Presbycusis:
a virtual reality deafness simulator

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Abstract

Hearing loss is a frequent problem in society. There are a number of causes that condition hearing loss in different age groups and have a negative impact on people’s daily lives. This thesis aims to raise awareness for hearing loss in the third age through a virtual reality simulator. For this, a basic understanding of hearing and the associated perceptual processes are given. Hearing loss associated with age, presbycusis, is described in several dimensions (physiological, social and its prevalence). Later, two auditory models, MAP and CASP and two software development kits (SDKs) - Resonance Audio and Oculus Audio - were analyzed, as well as two auditory simulators - Starkey and NIOSH - in which the simulator was inspired. Through the use of two softwares, Blender together with Unity, a virtual reality deafness simulator was developed aiming specifically to the hearing impairment in the elderly where the user is standing in a restaurant with noisy conditions with freedom of movement. Qualitative tests of the simulator were carried out through a questionnaire with questions that could be answered on the Likert scale. The results show a strong incentive regarding the use of virtual reality to approach the hearing loss for a specific age group as well as the understanding of the difficulties exhibited in noisy environments.

Keywords: presbycusis, hearing loss, virtual reality, elderly

1. Introduction

Hearing loss is a frequent problem in society. There are a number of causes that condition hearing loss in different age groups and have a negative impact on people’s daily lives. Of the various types of hearing loss, presbycusis, i.e. hearing loss with advancing age, has been of particular interest. This loss is distinguished mainly by difficulties in hearing discrimination, which results in an increased difficulty in not perceiving more than not listening. This is further exacerbated when there is background noise or when the acoustic conditions are not ideal.

It is in this context that the idea of creating a hearing loss simulator arose in order to sensitize society to the problems of hearing loss in different contexts and particularly focused on presbycusis in noisy environments - typical in the daily life of these people. The development of the work, therefore, is motivated to translate clearly the difficulty of understanding these patients in daily life, especially in situations with concurrent discourse sound sources (denominated situatons of cocktail party) through virtual reality.

Thus, the implementation of this work is based on building a simulator using virtual reality technology to create an environment in which those who do not suffer from hearing loss are aware of the difficulty experienced by the patient and change their attitudes towards the senior population. The simulator will promote a day in the daily life of this population with different competing sound sources as well as environments normally frequented by this age group. The simulator will have an interactive and pedagogical aspect in order to be used by young people and also - if the project evolves - for health professionals and other areas that contact older populations, so that they can relate better to this difficulty of their patients.

In order to try to improve communication between people and the next generations, there is a need to address presbycusis not only as an individual phenomenon, but also as a more social and familial model. It is essential to articulate the technological advances of prostheses with acoustic concerns in different types of environments, such as improving the understanding of the family of the patient and of society in general in relation to the discriminative difficulty of speech in everyday life.

The main objective is to be able to create through virtual reality a deafness simulator specifically focused on hearing loss with the advancement of age.
in cocktail party situations. This is an approach so that young people become sensitized to hearing loss and change small habits that contribute greatly to the early advancement of presbycusis.

In addition, three essential tools are described - Archipack, UMA and Resonance Audio - that allow a huge customization of the project. From this base it is possible to obtain an enormous amount of diversity with respect to the geometric model, the context in which it is inserted and the spatialization that surrounds it.

This document is structured in five sections. After the Introduction in section 1, a brief description of some principles of hearing, presented in section 2, follows. In section 3 the State Art is presented and section 4 describes the implementation of the project. The section 5 contains the results carried out through a questionnaire and in chapter 6 the conclusions are described.

2. Hearing principles
Hearing is the sense through which innumerable stimuli from the outside world such as speech, music, and other sounds are translated into the brain. In order to understand the human auditory system as well as several physiological responses associated with sound, in subsections 2.1 and 2.2 these subjects are explained.

