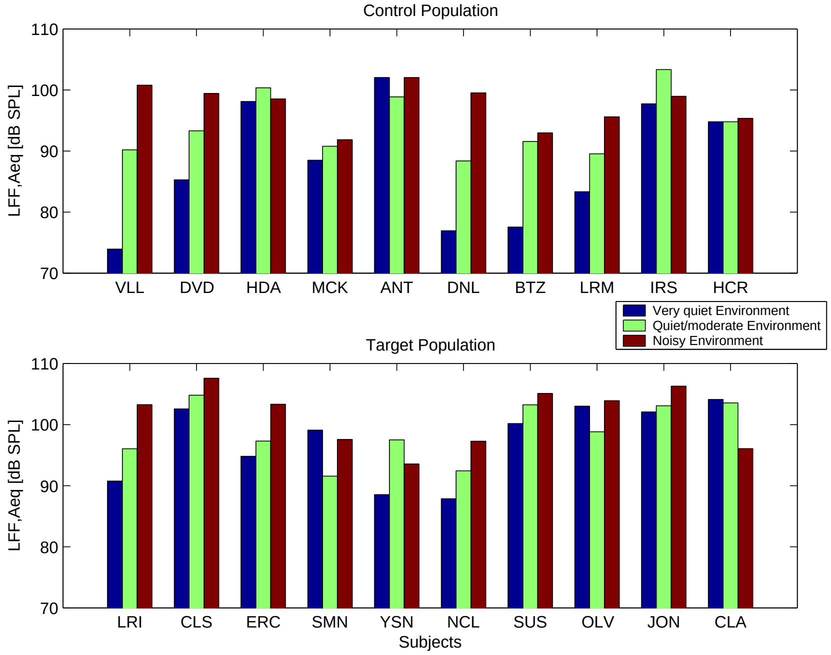

Figure K.1: *$L_{FF,Aeq}$ calculated for the subjects of the target and control population according to the data obtained in the listening test for a very quiet, a quiet/moderate and a noisy environment.*

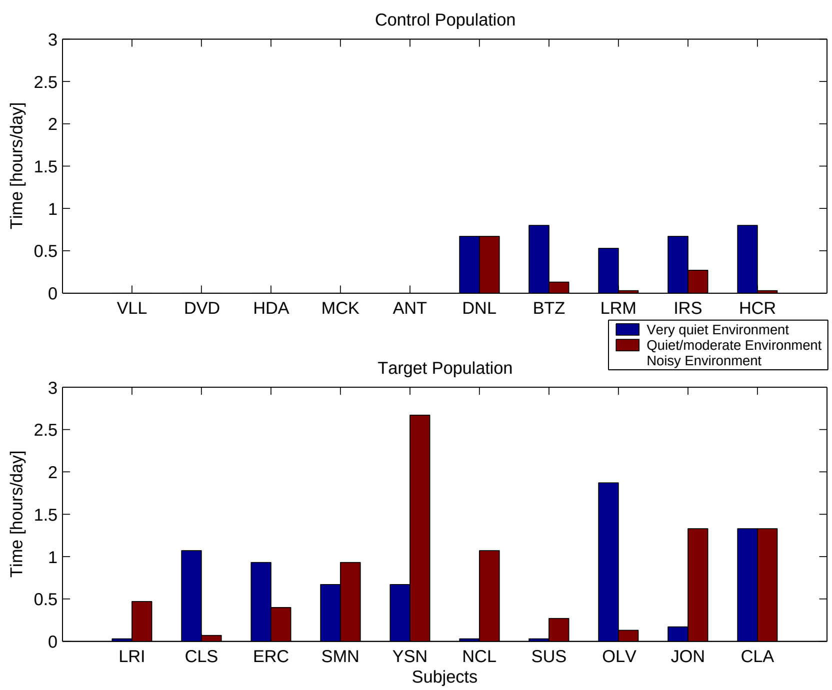

Figure K.2: *Exposure time calculated for the subjects of the target and control population according to the data obtained in the listening test for a quiet/moderate and a noisy environment.*

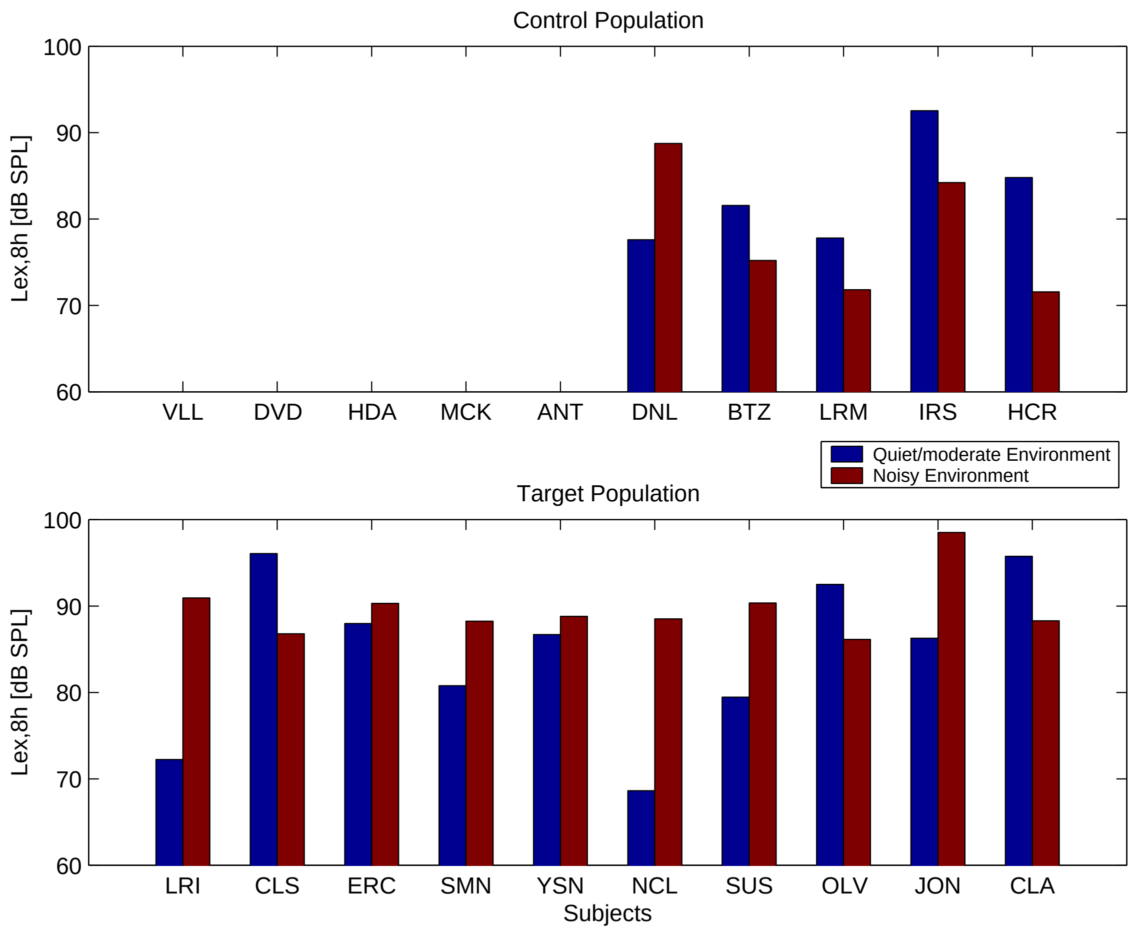

Figure K.3: *$L_{EX,8h}$ calculated for the subjects of the target and control population according to the data obtained in the listening test for a quiet/moderate and a noisy environment.*

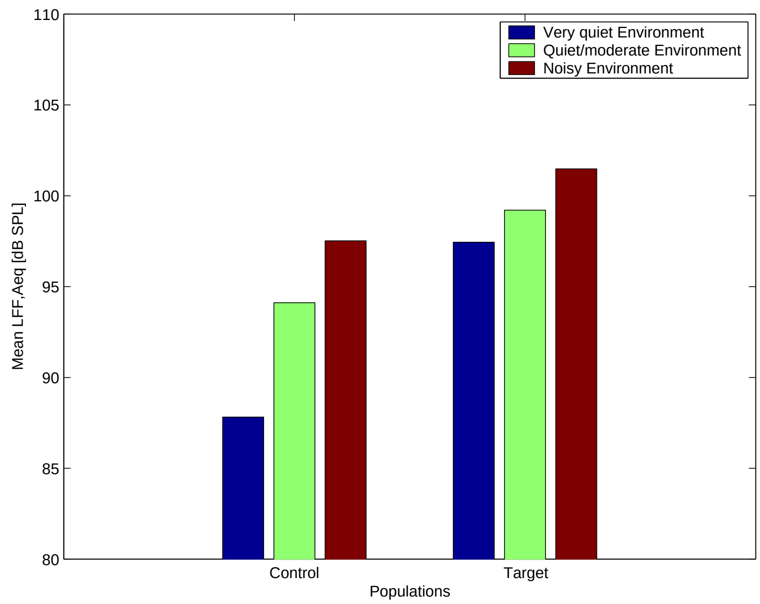

Figure K.4: *Mean $L_{FF,Aeq}$ calculated across all the subjects of the target and control population according to the data obtained in the listening test for a very quiet, a quiet/moderate and a noisy environment.*

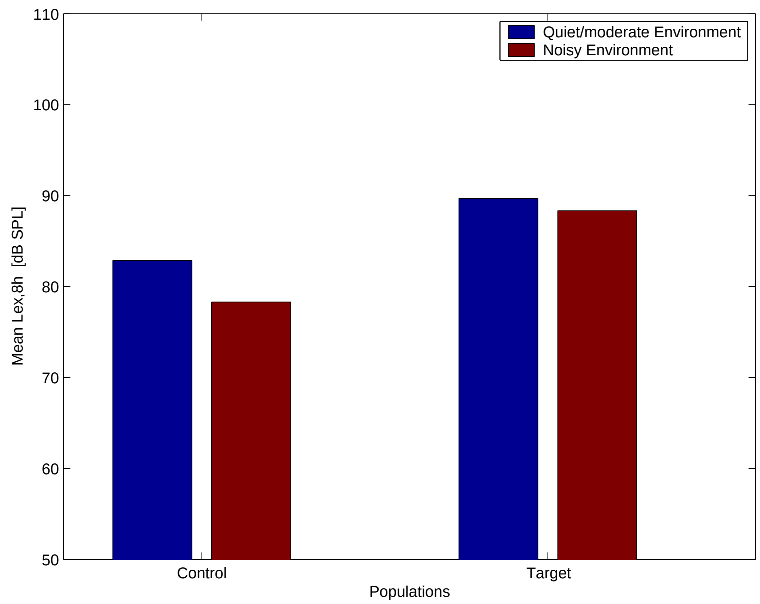

Figure K.5: *Mean $L_{EX,8h}$ calculated across all the subjects of the target and control population according to the data obtained in the listening test for a quiet/moderate and a noisy environment.*

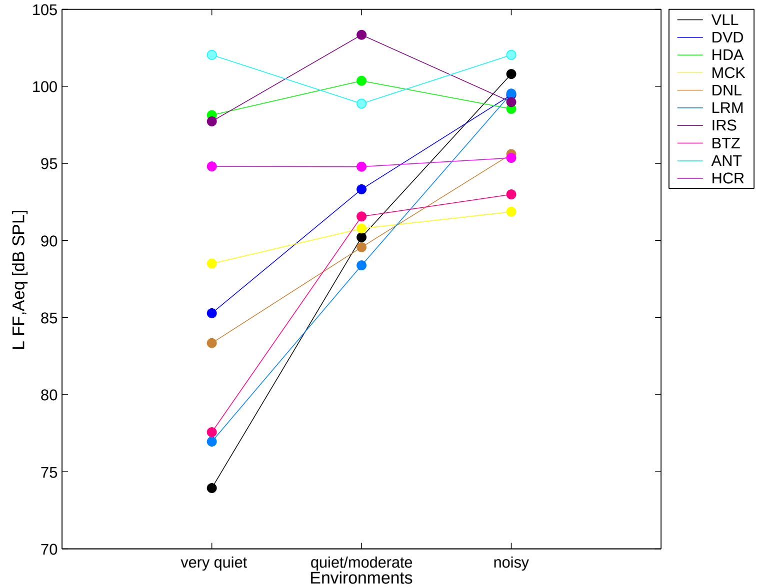

Figure K.6: *$L_{FF,Aeq}$ calculated for the subjects of the control population according to the data obtained in the listening test for a very quiet, a quiet/moderate and a noisy environment.*

