Effects of Room Acoustics on Players' Perceptions in Audio Games

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A thesis submitted in partial fulfillment of the requirements for the degree of

BSc OF AUDIOVISUAL SYSTEMS ENGINEERING

at the
CSIS - UNIVERSITY OF LIMERICK
ETSETB - UNIVERSITAT POLITÈCNICA DE CATALUNYA

2017
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Summary

In recent times, the evolution of video games has made possible the improvement of their visual contents in order to recreate reality as accurate as possible. Nevertheless, audio contents have not followed the same path, even though it has been proved its importance in a full immersive experience (Lokki and Gröhn 2005).

Aural characteristics and room acoustics play an important role in recreating a real environment (Larsson et al 2001; Gonot et al 2006; Podkosova et al 2016), leading to a full immersive experience. Because of that, the main question to answer in this project is the importance of room acoustics for a full immersive experience of the player. Developing a game, this project works with different types of room acoustics and spaces to evaluate the player’s reactions towards them. Additionally, different audio sources are used in order to create a sense of space location to the player, whose usefulness is evaluated.
Acknowledgements

First of all, I would like to thank my supervisor, Dr. Kerry Hagan, for being helpful and involved in the project all the time. I have been through a lot of changes and frustration with the technology used - thank you for reminding me to not get stuck in a prototype that it is not going to work as I expected.

Second, I would like to thank my home University, the Universitat Politènica de Catalunya, for giving me the opportunity of coming to the University of Limerick to finish my Bachelor studies. Moreover, I would also like to show my gratitude to the University of Limerick for giving me the material and space I needed to develop my project.

Finally, I would like to say thank you to my parents for also giving me this opportunity. I appreciate their effort for me moving to Limerick and finish my studies here.
1. **Introduction**

Recently, Video Games are a very important part of people's lives. They are not just used to entertain the population. Learning through Video Games has been acquiring force and it is developing its potential, especially in portable platforms. Nevertheless, the majority of these efforts and developments have been put together for evolving the visual content of these audiovisual creations. On the other hand, Audio content is not used as a tool to develop a game, only for immersive and additional purposes, such as embellishment of the game.

3D Audio technology is lately being developed for navigational purposes. Spatializing audio sources opens a new range of possibilities in different areas, such as Game Design. If the player can locate a sound on the game playable area, that might lead to a new manner of understanding game mechanics. A new human sense - hearing - is acquired to obtain information about the game - not only to embellish the scene.

On the other hand, Room Acoustics also play a very important role in recreating a realistic environment for the player. Game Developers’ interest is not set on this type of sound acoustics evolution, even though they probably make an impact on the player’s immersion. This project attempts to understand how important Room Acoustics are in an Audio Game, where the targets to achieve are stereo spatialised audio sources. Furthermore, this project aims to encourage the creation of new games where audio plays a role as important as visual content. Finding a balance between both - audio and visual content - can make a change in the industry and engage players.
2. Research

2.1. Audio Games and Room Acoustics

Nowadays, Audio Games are increasing their popularity among the general public. This type of game, first thought as games for the visually impaired people, is also enjoyable and playable for the sighted population. Audio Games are based on the mental representation of the environment via sound localisation. Using audio tokens for objects and important features in the game, the player can create a mental map to move around and localise themselves in the virtual environment.

A lot of research has been done in terms of how the brain reacts to the total loss of one sense. This effect, called neuroplasticity, explains how the compensation of one sense can enhance the abilities of another sense. Furthermore, this enhancement can be improved by training. As an example, virtual environments have been used to train visually impaired people in terms of navigation and adaptation to the situation and environment (Bălan et al. 2014).

The amount of Audio Games are still few comparing to the Video Games' catalogue. In addition, their quality cannot be compared, as there has been less development in techniques, software and hardware for audio in games. This gap is due to the difference of resources that audio in games need. Nevertheless, it has been proved that games do not necessarily rely only on visuals, as Audio Games can have the same purpose to entertain and challenge the player.

Audio Games rely on two types of sounds: verbal and non-verbal. Verbal sounds provide information and instructions to the player, which is useful to explain the game and even interact with the user. Different games have been developed using verbal sounds, i.e. Grizzly Gulch Western Extravaganza™. This game bases the decisions of the player as questions to be replied by the user. On the other side, there are not as many Audio Games that only use non-verbal sounds, i.e., The Towers of Hanoi. It is difficult to find games that do not rely on proper information such as visuals, text or instructions. There is still a long path to follow to make the most of non-verbal sounds in games (Targett and Fernström 2003).