2.1. Hearing and perception mechanisms
The structure of the human auditory system is composed of 2 subsystems, peripheral and central auditory system, the latter is part of the sensory nervous system. These two systems work together to achieve a correct functioning of hearing and balance. The peripheral auditory system is composed by the external, middle and inner ear and the part of the sensory nervous system responsible for hearing is constituted mainly by the auditory nerve and cortex.

2.1.1 Hearing anatomy
To see the operation of the outer, middle and inner ear, a cross-section of these three ears is shown in Figure 1. The outer ear, composed by the ear canal and external ear canal, functions to acquire and conduct sound to the middle ear. The middle ear performs an impedance transformation between external ear air and the cochlear fluid of the inner ear. The inner ear contains two distinct sensory organs: the vestibule and the cochlea. The cochlea, as a transducer organ, has the function of transforming the mechanical excitations into electrical excitations for the nerve fibers [6, 8].

In short, when a sound wave is conducted through the middle ear, the generated mechanical oscillations are transmitted by the stirrup, displacing the oval window at the base of the cochlea. Then the liquid inside the vestibular chamber, perilymph, pressures the basilar membrane causing it to vibrate up and down and these deformations are transmitted to the hair cells in the Organ of Corti. At the same time, the tectorial membrane is displaced, which is a stimulus for the auditory nerve filaments that carries the sound wave information to the brain [1, 2, 6].

The information contained in sound is encoded in nerve impulses and is transmitted to the central nervous system through the vestibulocochlear nerve where several synapses occur along the primary and non-primary auditory pathway. In each of these stages, the information is processed so that it can reach the thalamus and be distributed to the cerebral and associative cortex, respectively.

2.1.2 Sound perception phenomena
The young human ear, if not damaged, is capable of picking up sounds from 20 Hz to 20 kHz. The lowest intensity to which the sounds are perceptible is called the threshold of hearing. As it can be seen in Figure 2, this threshold increases significantly for frequencies less than 1 kHz and greater than 5 kHz, but it remains (3 dB in 0 dB) between 700 Hz and 7 kHz.

The increase in sound intensity leads to the appearance of two other thresholds: of discomfort and pain. These two thresholds have a variation over the frequency well below the variation of the hearing threshold. The pain threshold is between 120 - 140dB and for frequencies ranging from 5 kHz to 10 kHz the threshold decreases by 30 dB/decade. The discomfort threshold monotonically decreases 40 dB/decade from 200 Hz to 10 kHz and varies between 115 and 50 dB [9, 7].

2.2. Presbycusis - pathology, diagnostic and prevalence
Of the various types of hearing loss, presbycusis has been of particular interest, i.e. hearing loss with advancing age. This loss is distinguished mainly by difficulties in hearing discrimi-
nation, which results in an increased difficulty in not perceiving more than not listening. This is further exacerbated when there is background noise or when the acoustic conditions are not ideal.

2.2.1 Pathology and the cocktail party

Transmission deafness is related to obstruction of the outer ear or lesions in the middle ear such as otitis or damage to one of the three ossicles. Deafness of perception, or sensorineural hearing loss, is due to damage to the inner ear or auditory nerve. Finally, mixed deafness includes components of deafness of transmission and perception.

The main clinical problem of presbycusis is lack of understanding in background noise environments. When this pathology is only related to the central nervous system, patients exhibit a reasonable understanding of speech in silence, but in noisy environments there is a disproportionate decrease in their understanding. It should be borne in mind that the understanding of discourse is a cognitive process and that without the ability to process speech rapidly, words sound like inarticulate sounds. The complexity of the auditory system depends on certain areas of association of the brain to store elements of speech, and when someone listens, the brain compares the sounds received with those stored in working memory. Thus, the brain quickly judges the sound, its meaning and its linguistic relations, which allows one to make sense of the various stimuli of everyday life [3].

2.2.2 Audiometric tests

Within the hearing loss that is presbycusis, it is important to differentiate the degree of deafness that each patient exhibits. According to the BIA (International Bureau of Audiophonology), the degree of hearing impairment can be classified into 5 types: mild, medium, severe, profound and total. In Table 1 the different degrees of deafness are presented according to the tonal loss.