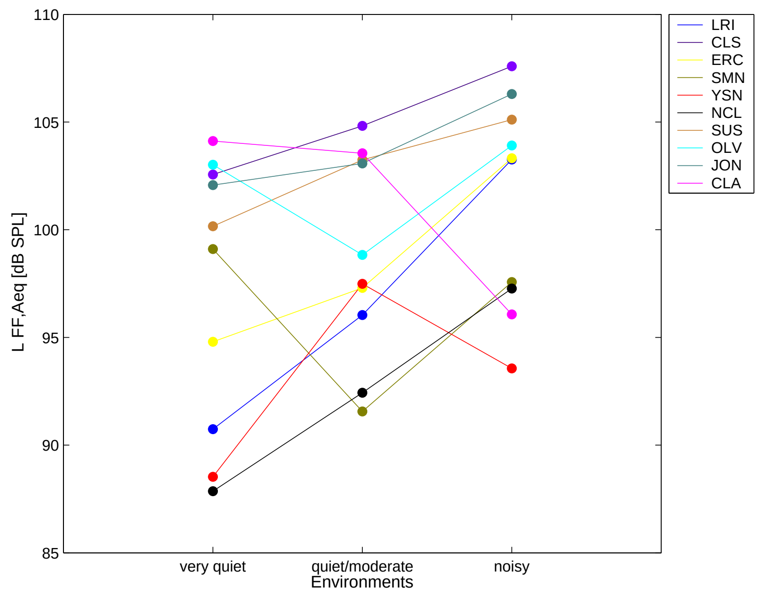

Figure K.7: *$L_{FF,Aeq}$ calculated for the subjects of the target population according to the data obtained in the listening test for a very quiet, a quiet/moderate and a noisy environment.*

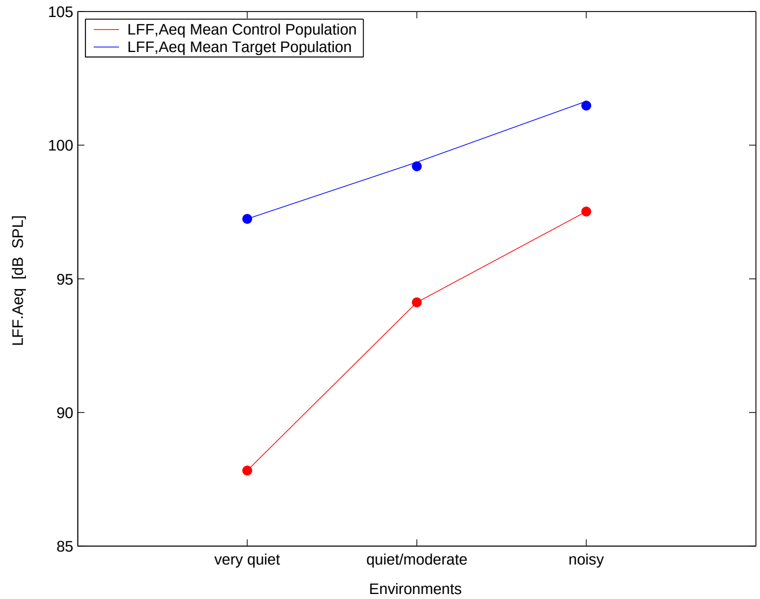

Figure K.8: *Mean $L_{FF,Aeq}$ calculated across all the subjects of the target and control population according to the data obtained in the listening test for a very quiet, a quiet/moderate and a noisy environment.*

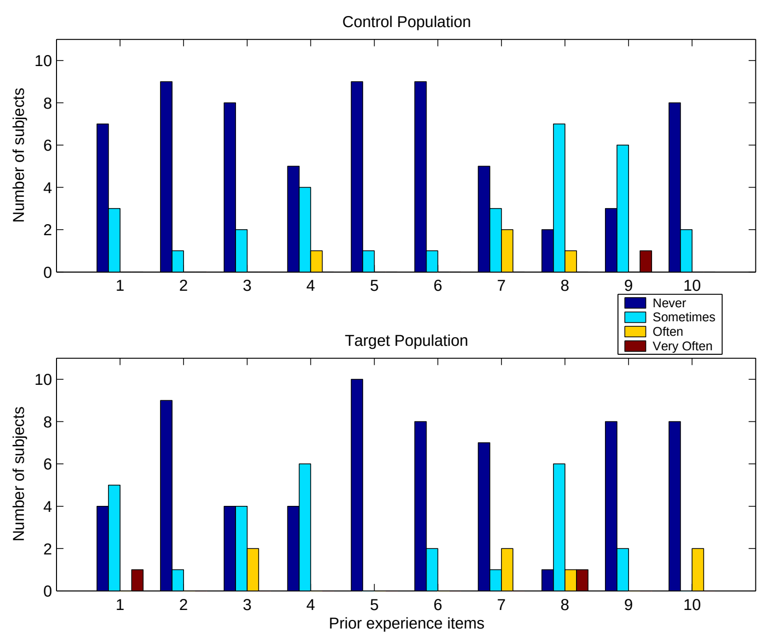

Figure K.9: *Number of people from the control and target population who suffer: 1-buzzing noises in your ear, 2-sudden lost of hearing, 3-wax in your ears, 4-pain due to powerful sounds, 5-hearing problems when listening TV, 6-hearing problems when talking by phone, 7-nervous after being in a noisy area, 8-ringing in the ears after being in a noisy area, 9-pain the ears when traveling by plane,10-hearing problems after listening a MP with headphones.*

APPENDIX L

HEARING THRESHOLD AND DPOAES

This appendix describes the pure tone audiometry and the DPOAEs measurements conducted in the listening test in order to assess the hearing of the subjects. The appendix finishes with the data obtained from these measurements.

L.1 Pure Tone Audiometry

The audiometry is carried out in the audiometric cabin B4 from the Acoustics Department at Aalborg University, which is a room with special treatment to the walls, ceiling, and floor in order to comply with the specifications about the noise floor stated in the standard ISO 8253-1 [26].

The audiometer Madser Orbiter 922 is chosen to perform the audiometry test. The audiometry method used is the pure tone audiometry, which is selected in Section 2.7 in Chapter 2. The subject is equipped with a set of headphones and two roller pens. One of these roller pens is red and the other one is blue corresponding to right and left respectively. The device tests the ears one at a time. The subject must press the corresponding roller pens whenever a sound is heard. In the end of this Appendix the results obtained in the audiometry tests are shown.

L.2 DPOAEs Measurements

The measurements are performed in the audiometer cabin B4 in the Acoustic Department at Aalborg University where there was a noise controlled environment. The equipment used to carry out the DPOAEs measurements is the ILO96 from Otodynamic. It is selected since it is the equipment available in the Acoustic Department at Aalborg University. This equipment can measure either TEOAEs or DPOAEs.

The equipment is based on a system amplification unit connected to a computer which has installed the software to measure and record the OAEs. The amplification unit has, apart from the connection to the computer, an ear probe which contains two small loudspeakers and a microphone. This ear probe is placed on the ear of the subject using a small foam which makes the placement on the ear easier. Every loudspeaker of the probe is used to play each pure tone and the microphone is used to record the DPOAEs produced by the ear of the subject.

DPOAEs were measured for both ears in each subject. The data from the measurement is collected in .SPR format and it is later processed in order to plot the results. The results obtained from these measurements are presented in the last section of this appendix.

After each measurement, the level of the DPOAEs is compared to the noise level to verify it is not masking the cochlear emissions. This can be seen in the equipment immediately after the measurement is carried out. If noise level masks the cochlear emissions, the measurements are repeated. Moreover in the ear calibration is done for each subject and for each ear. This is automatically performed by the DPOAEs measurement system.

Not only external noise can alters the OAEs response, but also the internal noises from the subject (coughing for example) can create difficulties when recording the DPOAEs. Therefore it is important to ask for the subject to remain quiet and try to not swallow during the measurements.

L.3 Results

The data obtained in the audiometry test was collected and is shown in Table L.2 and L.1.

The data obtained from the DPOAEs measurements is presented in one plot for every subject. The DPOEAs of the right and left ears are presented in the same graph, but in different colors. The thick red line in each graph correspond to DPOAEs or the right ear, whereas the thick blue line represent the results of the DPOAEs measurements of the left ear. The noise measured, which is plotted as blue and red fine lines in the graphs, corresponds to the noise measured during the DPOAEs measurements for the right and left ears respectively. The DPOAEs data is plotted as a function of the geometric mean of the pure tones of the DPOAEs ($\sqrt{f_1 . f_2}$).

		Frequencies [Hz]									
Subject	Ear	250	500	750	1000	1500	2000	3000	4000	6000	8000
VLL	L	-5	5	5	5	5	5	0	0	15	0
	R	-5	5	10	10	5	10	0	0	0	-10
DVD	L	0	5	0	5	5	10	5	0	10	-10
	R	10	5	5	5	5	5	0	5	10	5
HDA	L	5	5	5	5	5	5	0	5	15	-5
	R	5	10	0	0	0	5	0	15	25	5
MCK	L	5	15	20	15	15	15	10	25	20	10
	R	0	10	10	5	5	-5	5	5	5	0
ANT	L	0	5	0	5	-5	0	0	10	5	-10
	R	0	5	0	0	0	0	0	10	-5	-5
DNL	L	5	5	5	0	5	0	0	5	20	0
	R	0	5	5	0	5	0	-5	10	25	10
BTZ	L	5	5	10	5	5	0	-5	0	15	5
	R	5	0	5	0	0	0	0	5	15	5
LRM	L	5	5	0	5	5	5	0	5	15	5
	R	-5	0	-5	0	5	10	0	0	10	0
IRS	L	0	0	-5	-10	0	5	0	15	5	-5
	R	-5	0	5	0	15	5	5	0	20	-5
HCR	L	-5	5	10	10	5	5	10	15	10	5
	R	0	5	5	5	10	10	10	15	5	-10

Table L.1: *Hearing thresholds of the test subjects of the control population measured in the listening test.*

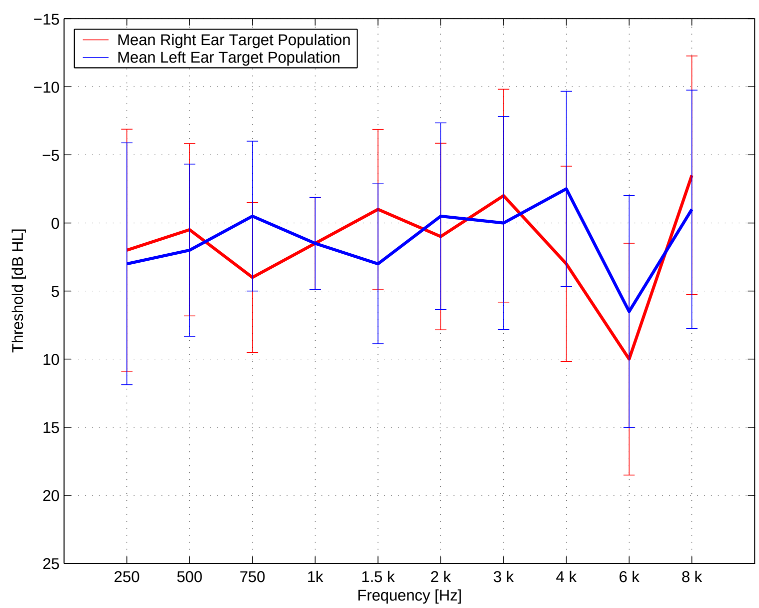

Figure L.1: *Mean and standard deviation of the hearing thresholds of the target population for left and right ear.*

		Frequencies [Hz]									
Subject	Ear	250	500	750	1000	1500	2000	3000	4000	6000	8000
EDR	L	10	10	5	5	10	5	15	35	50	45
	R	0	10	5	-5	-10	0	0	5	-10	5
LRI	L	-10	-10	5	5	-10	5	0	-10	10	5
	R	-10	-10	-5	0	-10	-10	0	-10	10	5
CLS	L	-5	-5	5	-5	-5	5	5	-5	10	-5
	R	5	5	-5	-5	10	5	5	5	-5	0
ERC	L	5	5	15	10	5	5	0	5	0	-5
	R	5	5	5	5	0	0	5	10	0	0
JLS	L	10	5	5	5	15	10	15	15	15	10
	R	5	10	15	20	25	25	20	20	20	35
SMN	L	5	0	5	0	5	5	0	5	10	5
	R	10	5	0	0	5	5	15	5	15	10
YSN	L	5	0	5	5	-10	-10	-10	5	15	-10
	R	5	0	-10	0	5	-10	-10	-5	20	15
NCL	L	-5	-5	-5	0	5	0	5	15	10	0
	R	5	0	5	0	5	0	0	-5	5	-10
SUS	L	5	0	0	0	5	5	-5	5	5	-5
	R	0	0	-5	0	0	5	-5	0	5	-5
OLV	L	5	5	0	0	-10	-5	-10	0	10	-10
	R	0	0	5	5	0	-10	-10	-10	-5	-10
JON	L	5	5	5	0	0	0	-5	5	20	0
	R	-10	0	0	5	5	5	-5	-10	15	-5
CLA	L	10	10	5	0	5	0	0	5	10	-10
	R	20	15	5	5	10	5	5	-5	5	-10