Room Acoustics play an important role in Audio Games. Mainly, they improve the player's immersion and, in addition, enhance the localisation of audio objects. Some research has proved that enhancing the audio spatialisation improves the player's navigational tasks in the game. Nevertheless, there is still a long path to follow to obtain better conclusions in that matter. This navigational research has been carried out using sounds called beacons¹.

¹ Sound sources that represent objects, created to find them in a 3D audio space.
beacons are used: contextualised (taking into account the room acoustics) and decontextualised (where the sound source is listened as a direct source). With these two types of beacons, a difference between including room acoustics or not can be analysed. It has been shown that room acoustics make an impact in the player’s experience. However, the experiments could not obtain a conclusive answer on how important room acoustics are for navigation purposes. Even so, the experiments were based on finding the beacons as soon as possible, and that could have been a handicap for the players, trying to rush the game objective as much as possible. That is the reason why, in this project, no time pressure is established. This project has been thought as a game, not as a navigational task, so the objectives and roles are very different, with the purpose of entertaining the player. Consequently, as the objective and rules for the player have changed, this new perspective could lead to conclusive results (Gonot et al. 2006).

2.2. Acoustics

2.2.1. Reverberation

Reverberation is a technique used to obtain audio signals from an Impulse Response (IR) and an anechoic audio message. The audio message is listened as if it had been recorded in the room, which corresponds to the IR audio. Impulse Responses can be obtained by recording or by simulation. Specifically, reverberation is the process of convolving both recordings to obtain the audio message or song listened from the room that belongs to the Impulse Response (Carrión 2016).

![Summary of the process of reverberation](Carrión 2016)
The Impulse Response is key in the process of reverberation. It is used to obtain the transfer function that permits to emulate the acoustic response of a room. The Impulse Response is independent from the audio message or music audio played in the space. In Figure 2 this process can be observed through the different waveforms (Carrión 2016).

![Figure 2. Waveforms of recordings during the before and after reverberation process.](image)

2.2.2. **Sound Localisation**

Sound localisation is the ability to identify the location of a sound in the 3D space. People can localise sounds in the auditory space by hearing sources directly in front of them or, less accurately, to their sides and behind their heads. When humans listen to a sound, different binaural cues are created depending on their location and, consequently, the emitting object can be located in the 3D space (Holzmann 2007).

Binaural cues are the location cues which are based on the comparison of left and right ear signals. There are thee primary ones:

- Interaural Time Difference (ITD)
- Interaural Level Difference (ILD)
- Head-Related Transfer Function (HRTF)

Interaural Time Difference (ITD) is the difference of times the sound reach the two ears. If the distance is the same, this measure equals to zero as there is no difference between ears. As we can observe in the left Figure 3, the waveform that corresponds to the right ear records sound before the left one, as the sound source is closer to the right ear. The maximum ITD difference occurs when the sound source is at 90 degrees from the front vision, as observed in the right Figure 3 (Holzmann 2007; Carrión 2016).
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Figure 3. Interaural Time Difference. Overview (left) and ITD measures (right) (Sun et al, 2015; Module Psychology 3203, 2005).

Interaural Level Difference (ILD) is the difference of sound pressure level (amplitude of the waveform) that reaches each ear. There are reductions in the farthest ear due to an acoustic shadow produced by our own head. Left image in Figure 4 shows the resulting waveform due to the acoustic shadow.

Low frequencies are the least attenuated because they resemble to an omnidirectional source. High frequencies, though, suffer these reductions as they propagate directionally. The right image in Figure 4 sums it up graphically. As we can observe, the ILD measure’s changes for low frequencies is minimum. On the other hand, the higher the frequency, the higher the ILD difference - which is also more or less pronounced depending on the angle between the source and the listener (Holzmann 2007; Carrión 2016).

Figure 4. Interaural Level Difference. Overview (left) and ILD measures (right) (Sun et al, 2015; Feilding, 2017).
The Head-Related Transfer Function (HRTF) is a transfer function that characterises how ears receive a sound from a source in the 3D space. The HRTF from each ear can be synthesised to obtain a binaural sound coming from a certain point in the 3D space. This mechanism varies between different listeners, as their heads and ear shapes are different. The HRTF transfer function explains the changes that the diffraction and reflection of the head, external ears and torso apply to the sound that the user listens to.