In Figure 3 there is shown a pure tone audiogram for a typical patient suffering from presbycusis. It is important to understand that hardly a patient is diagnosed as exhibiting only one type of different degrees of deafness since the most significant hearing loss occurs mostly at the higher frequencies. The tonal audiogram of Figure 3 is one of the most common diagnoses that allows to identify the type and degree of hearing loss that the patient suffers [5].

2.2.3 Prevalence and other considerations

In social terms it is important to realize that presbycusis has an alarming effect on the mental health and social life of the elderly. Normal hearing allows them to detect alarms, stay alert during sleep, listen in the dark, detect sounds from all directions, and it is also through good hearing that they can maintain effective contact with family and the world via means of communication. In addition, there is a strong dependence on hearing in order to compensate for other age-related impairments, so hearing loss is a factor contributing to isolation, depression and possible dementia in the elderly [10].

<table>
<thead>
<tr>
<th>Degree of deafness</th>
<th>Loss (dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mild</td>
<td>21 a 40</td>
</tr>
</tbody>
</table>
| Moderate           | Type I: 41 to 55  
|                    | Type II: 56 to 70 |
| Severe             | Type I: 71 to 80  
|                    | Type II: 81 to 90 |
| Profound           | Type I: 91 to 100  
|                    | Type II: 101 to 110  
|                    | Type III: 111 to 120  |
| Total              | + 120    |
Whether corrected or not, hearing loss is highly prevalent at a later stage of life, regardless of socio-demographic factors such as marital status, education, profession, and maturity. There is no higher prevalence in either gender, but there is a higher prevalence in groups with lower levels of education, which may be associated with people with limited access to health services or prolonged exposure to ototoxic factors such as noise or medication. In addition to the prevalence increase with advancing age, the elderly now represent the segment of the population with the fastest growth. It is estimated that by 2041, 25% of the worldwide population will be composed of people over 60 years. Thus, with the increasing prevalence and growth of the number of elderly, it is concluded that the total number of people with hearing loss increases at an even faster rate across the entire population [10].

3. State of the art
3.1. Physiological auditory models
In this section, two models are presented that simulate the physiological auditory response of the peripheral auditory system. The first model is intended to be used to model audiometric profiles (both hearing loss and healthy hearing) through three psychoacoustic measurements. The second model aims to describe the effects of mask, focusing on effects of discrimination of intensity and mask effects on frequency and time.

3.1.1 MAP - Model of the Auditory Periphery
The first model, MAP, aimed to serve as a basis for a normal hearing model and also to explore its effects in an algorithm of an auditory prosthesis, inspired by the physiology of the human auditory system through three psychoacoustic measures: absolute threshold of hearing, selectivity and frequency compression [4]. Due to inaccessibility of the inner ear, this type of development is particularly important in sensorineural deafness.

The MAP consists of several stages placed in series, each simulating the individual physiological responses that occur in the peripheral auditory system. Simulations of physiological responses are performed along the entire course of sound through the peripheral auditory system and include patterns of vibration of the eardrum, stapes and basilar membrane, electrical potentials of inner and outer hair cells, as well as action potentials in the auditory nerve fibers.

This model allows incorporating hearing impairment in terms of internal ear pathology in several ways: a general reduction of outer hair cell gain, a reduction in endocochlear potential and dead regions along the cochlear partition, in which no response is generated. A detailed explanation of the operation of the MAP and all its stages is found in [6].

3.1.2 CASP - Computacional Auditory Signal-processing and Perception
The CASP, like the MAP, consists of several stages placed in series simulating the individual physiological responses that occur in the peripheral auditory system. It begins with the outer and middle ear transfer functions, followed by a non-linear processing phase of the MB corresponding to the DRNL filter bank and a phase of sensory cell transduction. Subsequently, there is a bank of bandpass filters preceded by a low pass filter, and finally a block of internal noise of constant variance.