Table L.2: *Hearing thresholds of the test subjects of the target population measured in the listening test.*

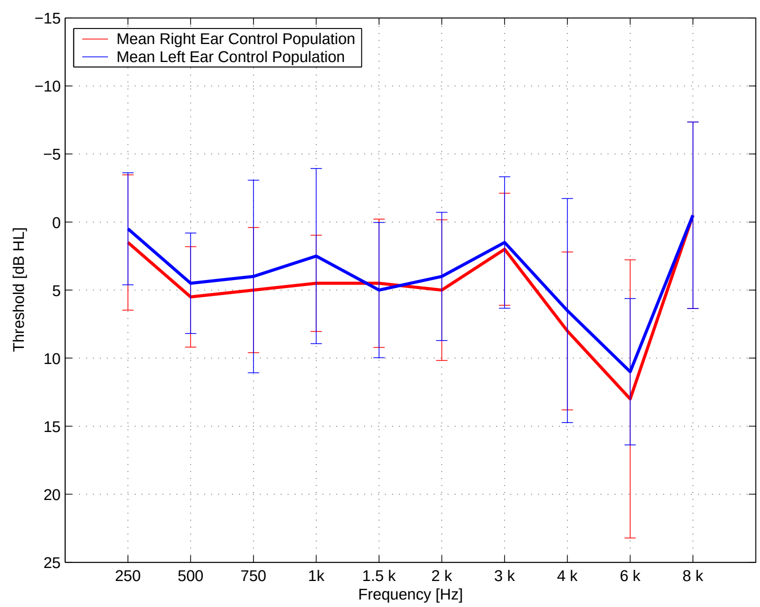

Figure L.2: *Mean and standard deviation of the hearing thresholds of the control population for left and right ear.*

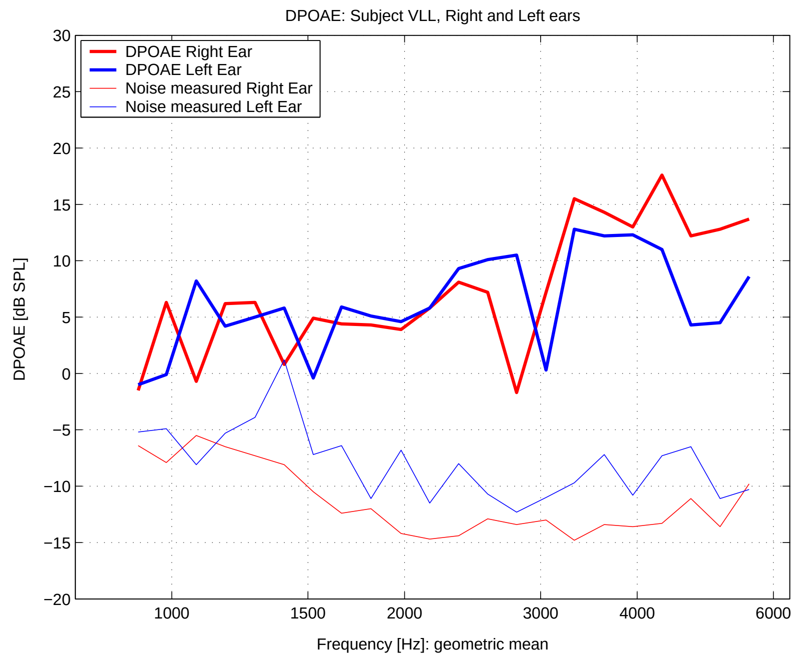

Figure L.3: *DPOAEs of right and left ears in subject VLL. This subject belongs to the control population.*

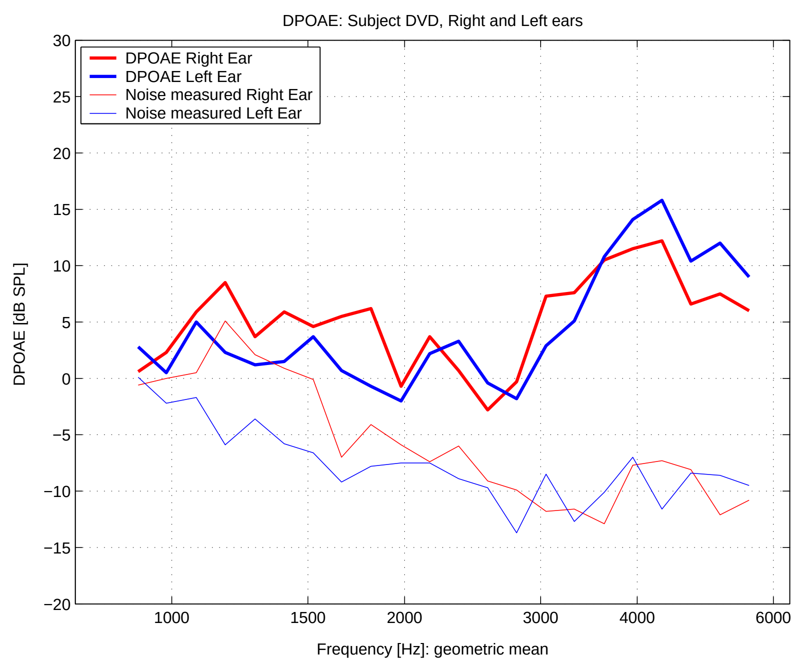

Figure L.4: *DPOAEs of right and left ears in subject DVD. This subject belongs to the control population.*

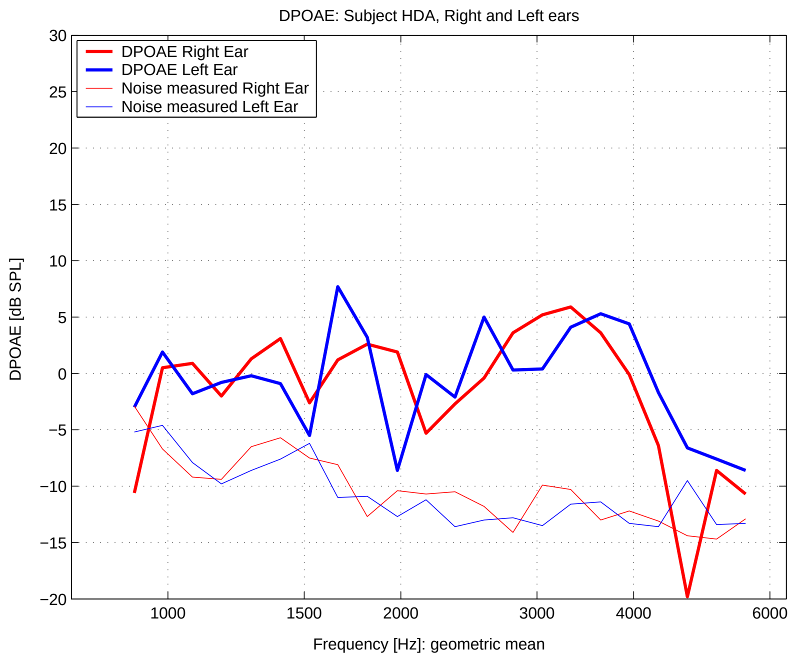

Figure L.5: *DPOAEs of right and left ears in subject HDA. This subject belongs to the control population.*

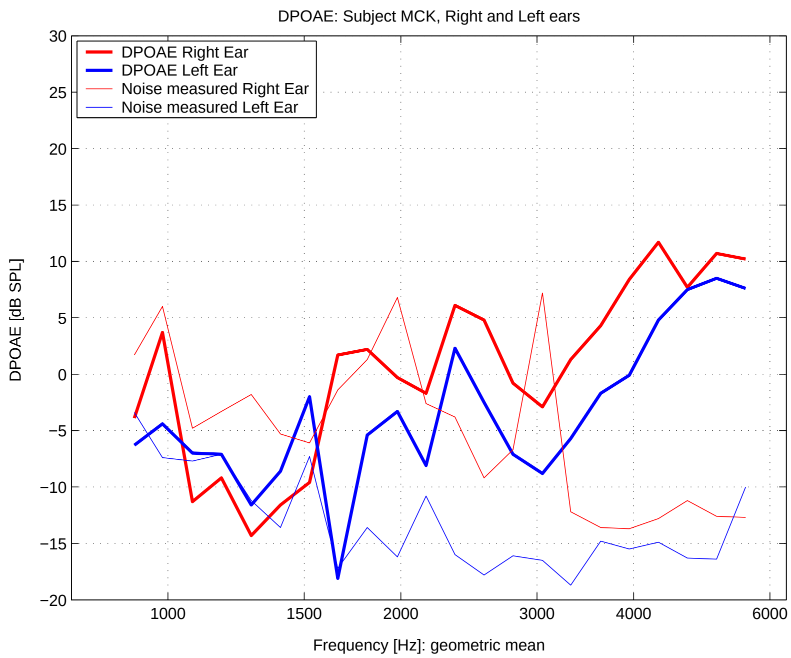

Figure L.6: *DPOAEs of right and left ears in subject MCK. This subject belongs to the control population.*

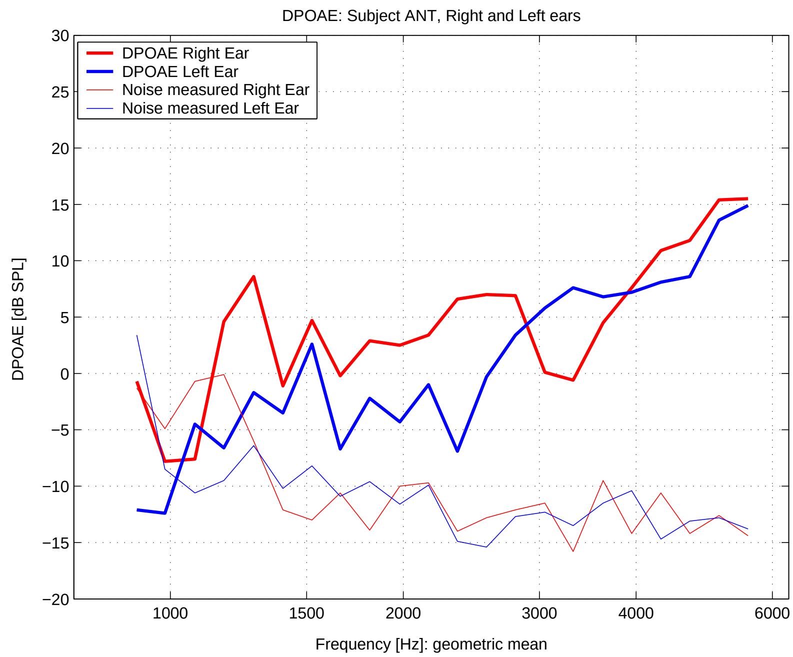

Figure L.7: *DPOAEs of right and left ears in subject ANT. This subject belongs to the control population.*

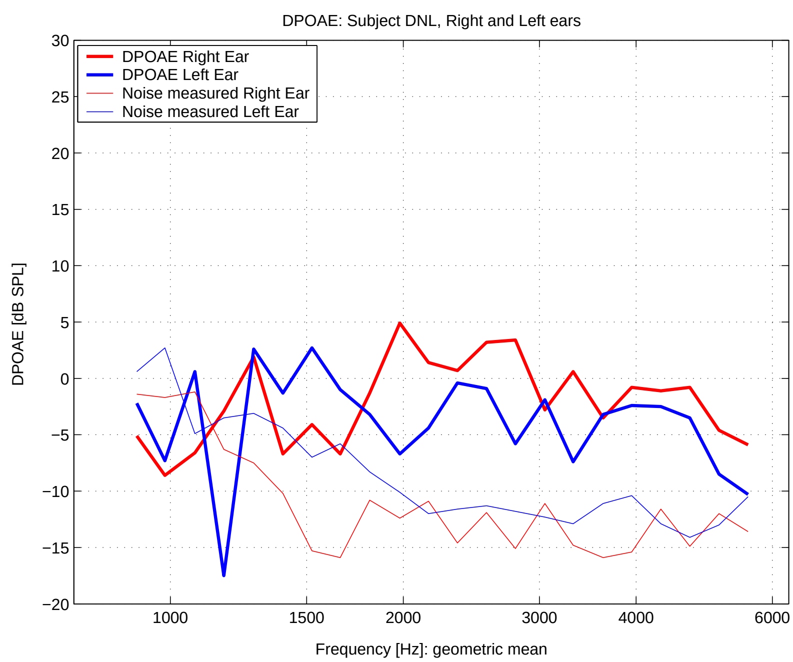

Figure L.8: *DPOAEs of right and left ears in subject DNL. This subject belongs to the control population.*

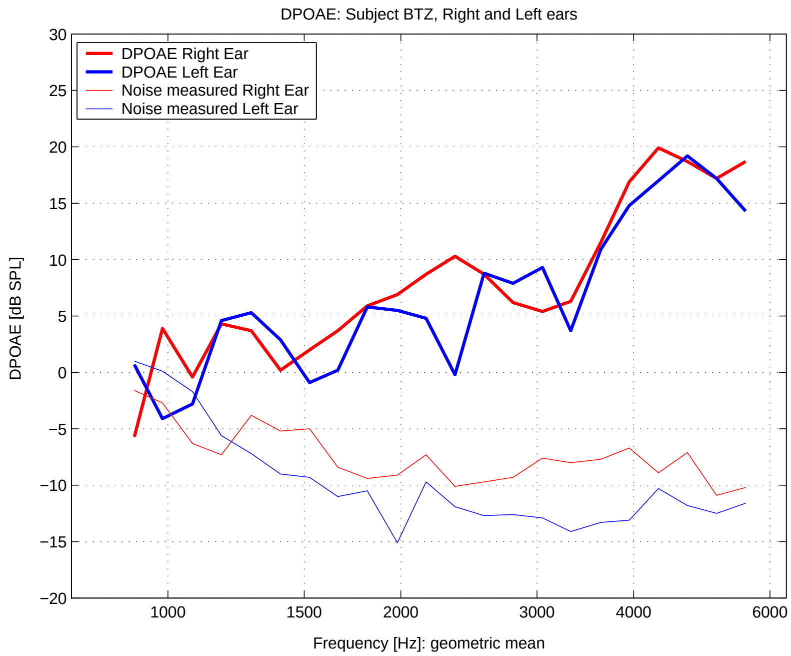

Figure L.9: *DPOAEs of right and left ears in subject BTZ. This subject belongs to the control population.*

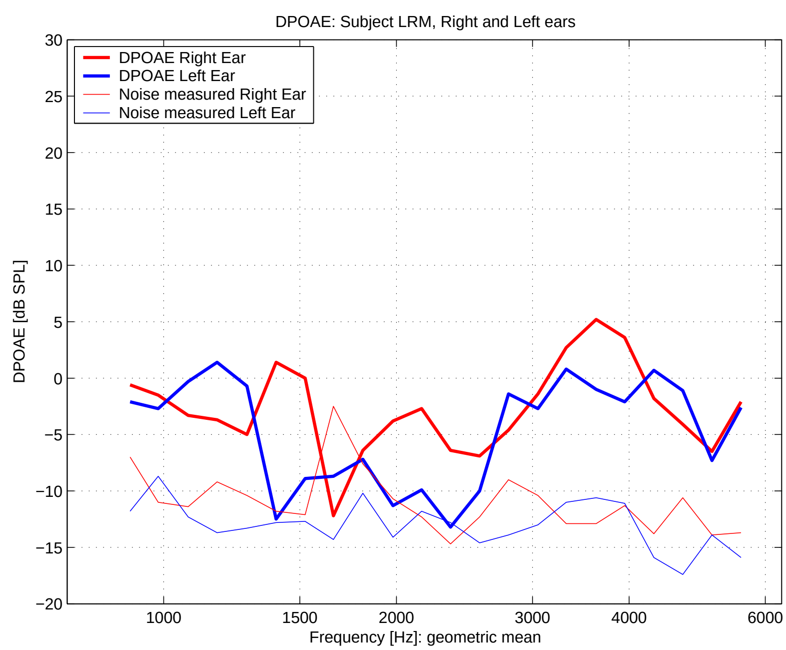

Figure L.10: *DPOAEs of right and left ears in subject LRM. This subject belongs to the control population.*

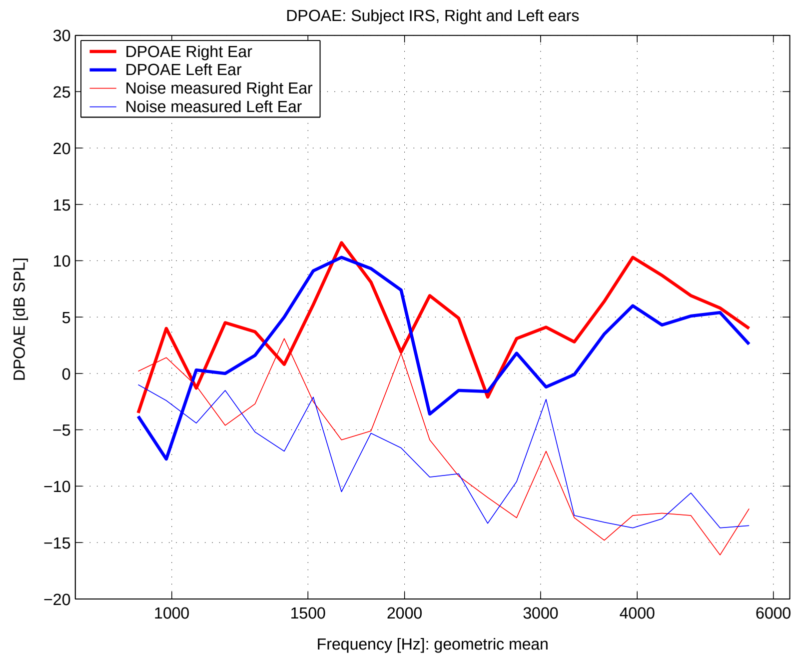

Figure L.11: *DPOAEs of right and left ears in subject IRS. This subject belongs to the control population.*

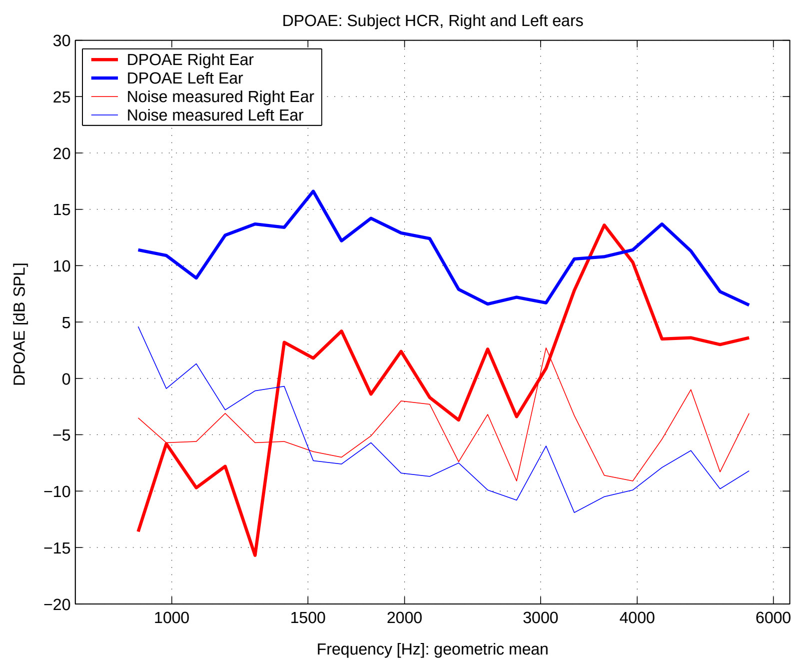

Figure L.12: *DPOAEs of right and left ears in subject HCR. This subject belongs to the control population.*

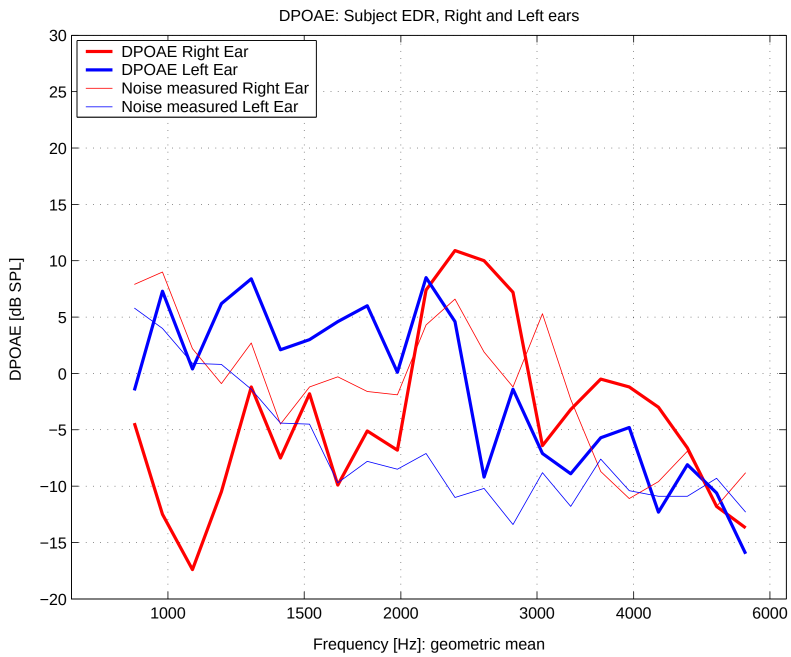

Figure L.13: *DPOAEs of right and left ears in subject EDR. This subject belongs to the target population.*

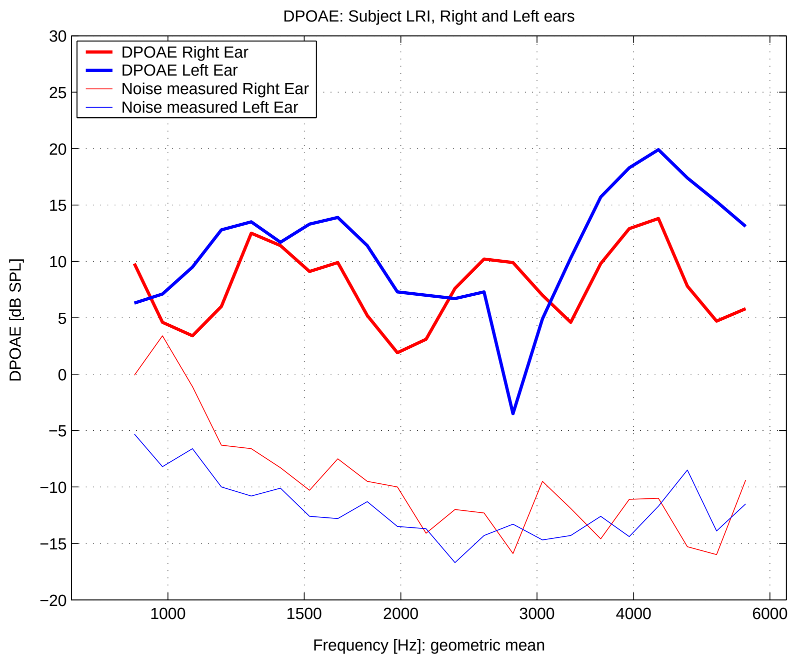

Figure L.14: *DPOAEs of right and left ears in subject LRI. This subject belongs to the target population.*

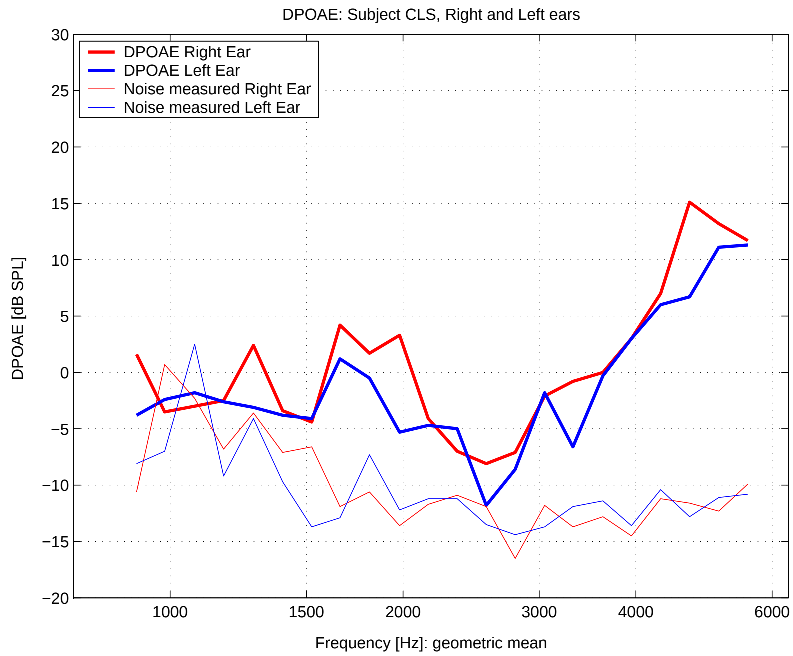

Figure L.15: *DPOAEs of right and left ears in subject CLS. This subject belongs to the target population.*