In some cases of discrimination of intensity and signal integration in the noise the simulation results were similar to those of the original model. Regarding cases with direct masking with noise and tone masks, spectral masking with high levels of masking, the CASP showed a much better agreement with the data than the original model, mainly as a consequence of level-dependent compression and frequency selectivity in the original model in cochlear processing.

3.2. Hearing loss simulators
In this section, two simulators are analyzed: in the 3.2.1 section, the different degrees of hearing loss are analyzed in the different contexts provided by Starkey in its website. In the 3.2.2 section, the NIOSH (National Institute for Occupational Safety and Health) simulator is presented in which different degrees of deafness are exposed to someone who has been exposed to noise.

3.2.1 Starkey
On the Starkey site, a fairly simple simulation is shown for what hearing loss is. They are given the choice of seven different contexts, in which it is possible, for each one of them, to choose the degree of deafness that one intends to simulate. There are 3 possible degrees of deafness: light, medium and severe, and according to the chosen context, the corresponding dialog appears in a text box.

This simulator is quite simple and can not be used to customize any audio, either in real time or through the simulation of non-linear factors of hearing loss. On the other hand, the simulator has common objectives with this project as giving a small understanding of the difficulty that someone with hearing loss, child or adult, has in situations of dialogue with different types of noise. One must note

1https://www.starkey.com/hearing-loss-simulator#/hls/page/1
the context in which a deafness simulator is provided by a private company as part of a marketing strategy.

### 3.2.2 NIOSH

The NIOSH hearing loss simulator aims to promote the prevention of hearing loss, demonstrating the effects of prolonged exposure to noise. It has as variables the age, the sex, the amount of years that were exposed to the noise as well as a manual modification of the attenuation of the sound intensity. The simulator displays a control panel where it is possible to adjust the various noise exposure parameters such as the number of years of exposure and the level to which the person was exposed, as well as the age and type of hearing loss to be simulated.

This simulator, although more complete than the Starkey simulator, does not allow to know how the effects of aging, intensity of exposure to noise and number of years of exposure are implemented. However, through the frequency band in the lower left corner, it is possible to trace the 4 curves (3 of deafness and 1 of exposure to noise) that the simulator has by default, as shown in Figure 4.

It is important to note that this simulator only incorporates hearing loss with advancing age in contexts of hearing loss by exposure to noise and does not consider this factor alone, and therefore becomes very limiting within the practical utility of a specific simulator of presbycusis.

### 3.3. Sound spatialization

In the 3.3.1 subsection, the Oculus Spatializer SDK, released in October 2014, is described; in the subsection 3.3.2, another SDK is described, Resonance Audio by Google, launched in March 2018 and lastly in the 3.3.3 3D Tune-In Toolkit since the library only became available in March 2019.

For the development of this work, the Unity program proved to be quite adequate since it integrates the first two tools described in this section with relative ease. Currently, the 3D Tune-In Toolkit does not have direct implementation with Unity available.

#### 3.3.1 Oculus Spatializer SDK

The Oculus sound spatial SDK includes spatialization and propagation of audio through volumetric sound sources, near-field spatialization, open-space modeling, ambisonic audio format, and finally, attenuations and reflections in order to simulate distances².

This SDK does not support the occlusion of sound waves in the simulated environment according to the surrounding objects, nor does it take into account the directionality of the sound sources, nor any way to configure it. In the context of creating the auditory simulator in a closed virtual space, these aspects make the Oculus Spatializer SDK unattractive.

#### 3.3.2 Resonance Audio SDK

This SDK simulates how sound interacts with the human ear and the surrounding environment. It is supported on several platforms and has been optimized to work with limited computing resources³.

Reflections and reverberation are divided into 3 groups. The first sound wave that travels directly to the auricle, or the direct sound of the source, that diminishes as the sound source moves away; the first reflections of the sound source, which give a sense of the size and shape of the division in which the person is and the late reverberation that occurs when the reflections become indistinguishable from one another. By changing the size of the geometric model and the bill of materials that makes it up, the reverberation engine reacts in real time and adjusts the sound waves to its new conditions.