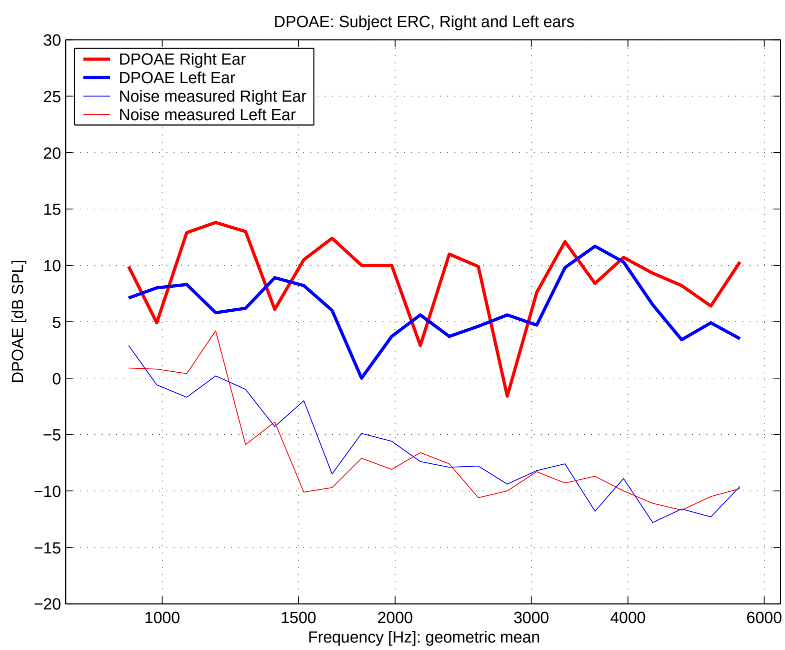

Figure L.16: *DPOAEs of right and left ears in subject ERC. This subject belongs to the target population.*

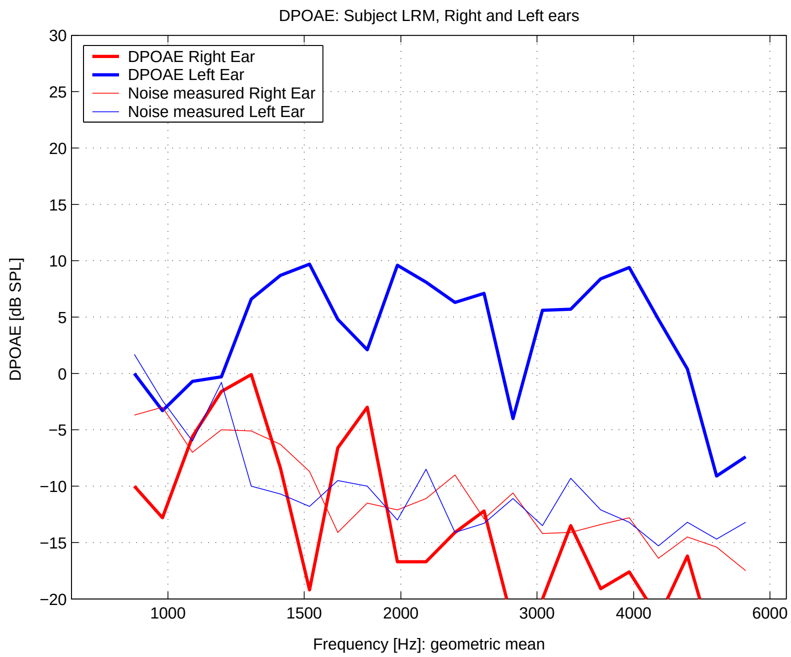

Figure L.17: *DPOAEs of right and left ears in subject JLS. This subject belongs to the target population.*

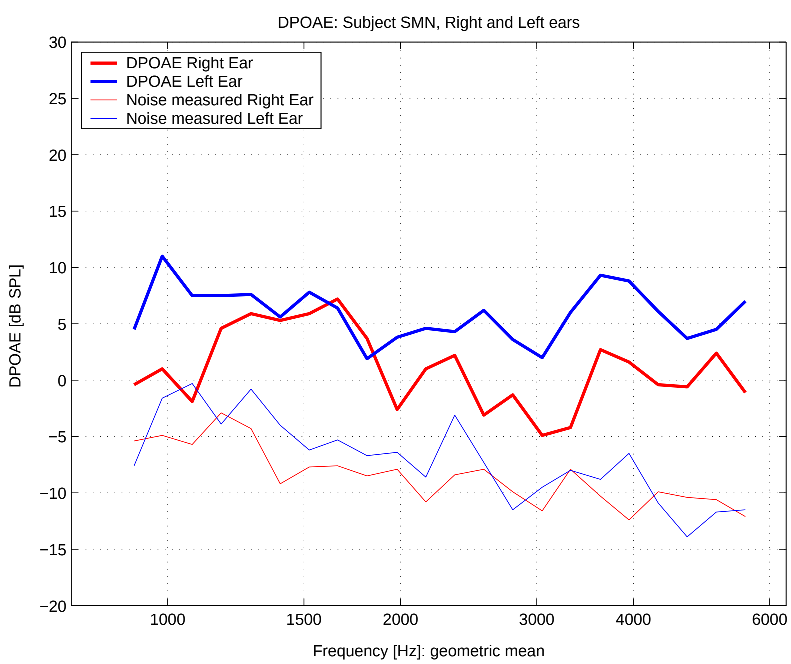

Figure L.18: *DPOAEs of right and left ears in subject SMN. This subject belongs to the target population.*

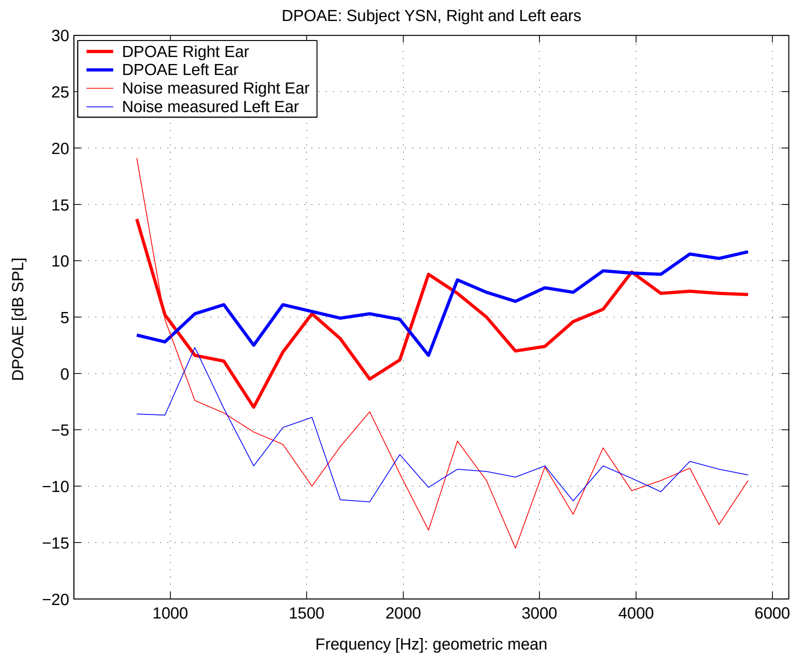

Figure L.19: *DPOAEs of right and left ears in subject YSN. This subject belongs to the target population.*

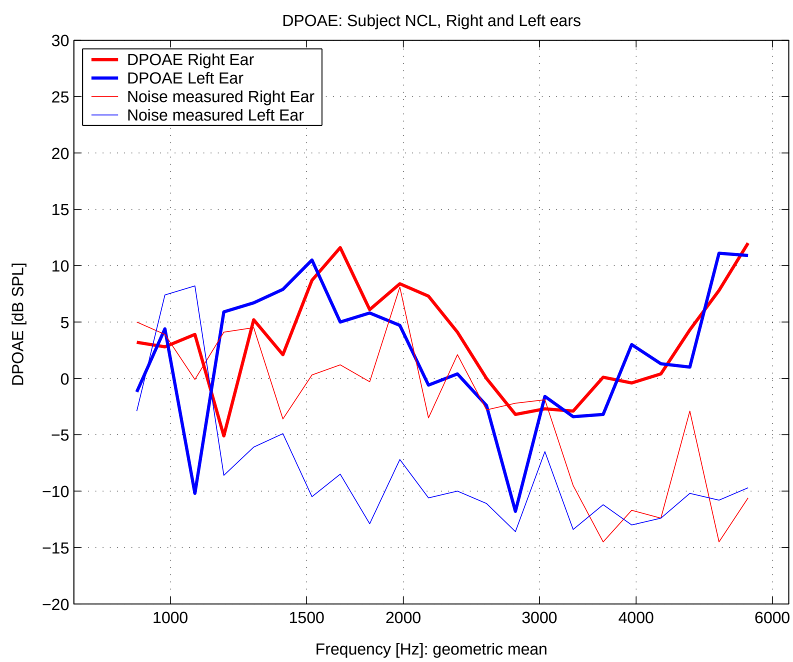

Figure L.20: *DPOAEs of right and left ears in subject NCL. This subject belongs to the target population.*

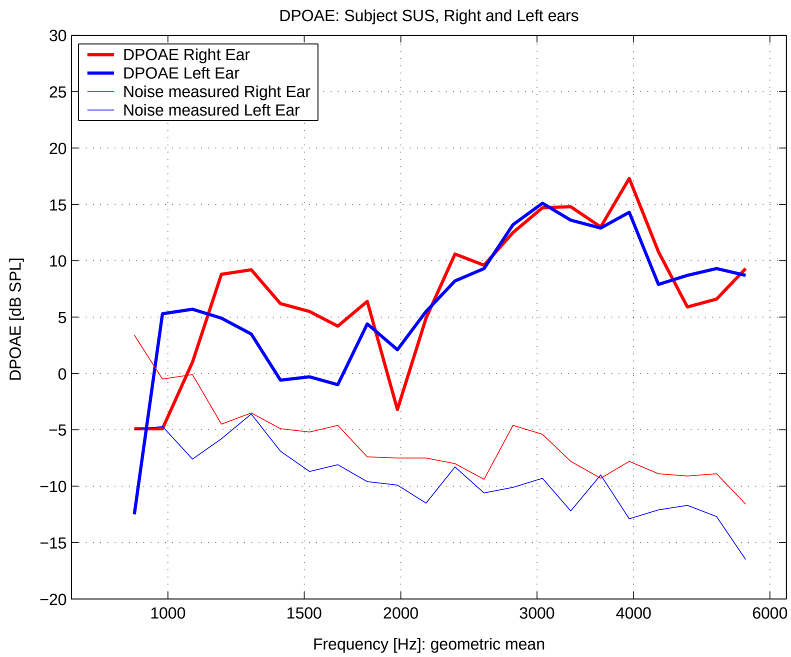

Figure L.21: *DPOAEs of right and left ears in subject SUS. This subject belongs to the target population.*

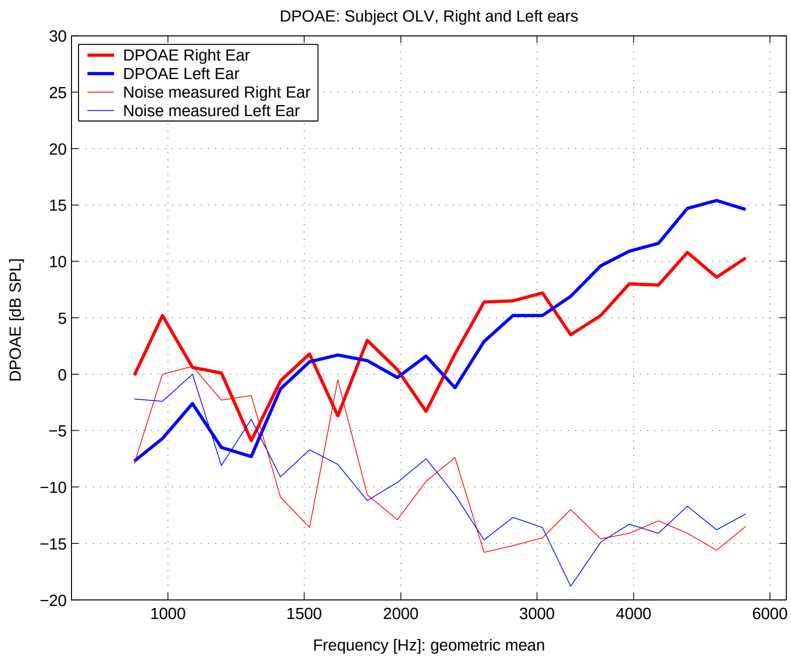

Figure L.22: *DPOAEs of right and left ears in subject OLV. This subject belongs to the target population.*