The SDK also takes into account the occlusion of objects between the sound source and the user. The different spectral components are treated differently, with high frequencies being more affected by occlusion than low frequencies.

In addition to supporting directivity of sound sources and occlusion caused by the surrounding environment, Resonance Audio projects all sound sources into a high-order global sound field. With this optimization in which Head Related Transfer Functions are applied only once to the sound field, it is possible to keep the cost per sound source at its minimum, which allows a high number of them in the virtual environment (60 % CPU with 200 sources in a Google Pixel and ambisonic of 3rd order).

³[https://resonance-audio.github.io/resonance-audio/discover/concepts.html](https://resonance-audio.github.io/resonance-audio/discover/concepts.html)
3.3.3 3D Tune-In Toolkit

This project presents a C++ library that integrates binaural sound spatialization, sonication through loudspeakers, simulation of hearing loss and simulation of hearing aids.

The Toolkit features two test applications (Binaural Test App and Loudspeaker Test App). These applications can be used to perform binaural spatialization and through columns with different sound sources, simulating different virtual environments and additionally exploring hearing loss and hearing aids. In addition to these two applications the 3D Tune-In Toolkit also has an online version where you can try out some of the features of the library.

This software can not be integrated into the simulator for two reasons. The user will not be static and will have freedom of movement, which makes it impossible to integrate this software in the scope of the work, however, the main factor is that it was only made opensource in March 2019, which did not allow the deepening of the sound spatialization of the tool and the possible integrations in the simulator. Nevertheless, it may be useful for future work in which, for example, this application is integrated into a cocktail party “game mode” in which the participant has no freedom of movement, for example being seated at the table with various sound stimuli around him.

3.4. Virtual Reality

According to the objective of this study, virtual reality (VR) can be used to sensitize and raise awareness (especially young people) of the sonic trauma of hearing loss with the advancing age and, consequently, to take actions that help them to delay this type of trauma, and also to develop attitudes of cooperation and understanding for those who suffer from presbycusis.

At the moment this type of technology has some applications in the universe of hearing and those who suffer with its loss. Some of the examples of VR application in auditory health include avatars that translate sign language into English that can be very useful in interactions involving hotel employees, bank tellers, airport security personnel and receptionists in medical facilities, ie interactions in that the conversation is so short that a certified translator is not available. Another application includes the use of VR in auditory research laboratories that, especially for children, can be an austere and disconcerting place. In this way it is possible to create a more familiar and user-friendly environment in which, in addition to being able to perform tests in more complex environments without having to physically be in these places, it also allows the necessary experimental control.

As mentioned in the introduction, it is necessary to treat presbycusis as a social rather than individual social problem. VR can be used as the bridge between these two groups of people so that it is possible to achieve a better hearing prevention of the younger layers that do not yet suffer from presbycusis, avoiding risky behaviors that damage their hearing. By being able to make people who do not suffer from presbycusis be aware of what this problem means in people’s lives, an approximation between these two distinct groups is promoted, improving communication between the patient and the other person.

The device for the implementation of the simulator will be the Oculus Rift which is represented in Figure 5. Having integrated headphones and controllers allows for easier implementation of the simulator and, although it is mostly used in the gaming industry, its usefulness in other fields, such as those already mentioned (car, health, hotel), is emerging.

4. Methodology

4.1. Overview

In this subsection, an overview is provided that covers the implementation of the work. The starting point for the development of the simulator begins with the implementation of a physical space in which all the acoustic stimuli will be simulated. Subsequently, this space is imported to Unity, in which all the relevant sound sources are added to obtain a coherence between the space and the sound stimuli.

Two different essential phases of the project can be considered: the first corresponds to the construction of the virtual geometric model and the

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4https://github.com/3DTune-In/3dti_AudioToolkit/releases
5http://online-toolkit.3d-tune-in.eu/

Figure 5: Oculus Rift and its commands.