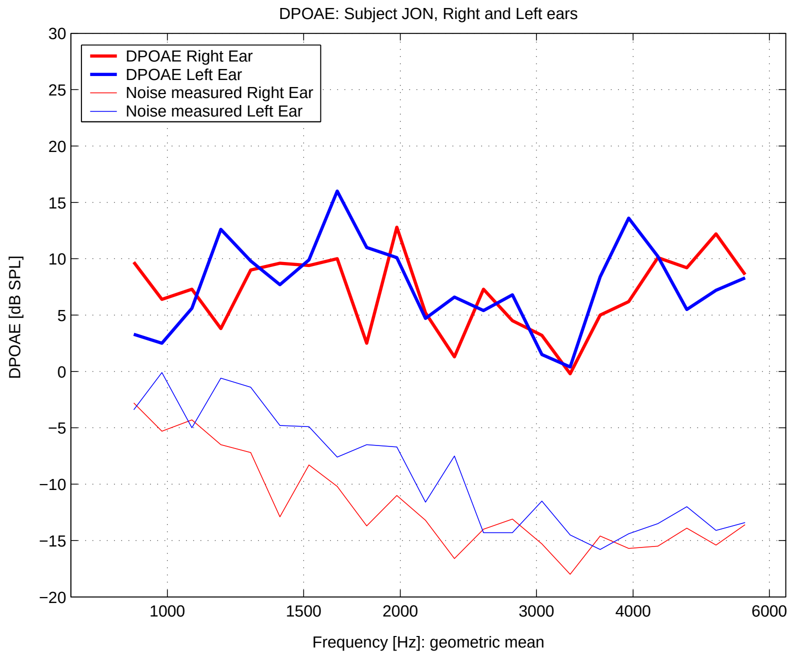

Figure L.23: *DPOAEs of right and left ears in subject JON. This subject belongs to the target population.*

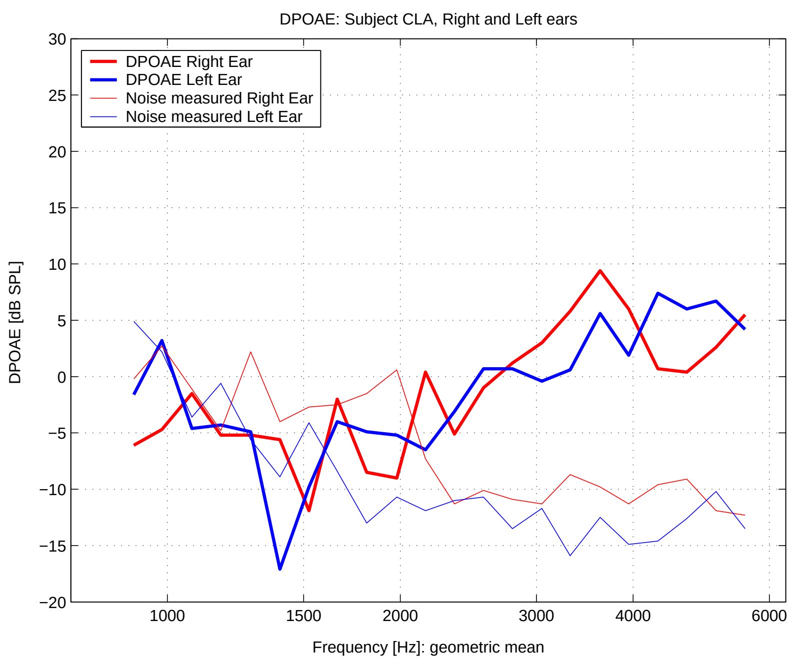

Figure L.24: *DPOAEs of right and left ears in subject CLA. This subject belongs to the target population.*

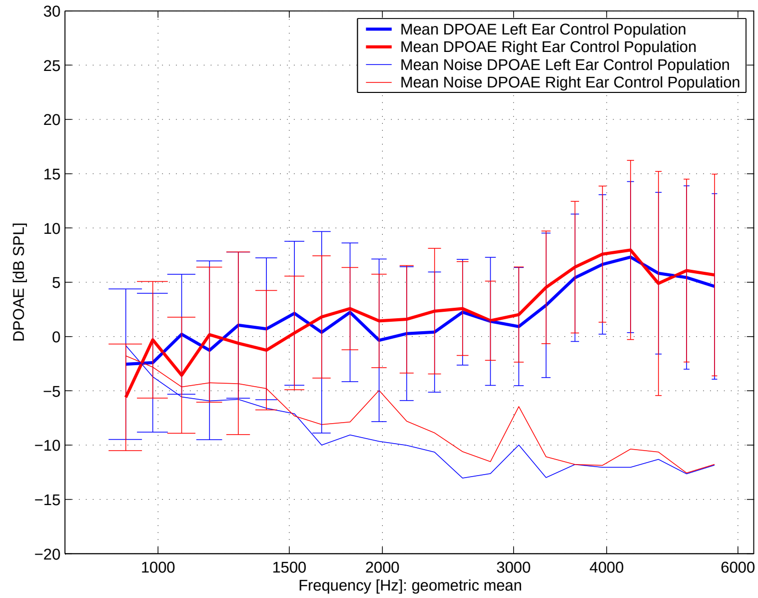

Figure L.25: *Mean and standard deviation DPOAE of the test subjects of the control population for left and right ear.*

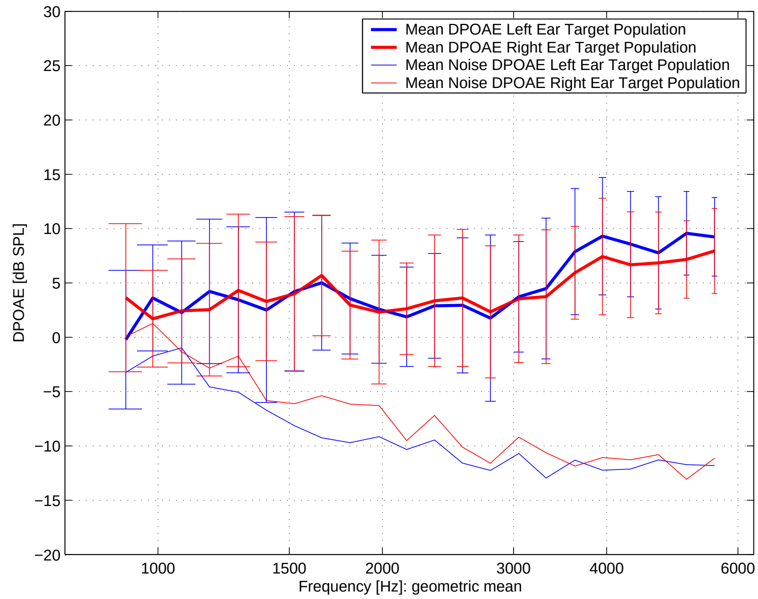

Figure L.26: *Mean and standard deviation DPOAE of the test subjects of the target population for left and right ear.*

APPENDIX M

LISTING ENVIRONMENTS

The following appendix describes the simulation of the quiet/moderate and noisy environments of the listening test. The background noise in a bus and in a street are used as references environments to simulate these situations respectively.

M.1 Method

The simulation is done in a listening room by playing in an omnidirectional source two different signals corresponding to each environment. The omnidirectional sound source is used because it allows to create a semi-diffuse sound field where the sound pressure level is approximately the same in all the room. This is desired because in a real situation where a MP with headphones is used, the background noise generally corresponds to a semi-diffuse sound field.

M.2 Equipment and Setup

The complete listening test setup is shown in Figure M.1. In this figure it can be seen the sound source which produces the environments as well as the computer and the amplifier that drive the signals. Table M.1 lists the equipment utilized.

Item	Model	LAB-Nr:
Omnidirectional source		
Power Amplifier	00000000	00000000
Computer	00000000	00000000

Table M.1: Equipment used for the listening test.

M.2.1 Sound Stimuli for the Environments

Most noise in the environments contains energy at many different frequencies combining together to give it its overall character. Therefore is complicated to analyze these environments.

The noise from a bus is a continuous non stationary noise, which has its energy content at low frequency. Moreover the amplitude of the signal varies over the time because the noise emitted

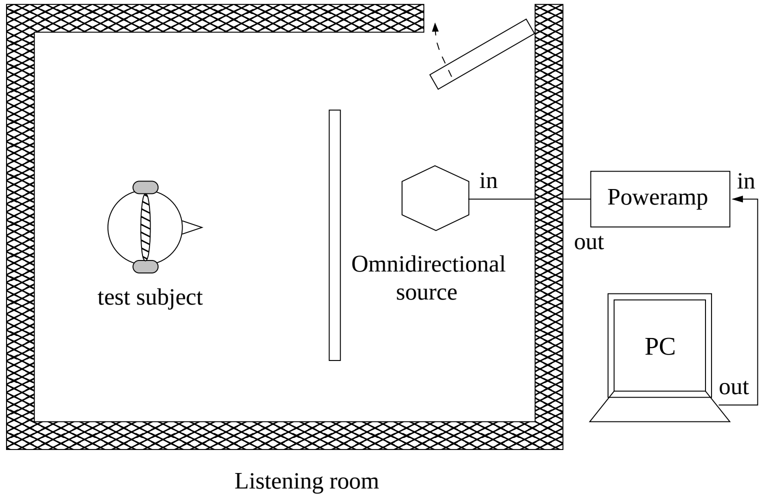

Figure M.1: *Setup used for the listening test. The subject is equipped with his own portable MP or with the reference portable MP used in the pilot test. The task of the subject in this part of the listening test is to adjust the control volume position when a noisy (bus), a moderate (street), and a quiet (silence) sound environments are being simulated.*

by a bus depends on its speed, its acceleration and many other parameters. Therefore it is a complex sound which is difficult to simulate.

The noise from a street can be related to many different noises. In this case it is defined as environmental noise, for example the song of a bird, some cars passing by or the sound of the wind, corresponding to a quiet or moderate environment.

These environments are simulated with two WAV files: one recorded inside of a bus and one recorded in a street. These signals are obtained from a sound database in Internet [2]. The signal for the bus environment is a sample of 46 seconds which contains some of the different noises that can be produced in a bus, for example people talking, the sound produced when opening and closing the doors of the bus, or the sound produced by the bus when braking or starting. The signal for the street environment is a sample of 90 seconds which contains different noises that can be recorded in a quiet street.

Figures M.3 and M.2 show the time signals that are used.

A possible problem with these signals is that they are not very long, so the subject may need more time than the duration of these files to adjust the volume. For this reason each of these signals is concatenated until getting a duration of 5 minutes approximately each one. The concatenation is done as a linear cross-fade of 5 seconds between the signals to concatenate. The signals are amplified such that the energy of the end of the first file is equal to the energy of the next file. Figure M.4 shows an example of a pair of files of the street environment concatenated.

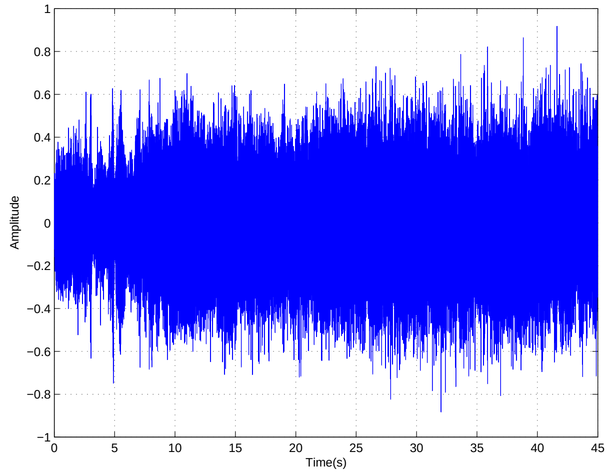

Figure M.2: *Noise signal used for the simulation of the* bus *listening environment*

In order to decide the sound pressure level at which these files have to be played, some field measurements are performed inside of two buses and in a street..

M.2.2 Results

Noise levels were measured using a Monacor SM-4 sound level meter set to a A-weighting slow meter response. The slow meter response is selected because the reading of the values in the sound level meter is easier. This is because the integration time in order to calculate the sound pressure level is longer when using the slow meter response in the sound level meter.

The objective of these measurements is to obtain a maximum and a minimum sound pressure level for each of the environments mentioned before. In order to do that several measurements are done in each environment. The time of the performance of the measurement is always between 10 A.M. and 4 P.M.

M.2.3 Bus Measurements

These measurements are performed inside of the buses number 2 and number 12 at Aalborg (Denmark). Measurements in bus stops are not carried out.
Since the noise in a bus may vary depending on many variables such as the recording time, the type of bus, the traffic noise, the number of passengers traveling in the bus, etc. a total of 18 measurements are performed in different moments. These measurements are carried out in three different positions in the bus: In the end, in the middle and in the beginning of the bus. Moreover two repetitions are performed in each position in different moments: When the bus stops, when the bus moves and when the bus starts or brakes.

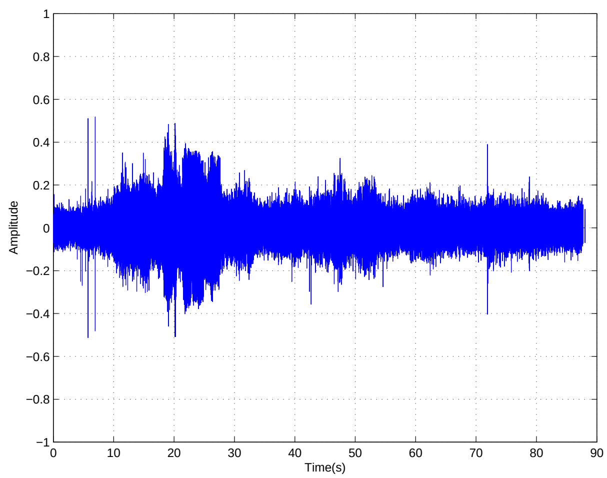

Figure M.3: *Noise signal used for the simulation of the* street *listening environment*

M.2.4 Street Measurements

To estimate the sound pressure level in a street is not a easy task, as well as in the bus, because many parameters have an important influence in the sound pressure level measured. Since the idea is to simulate an environment with a moderate or low noise level, a not very noisy street close to Aalborg University is used. The street selected is Fredrik Bajers Vej. The measurements are performed close to the entrance of the building seven of Aalborg University, which is in this street. There are different noises that can be recorded in this street depending on the situation. In this case the measurement is focus on recording the level of the sound produced by people talking in the street with a moderate or low environmental noise. Moreover the position in the street is taken into account for the recordings. Therefore two positions are defined: close to the road and far away from the road. A total of 9 measurements are performed in different moments depending on the amount of people present.

M.2.5 Field Measurements Results

The data were collected by a reading of the screen in the sound level meter. Table M.2 and Table M.3 shows the data collected for the *street* environment and the *bus* environment respectively. These tables show A-weighted sound pressure levels.

From the results of this appendix, the maximum and minimum sound pressure level measured for the listening environments are obtained. These are 90 and 106.2 dB for the *bus* listening environment and 64.5 and 77, 3 dB SPL for the *street* listening environment.

After testing these levels in the listening room used for the simulation it was observed that the noise levels in the *bus* situation where to high compare to a read situation. For these reason it was decided to reduce this levels until a realistic situation was achieved.

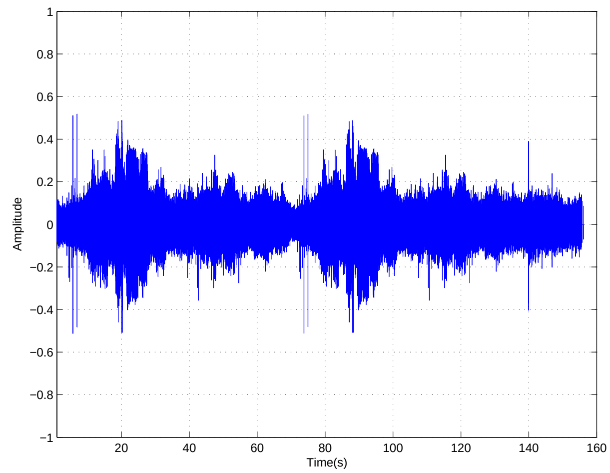

Figure M.4: *Signal of the* street *listening environment created by concatenating the selected file twice in a row.*

	Positions in the bus		
State of the bus	Beginning	Middle	End
stopped	90	88,8	95
starting	93,7	96,0	98
moving	96	95,7	106,2
stopped	89,0	90	97
starting	94,4	94	98,8
moving	99,7	98	104,7

Table M.2: *A-weighted sound pressure level measured for the* bus *listening environment. Three different positions in the bus and three different states of the bus are taken into account. These measurements are performed twice.*

	Number of people present	
Position in the street	0-2 persons	More than 2 persons
close to the road	65,4	70,2
far from the road	50,9	63,9
close to the road	77,3	70,9
far from the road	66,0	65,4

Table M.3: *A-weighted sound pressure level measured for the* street *listening environment. Different situations are taken into account depending on the amount of people present in the recording and depending on the position in the street. These measurements are performed twice.*

APPENDIX N

ANALISY OF VARIANCE (ANOVA)

In this appendix it can be found a brief explanation of the ANOVA test method applied.
ANOVA is used to test for the equality of several means. The test designed with two factor requires a two-way ANOVA. By which it is possible to test the equality among the treatment means of the two factors as well as the interactions between them. The treatments means of each factor is tested for equality and it can be stated if, they are different within a level of significance.

Furthermore, the two-way ANOVA provides a knowledge about the interaction effect of the factors. This effect is best explained by a small example: A person might like both fish and meat separately. But when mixing them (interaction), the taste might not please the person.

Statistical hypotheses are a statement about the problem situation. The population mean for the i'th treatment is denoted μ_i, the tested null-hyphothesis H_0 is denoted as:

$$H_0 : \mu_1 = \mu_2 = ... = \mu_i.$$

In order to test the hyphoteses the standard level of significance among statisticians is used. This value is noted as α, moreover it is equal to 0.05. This implies a maximun of 5% of probability of making a Type I Error. This error occurrs if the null hypothesis is rejected when it is true. It can be noted as:

$$\alpha = P(type \;\; I \;\; error) = P(reject \;\; H_0 \; |H_0 \quad is \;\; true)$$

Three assumptions are required for the ANOVA method to be exact, however a violations of these assuptions does not necessarily to lead false conclusions:

1. The treatment data must be normally distributed
2. The variance must be the same for all treatments
3. The observations must be independient. Being an observation one of the possible convinations between the treatments of the two factors.

Figure N.1shows the normalization plot. The observations marked with circles are normally distributed if the residual from the line is small.

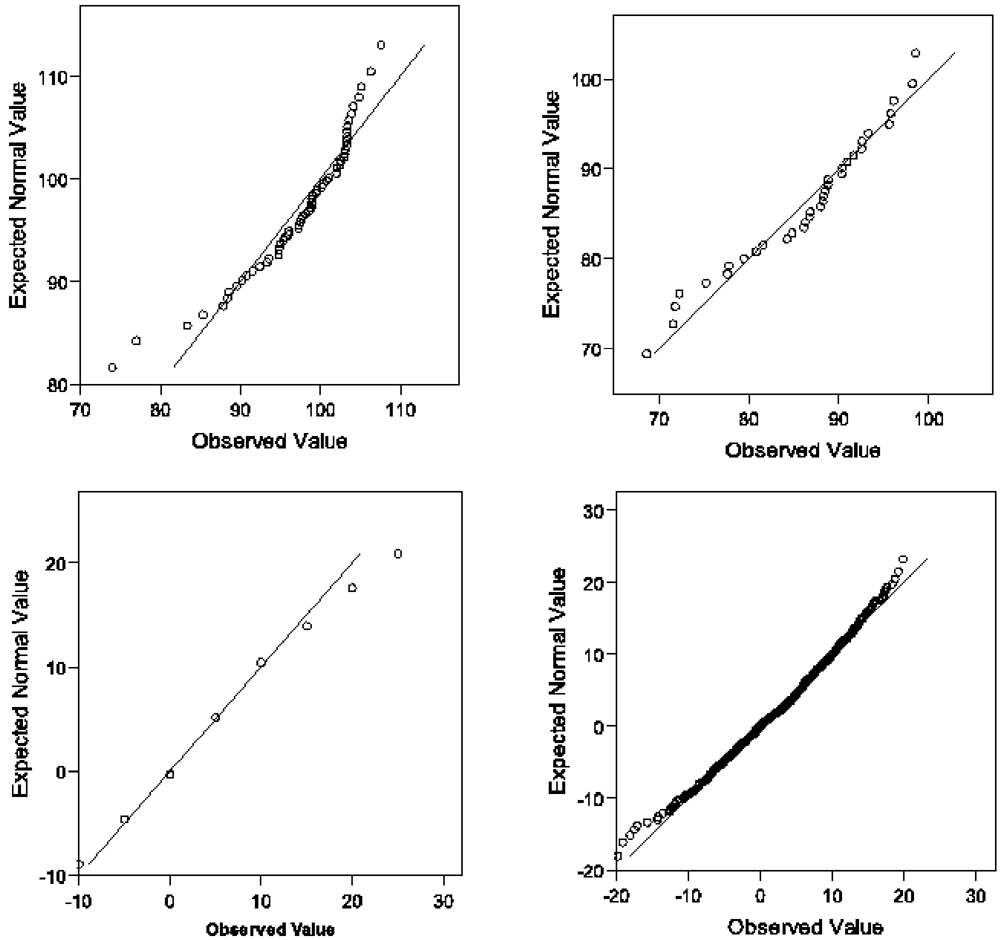

Figure N.1: *Representation of the normalization plot of the dependent variables:* $L_{FF,Aeq}$*(left-up),* $L_{EX,8h}$ *(right up), HL(left-down), DPOAEL(right-down)*

The compliance with the second assumption can be appreciated from the standard deviation values shown in the listening level, exposure level, hearing thresholds and DPOAEs analysis performed for this project.

The third assumption can be assumed since there are two different groups of test subjects.

APPENDIX O

INDEPENDENT SAMPLES T-TEST ANALYSIS

In this appendix it can be found a brief explanation of the T-tests test method applied.

An Independent Samples T-test compares the mean scores of two groups on a given variable. In this test the dependent variables are: $L_{FF,Aeq}$, HL and DPOAEL.

The next assumptions are made:

- The dependent variable is normally distributed. It can be appreciated from Figure N.1.
- The two groups have approximately equal variance on the dependent variable. The equality of variances is tested using Levenet's Test. It is explained below.
- The two groups are independent of one another

The hypotheses formulated are:

- Null: The means of the two treatments tested are not significantly different.
- Alternate: The means of the two treatments tested are significantly different

The null hypotheses can be rejected if the p-value obtained from the t-test is less than 0.05.

O.0.6 Listening Level T-test

This section describes the T-Tests performed by the treatments defined for factor environment. These treatments are: very quiet, quiet/moderate and noisy environment. The $L_{FF,Aeq}$ means are compared in groups of two by two. Then, the three T-test performed are:

1. T-test beetween: Very quiet and quite/moderate environment
2. T-test beetween: Very quiet and noisy environment
3. T-test beetween: Quite moderate and noisy environment

T-test between: very quiet and quite/moderate environment

In Table O.1 the results of the Levenet's test are shown. The significance value (Sig) is 0.012 which is smaller than 0.05. Then, it can not be assumed that the variances of both groups are approximately equal. Therefore a p-value equal to 0,084 can be read from the second line of Table O.1.

	Levene's Test		t-test for Equality of Means						
HL Assumption	F	Sig	t	df	p-value	Mean Difference	Std. Error Difference	Confidence Interval Lower	Upper
Equal variances	6.933	0.012	-1.780	42	0.082	-4.015	2.255	-8.568	0.536
Not Equal variances			-1.780	33.980	0.084	-4.015	2.255	-8.600	0.568

Table O.1: *Results from Independent Samples T-test between: very quiet and quite/moderate environment.*

T-test between: quiet/moderate and noisy environment

Table O.2 shows the results of the Levenet's test and the Independent Samples T-test. Since Sig is equal to 0.186, it can assume that the variances are approximately equal.
The p-value obtained from the T-test is 0.067, which is greater than 0.05.

	Levene's Test		t-test for Equality of Means						
HL Assumption	F	Sig	t	df	p-value	Mean Difference	Std. Error Difference	Confidence Interval Lower	Upper
Equal variances	1,812	0.186	-1.880	42	0.067	-2.788	1.482	-5.780	0.204
Not Equal variances			-1.880	40.534	0.067	-2.788	1.482	-5.783	0.207

Table O.2: *Results from Independent Samples T-test between: quiet/moderate and noisy environment.*

T-test between: very quiet and noisy environment

Table O.3 shows that it can not be assumed equality of variances. However, the null hypothesis can be rejected as the p-value is 0.004.