Figure 6: Implementation of the simulator and tools used.
second is where the sound sources (and their spatialisation), the player and the remaining avatars are implemented.

4.2. Blender
The first software to be used in the development of the simulator is Blender, with the purpose of building the geometric models of the physical space that one wants to simulate. The built physical space was based on the ‘Gula’s for kitchen lovers’ restaurant and to facilitate its implementation an add-on - Archipack - that contains objects used to create a virtual environment was used. In Figure 7, the constructed physical space is represented.

4.2.1 Archipack
In Table 2 are the different Archipack presets implemented in the model construction.

This add-on aims to provide the skeleton of the geometric model to be incorporated into the simulator quickly and efficiently. Archipack allows the customization of all objects present in the 2 Table and in this way, the construction of any skeleton of a model becomes simpler and more efficient.

4.2.2 Imported FBX
In addition to using Archipack, objects already built and published for free were used. In this way, efficiency is added together with a better graphic representation through simple existing models of some objects such as chairs, tables, cups, lamps, washbasins and various decorations.

4.3. Unity
In this section it is described how the different components of the simulator were implemented in Unity. In the subsection 4.3.1 it is described how the different characters of the simulator were created in order to create a cocktail party situation with the UMA (Unity Multipurpose Avatar). Later, in the 4.3.2 section, it is explained how Resonance Audio is incorporated into the model, sound sources and different types of deafness, and finally the application of the Oculus to the player’s movement is depicted.

4.3.1 UMA - Unity Multi-purpose Avatar
In the simulator the purpose is to illustrate the effect of cocktail parties and apply it to presbycusis. However, to have coherence between the visual representation and the auditory stimuli, it is necessary to include dozens of humanoid avatars, each with its individual animation. In order to create several humanoid models for free and without resorting to 3D modeling software, such as Blender, a asset from the Unity store - UMA was used. UMA allows the creation of numerous characters that serve to give authenticity to the simulation, with a limited number of clothes and a huge customization of the human body (including the face).

The animations of all the avatars included in the simulator are reduced to the Idle animation, and the avatars that have sound sources to simulate the discourse have a higher speed of animation in relation to the silent avatars.

4.3.2 Resonance Audio
The sound spatialisation of the simulator was all done through the Google SDK, Resonance Audio. The use of this SDK in the simulator can be divided into three distinct phases. The first includes the application of the shoebox model to the structure of the geometric model. The second includes its application to passive sound sources and discourse that the avatars are to simulate having and, finally, the application of the different degrees of deafness to the simulation.

The shoebox model allows the simulation of sound spatialization in closed environments such as the model constructed in 4.2. Resonance Audio allows customization of materials, reflections, reverberation and box size.

Taking into account the application of the simulator, the sound sources were categorized into two groups: passive and active. The passive are
sources that are expected to exist in the environment created so as to create a greater immersive-ness - plates and glasses to beat, running tap water, sound from the outside of the street and traffic. Active sound sources are the discourses included in the avatars.

To simulate deafness, three low-pass filters with different cut-off frequencies were used, as well as a level of attenuation for all sound sources according to the degree of deafness - slight, medium or severe.

In order for the user to change between the different degrees of deafness, a small menu is created, represented in Figure 8. This menu causes the simulation pause, in which the audio is frozen and allows you to switch between the different degrees of deafness.

4.3.3 Oculus Rift

The last step of the simulator is to integrate the Oculus Rift with the user. For this, another SDK - Oculus Integration - is used which allows the Oculus Rift to be integrated in the project. The player is represented in Figure 9 and for his displacement only one of the commands that comes together with the Oculus Rift is used.

Moving across the restaurant is an important aspect of the simulation and is done through the joystick in the right command of Oculus. While providing greater immersion within the simulator - unlike a flying carpet or teleportation interaction - this type of interaction can cause some discomfort, namely dizziness and bad mood. This is due to the fact that in the simulation the user is moving, however he is physically static.

4.3.4 Additional notes

Most of the development of the simulator was done without access to the Oculus which prevented the realization of an interactive menu in 3D for not knowing how to work this strand. In addition, an interactive component is lacking in addition to choosing the degree of deafness. As a possible interactive/gamification element, it was hypothesized that there was an objective that involved the interpretation of the various discourses in the simulation. However, together with the first observation, the sound sources of the avatars are not optimal for the context of the simulator since they are recordings of an episode of an episode of a person’s life and not of a real speech between two people. These recordings, to which access was facilitated by belonging to an earlier project, allowed the easy inclusion of several discourses in the simulator and thus somehow give the illusion that the avatars are talking to each other.

5. Results

Together with the simulation, a questionnaire was made in order to qualitatively and simply evaluate the main components of the simulator. The questionnaire is divided into three parts: sound sources, virtual reality and deafness composed respectively by 4, 4 and 3 questions.

5.1. Responses

Before the user started the experiment the following steps were performed: first, the contextualization of the simulated space was given where the users will be placed at the beginning of the experiment, specifically in front of the entrance door of the restaurant. Users can only rotate on themselves and their movement in the restaurant is done through the joystick of the right Oculus command. Throughout the simulation the degree of deafness goes from nonexistent to mild, followed by medium and finally severe deafness. If users wish they can regain any of these degrees of deafness.

Subsequent to the experiment, users were asked to complete a survey with 12 questions that would allow them to evaluate the degree of satisfaction with the different aspects of the simulator.

Table 3: Parameters of the filters applied to the simulator.

<table>
<thead>
<tr>
<th>Degree of deafness</th>
<th>Filter Features</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nonexistent</td>
<td>At.: 0 dB, F_c: 10 kHz</td>
</tr>
<tr>
<td>Mild</td>
<td>At.: 15 dB, F_c: 4 kHz</td>
</tr>
<tr>
<td>Moderate</td>
<td>At.: 30 dB, F_c: 2 kHz</td>
</tr>
<tr>
<td>Severe</td>
<td>At.: 60 dB, F_c: 1.5 kHz</td>
</tr>
</tbody>
</table>
are assessed according to the Likert scale (1 - I totally disagree, 2 - partially disagree, 3 - Neutral, 4 - I agree partially, 5 - I completely agree).

5.2. Results of the questionnaire
The experiment was performed by 9 people, 5 men and 4 women with an average age of 25 years. Each experience took an average duration of 10 minutes.

The question about being dizzy as a consequence of the use of the simulator had ambivalent answers in which about 66% of the users felt some type of malaise/dizziness. Questions regarding the use of virtual reality and ease of use of the commands obtained the full agreement of all users.

Most users believe simulation can help raise awareness of the difficulties associated with presbycusis in noisy environments.

At the end of the questionnaire there was a question regarding the hearing loss of the users themselves and 25% of them believe they have some type of loss although it has not been diagnosed.

5.2.1 Analysis of results
Although the nature of the questionnaire is qualitative, it is possible to conclude some fundamental aspects. In the first place, virtual reality is a decisive factor for a better immersion in a simulation experience that has as main focus the hearing and the sensibility for the loss of it. The spatialization of the fonts is adequate which may encourage the creation of more different geometric models through Blender and consecutive spatialization through the Resonance Audio SDK. Finally, most users fully agree that the simulator can help raise awareness of the difficulties experienced by hearing loss as they age, which is an incentive to get a version of the simulator that can be implemented in schools.

The questionnaire responses generally point to user satisfaction with most aspects of the simulation with exceptions in non-visible sound sources and some discomfort after using the simulator. Some comments include the possible implementation in 'schools / universities and thus raise awareness among young people' as well as 'it was advantageous to have a simulation in a noiseless environment ... to understand what different levels of deafness imply in other situations everyday'. Other comments regarding deafness level say that perceptions of the avatars’ speeches were more noticeable at the level of mild deafness given the background noise in the restaurant.