	Levene's Test		t-test for Equality of Means						
HL Assumption	F	Sig	t	df	p-value	Mean Difference	Std. Error Difference	Confidence Interval Lower	Upper
Equal variances	17.514	0.001	-3.148	42	0.003	-6.804	2.162	-11.165	-2.442
Not Equal variances			-3.148	30.370	0.004	-6.804	2.162	-11.215	-2.392

Table O.3: *Results from Independent Samples T-test between: very quiet and noisy environment.*

O.0.7 Hearing Threshold and DPOAE T-test

In this sections there is not described in detail the procedure followed to obtained the results from each T-Tests performed. A single matrix which contains the p-value results from each test is shown.

HL T-test among the ears of both populations

Table O.4 shows the p-values obtained from the HL T-Tests performed among the two ears of both populations.

	LC	RC	LT	RT
LC		0.378	**0.000**	**0.000**
RC	0.378		**0.006**	**0.005**
LT	**0.000**	**0.006**		0.837
RT	**0.000**	**0.005**	0.837	

Table O.4: *Results from Independent Samples T-test: among the ears of both populations*

HL T-test among the frequencies

Table O.5 shows the p-values obtained from the HL T-Tests performed among the 10 frequencies tested.

	250	500	750	1000	1500	2000	3000	4000	6000	8000
250		0.287	0.309	0.537	0.410	0.641	0.783	0.211	**0.000**	**0.037**
500	0.287		1.000	0.571	0.843	0.546	0.169	0.679	**0.000**	**0.002**
750	0.309	1.000		0.534	0.851	0.565	0.190	0.689	**0.000**	**0.003**
1000	0.537	0.571	0.534		0.753	0.914	0.346	0.389	**0.000**	**0.004**
1500	0.410	0.843	0.851	0.753		0.705	0.266	0.578	**0.000**	**0.005**
2000	0.641	0.546	0.565	0.914	0.705		0.449	0.377	**0.000**	0.11
3000	0.783	0.169	0.190	0.346	0.266	0.449		0.134	**0.000**	0.62
4000	0.211	0.679	0.689	0.389	0.578	0.377	0.134		**0.001**	**0.003**
6000	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.001**		**0.006**
8000	**0.037**	**0.002**	**0.003**	**0.004**	**0.005**	0.110	0.620	**0.003**	**0.006**	

Table O.5: *Results from Independent Samples T-test among the ears of both populations*

DPOAE T-test among the frequencies

Table O.6 presents the p-values obtained from the DPOAE T-Tests performed among the two ears of both populations. A dependence between right and left ears of control and target populations is found.

	LC	RC	LT	RT
LC		0.416	**0.000**	**0.000**
RC	0.416		**0.000**	**0.001**
LT	**0.000**	**0.000**		0.568
RT	**0.000**	**0.001**	0.568	

Table O.6: *Results from Independent Samples T-test among the ears of both populations*

DPOAE T-test among the frequencies

The p-values obtained from the the DPOAE T-tests carried out among the 22 frequencies tested in DPOAE are presented in table O.7.

	905	984	1076	1172	1282	1398	1524	1658	1810	1980	2156
905		0.624	0.372	0.132	0.065	0.132	0.018	0.015	0.018	0.090	0.144
984	0.624		0.683	0.280	0.148	0.283	0.050	0.039	0.052	0.215	0.318
1076	0.372	0.683		0.470	0.269	0.481	0.105	0.081	0.115	0.394	0.544
1172	0.132	0.280	0.470		0.706	0.971	0.413	0.326	0.479	0.960	0.863
1282	0.065	0.148	0.269	0.706		0.673	0.680	0.553	0.782	0.719	0.566
1398	0.132	0.283	0.481	0.971	0.673		0.380	0.298	0.441	0.927	0.890
1524	0.018	0.050	0.105	0.413	0.680	0.380		0.833	0.862	0.399	0.286
1658	0.015	0.039	0.081	0.326	0.553	0.298	0.833		0.698	0.310	0.221
1810	0.018	0.052	0.115	0.479	0.782	0.441	0.862	0.698		0.465	0.331
1980	0.090	0.215	0.394	0.960	0.719	0.927	0.399	0.310	0.465		0.806
2156	0.144	0.318	0.544	0.863	0.566	0.890	0.286	0.221	0.331	0.806	
2350	0.044	0.113	0.225	0.694	0.982	0.446	0.630	0.500	0.736	0.704	0.535
2563	0.019	0.055	0.119	0.479	0.777	0.442	0.873	0.710	0.991	0.466	0.333
2793	0.091	0.214	0.390	0.947	0.734	0.914	0.415	0.324	0.484	0.985	0.794
3049	0.010	0.032	0.077	0.397	0.693	0.359	0.948	0.769	0.899	0.373	0.253
3316	0.001	0.005	0.012	0.104	0.233	0.087	0.416	0.582	0.289	0.082	0.050
3626	0.000	0.000	0.000	0.000	0.002	0.000	0.005	0.015	0.001	0.000	0.000
3948	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000
4306	0.000	0.000	0.000	0.000	0.001	0.000	0.002	0.006	0.001	0.000	0.000
4695	0.000	0.000	0.000	0.007	0.021	0.005	0.043	0.082	0.022	0.004	0.002
5121	0.000	0.000	0.000	0.002	0.006	0.001	0.013	0.030	0.005	0.001	0.000
5582	0.000	0.000	0.000	0.001	0.006	0.001	0.012	0.027	0.005	0.001	0.000

	2350	2563	2793	3049	3316	3626	3948	4306	4695	5121	5582
905	0.044	0.019	0.091	0.010	0.001	0.000	0.000	0.000	0.000	0.000	0.000
984	0.113	0.055	0.214	0.032	0.005	0.000	0.000	0.000	0.000	0.000	0.000
1076	0.225	0.119	0.390	0.077	0.012	0.000	0.000	0.000	0.000	0.000	0.000
1172	0.694	0.479	0.947	0.397	0.104	0.000	0.000	0.000	0.007	0.002	0.001
1282	0.982	0.777	0.734	0.693	0.233	0.002	0.000	0.001	0.021	0.006	0.006
1398	0.446	0.442	0.914	0.359	0.087	0.000	0.000	0.000	0.005	0.001	0.001
1524	0.630	0.873	0.415	0.948	0.416	0.005	0.000	0.002	0.043	0.013	0.012
1658	0.500	0.710	0.324	0.769	0.582	0.015	0.001	0.006	0.082	0.030	0.027
1810	0.736	0.991	0.484	0.899	0.289	0.001	0.000	0.001	0.022	0.005	0.005
1980	0.704	0.466	0.985	0.373	0.082	0.000	0.000	0.000	0.004	0.001	0.001
2156	0.535	0.333	0.794	0.253	0.050	0.000	0.000	0.000	0.002	0.000	0.000
2350		0.731	0.722	0.633	0.175	0.001	0.000	0.000	0.011	0.003	0.002
2563	0.731		0.484	0.112	0.302	0.002	0.000	0.001	0.024	0.006	0.005
2793	0.722	0.484		0.860	0.090	0.000	0.000	0.000	0.005	0.001	0.001
3049	0.633	0.112	0.860		0.995	0.001	0.000	0.000	0.023	0.005	0.005
3316	0.175	0.302	0.090	0.995		0.036	0.003	0.014	0.174	0.670	0.062
3626	0.001	0.002	0.000	0.001	0.036		0.277	0.532	0.673	0.979	0.953
3948	0.000	0.000	0.000	0.000	0.003	0.277		0.713	0.192	0.371	0.386
4306	0.000	0.001	0.000	0.000	0.014	0.532	0.713		0.360	0.606	0.625
4695	0.011	0.024	0.005	0.023	0.174	0.673	0.192	0.360		0.691	0.670
5121	0.003	0.006	0.001	0.005	0.670	0.979	0.371	0.606	0.691		0.977
5582	0.002	0.005	0.001	0.005	0.062	0.953	0.386	0.625	0.670	0.977	

Table O.7: *Results from Independent Samples T-test among the frequencies*

APPENDIX P

STATISTICAL ANALYSIS

This appendix contains a list of Tables and Figures obtained during from statistical analysis.

Table P.1 represents the HL mean and the standard desviation values of the data collected from audiometric test.

Factor B	Mean HL (dB)				Standard Deviation				Number of Subjects		HL Mean
f(Hz)	LC	RC	LT	RT	LC	RC	LT	RT	Control	Target	(dB)
250	0.50	1.50	3.00	2.00	4.12	4.97	6.32	8.88	10	10	1.75
500	4.50	5.50	2.00	0.50	3.69	3.69	6.15	6.32	10	10	3.12
750	4.00	5.00	-0.50	4.00	7.07	4.59	5.27	5.5	10	10	3.12
1000	2.50	4.50	1.50	1.50	6.43	3.54	4.22	3.37	10	10	2.50
1500	5.00	4.00	3.00	-1.00	4.97	4.71	6.99	5.87	10	10	2.87
2000	4.00	5.00	-0.50	1.00	4.71	5.16	4.97	6.85	10	10	2.37
3000	1.50	2.00	0.00	-2.00	4.83	4.12	5.37	7.82	10	10	0.37
4000	6.50	8.00	-2.50	3.00	8.23	5.8	6.77	7.17	10	10	3.75
6000	11.00	13.00	6.50	10.00	5.37	10.22	5.16	8.51	10	10	10.12
8000	-0.50	-0.50	-1.00	-3.50	6.85	6.85	6.35	8.76	10	10	-1.37
Mean (dB)	3.90	4.85	1.15	1.55							

Table P.1: *Data collected from the from audiometric test.*

Table P.2 presents the DPOAE mean and the standard desviation values of the data collected from DPOAE measurements.

Factor B	Mean $L_{FF,Aeq}$ (dB)				Standard Deviation				Number of Subjects		DPOAE Mean
f(Hz)	LC	RC	LT	RT	LC	RC	LT	RT	Control	Target	(dB)
904,89	-2.55	-5.60	-0.22	3.64	6.93	4.90	6.37	6.81	10	10	-1.18
983,68	-2.41	-0.30	3.62	1.70	6.39	5.37	4.88	4.45	10	10	0.65
1075,53	0.21	-3.56	2.27	2.43	5.52	5.34	6.59	4.78	10	10	0.33
1172,27	-1.27	0.17	4.22	2.54	8.23	6.22	6.64	6.10	10	10	1.41
1281,62	1.05	-0.62	3.45	4.31	6.72	8.40	6.71	7.02	10	10	2.04
1397,59	0.71	-1.26	2.51	3.30	6.53	5.50	8.51	5.45	10	10	1.31
1524,34	2.14	0.33	4.21	3.99	6.63	5.23	7.30	7.11	10	10	2.66
1657,81	0.39	1.81	5.01	5.69	9.27	5.63	6.19	5.54	10	10	3.22
1809,77	2.23	2.57	3.56	2.96	6.38	3.79	5.10	4.96	10	10	2.83
1979,87	-0.35	1.44	2.57	2.32	7.48	4.30	4.96	6.62	10	10	1.49
2155,95	0.27	1.59	1.88	2.62	6.16	4.95	4.57	4.21	10	10	1.59
2349,98	0.41	2.34	2.89	3.36	5.53	5.78	4.82	6.05	10	10	2.25
2562,70	2.24	2.58	2.94	3.62	4.87	4.32	6.21	6.31	10	10	2.84
2793,45	1.40	1.46	1.76	2.34	5.89	3.64	7.65	6.07	10	10	1.74
3048,78	0.92	2.02	3.72	3.54	5.43	4.38	5.08	5.86	10	10	2.55
3316,17	2.88	4.53	4.48	3.73	6.65	5.18	6.47	6.15	10	10	3.90
3626,17	5.41	6.39	7.88	5.93	5.86	6.05	5.79	4.27	10	10	6.40
3948,24	6.65	7.59	9.30	7.43	6.42	6.26	5.40	5.36	10	10	7.74
4305,73	7.32	7.97	8.57	6.67	6.95	8.24	4.85	4.86	10	10	7.63
4694,53	5.83	4.89	7.77	6.84	7.44	10.32	5.17	4.67	10	10	6.33
5120,51	5.44	6.08	9.57	7.16	8.44	8.42	3.84	3.57	10	10	7.06
5581,93	4.62	5.67	9.24	7.94	8.54	9.29	3.61	3.90	10	10	6.86
Mean (dB)	4.60	4.27	1.97	2.18							

Table P.2: *Data collected from DPOAE measurements.*