6. Conclusions
As a final chapter, it is important to summarize the key points of the work developed in the 6.1 section. In section 6.2 some ideas are described that can be developed and that help to improve the simulator and the different aspects associated with it (immersion, spatialization, avatars, deafness, etc).

6.1. Work done
This work aimed at the implementation of a deafness simulator that allows the younger population to become aware of the problem of hearing loss with advancing age, particularly in cocktail party situations. The implementation was done through two softwares, Blender and Unity. In Blender, and with the help of Archipack, the geometric model of space was made to simulate and in Unity all the processing of sound sources and their spatialization through Resonance Audio. Also there were created and introduced in the simulator the humanoid avatars with the help of the UMA.

The original idea of the simulator was to accompany the daily life of an elderly person in various places such as home, cafe, restaurant, church and even on the street. This idea became impracticable due to the workload and the amount of time available to perform the work, however, a virtual reality deafness simulator specifically focused on hearing loss with the advancement of age in cocktail party situations.

The first obstacle of the project was the attempt to adapt the auditory models to the simulator. This task proved to be meaningless since the physiological responses of the auditory system and the functional models simulating them were not necessary within the scope of the project. Although they contribute to a more in-depth knowledge of the auditory system modeling, MAP and CASP had no application in the simulator.

Another of the difficulties found is based on the way in which the degree of deafness of the users was executed. On the one hand, low-pass filters with parameters that fit a typical curve of each degree of deafness are an extremely simple and effective way of making the difficulties encountered by someone suffering from hearing loss perceptible. On the other hand, the lack of sound perception with the worsening degree of deafness comes only from the users and not from the processing done in the sound sources.

Finally, the room where the tests were conducted was not acoustically isolated and Oculus’ head phones did not completely cover the ears, nor did they have ‘noise-cancelling’ technology so any outside noise could have contributed to a negative experience in the simulator. However, the results of the questionnaire were quite encouraging to continue with this type of projects related to the hearing loss of the elderly through the virtual reality that being a relatively new technology, is a way to cap-
tivate young people better.

6.2. Future work
As a section part of this work, I leave here a set of suggestions that can be implemented in the simulator or another similar creation.

As already mentioned, this simulator may be part of a larger project incorporating an entire day of an elderly person suffering from presbycusis. As an example, the user could 'wake up' at home, then go to lunch at a restaurant, go to church in the afternoon, go to a show at night and then return home. This simulation although it may come to increase the immersiveness has a huge cost and time development.

The choice of the use of hearing aids may be added to the simulation. The 3D Tune-In Toolkit tool can be very useful in this regard (at this point a specific tool for Unity is being built but the C++ library is already available) once it has a built-in hearing aid simulation.

Another factor that can be exploited is the incorporation of an element of interactivity between the user and the simulation. Some objective that the user has to fulfill to finish the simulation. This interaction can be a question in the simulator related to the topic of conversation of one of the avatars in which the user would respond through the commands of the Oculus or using automatic speech recognition.

Regardless of the development of a day in the everyday life of an elderly person, the creation of different geometric models with antagonistic acoustic characteristics is always something to consider. If the geometric models are based on actual sites a test can be made with a sound level meter in order to test if the background noise corresponds to what is represented in the simulator.

The creation of humanoid root avatar models has many advantages. They can incorporate specific animations and provide greater coherence between the virtual environment, the context in which it is inserted and the avatar's own speech. The only negative aspect is the amount of time available in implementing the avatar(s) particularly in noisy situations where the number of avatars required becomes high.

Still in relation to the avatars, in addition to the body animations, another aspect to consider is the synchronization of the lips in relation to the dialogue produced by the avatars.

The last consideration for the simulator concerns the fact that presbycusis is only one of several types of deafness that has been explored. There are other types of deafness that affect different age groups than this one and all of them can be included in a simulation scope. Presbycusis can also be explored in another strand different from cocktail parties in order to characterize the condition in various dimensions.

References