Head-Related Transfer Functions are measured in anechoic chambers to minimise the influence of reflections and reverberation, and one microphone per ear is placed on a dummy head. The transfer function is measured with small increments of the source angle (between 15 and 30 degrees), resulting a graph from each ear, as observed in Figure 5 (Holzmann 2007; Carrión 2016).

The cocktail party effect enables the listener to focus his or her auditory attention on a particular stimulus and filter other background sounds, considering them as noise. This effect enhances the localisation of sources. Nevertheless, not all people develop this ability and, additionally, there are some subjects that can even acknowledge the background conversations and reply when they are called - even though they were not paying attention to the background conversations. It should be noted that this ability would help in finding audio sources but it is not mandatory to have it developed (Conway et al 2001).

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2 Head-shaped figure used to record binaural audios. Microphones are placed in each ‘ear’ so it resembles human hearing.
2.2.3. **Room Acoustics Concepts**

In this section, basic concepts in the study of room acoustics are explained. When a room is characterised, different parameters have to be taken into account - materials, objects, geometry and air absorption are the most important ones.

Materials determine how dry or wet the room acoustics are, which can be measured by the Reverberation Time (RT) and the Early Decay Time (EDT). When studying concert hall’s acoustics, other specific parameters can be measured to determine the acoustic quality of the hall. Material properties of the room - the most important one being the absorption rate - can drastically change a room’s performance. For example, concrete walls create a very reverberated room, whereas carpet walls create a very dry room, as the absorption rate of the material is very high (Carrión 1998).

Objects in the room also influence in the absorption of the room. Depending on the materials, they increase or decrease the absorption rate of the room. That is why a well chosen group of furniture can help when designing room acoustics - and can even eliminate echo (Carrión 1998).

Geometry of the room is also key in order to avoid acoustic problems such as echo. Echo reverberation appears when walls are parallel to each other and their material is very reverberant. It is important to avoid those premises in order to avoid echo in rooms. Moreover, if the geometry of the space is complex, the reverberation tends to increment (Carrión 1998).

Air absorption only affects big spaces for high frequencies - more than 2 kHz - and with small percentages of relative humidity. The air absorption, depending on the humidity and the frequency, can be observed in Figure 6 (Carrión 1998).

![Figure 6. Attenuation of sound depending on frequency and relative humidity (Eargle and Foreman 2002).](image-url)
As explained before, two important measures of a room’s acoustic performance are the Reverberation Time (RT) and the Early Decay Time (EDT). A correct RT assures a comfortable reverberation and good intelligibility of a message. If the room is not acoustically treated, the reverberation camp can be too wide and the direct sound too small. Consequently, two people would struggle to understand each other, creating the need to raise the voice to be understood (left image in Figure 7). On the other hand, if the room is acoustically treated, the direct sound area is bigger and there would be no communication problems (Carrión 1998).

The Early Decay Time (EDT) is defined as six times the time that occurs since the source stops emitting until the pressure sound level diminishes 10 dB. The EDT varies depending on the frequency measured. In the hypothetical case of perfect diffusion of sound in the room, the EDT and RT decay curve would coincide - corresponding to an exponential evolution, which means a straight line in semilogarithmic scale. In reality, the decay curve presents two different slopes because of that lack of perfect diffusion. The relation between EDT and RT can be observed in Figure 8 (Carrión 1998).
2.2.4. Temporal Evolution of Sound in a Room

When a sound is emitted in a closed environment, walls and materials of the space produce reflections which arrive to the listener. In an open environment, though, the only sound that the user listens to is the direct sound emitted by the source, as there are no surfaces where it could be reflected.

These room reflections can be divided in two different groups - the early reflections, which are the first reflections within approximately 100 ms since the direct sound starts its propagation; and the late reflections, which are all the reflections from 100 ms until the sound dies. Late reflections have less energy as the sound level diminishes until it fades away. Figure 9 corresponds to the propagation of direct sound, early reflections and late reflections. As it can be observed in the echogram, the first ray corresponds to the direct sound; the rays within the first 100 ms to the early reflections and the rest to the late reflections, showing a descending pattern (Carrión 1998).

Figure 9. Echogram of a room (Carrión 1998).
2.2.5. **Perception of Early Reflections. Echo**

Early reflections tend to create echo environments, as they are powerful enough to be listened as the direct sound. In concert hall’s acoustics, early reflections should be diminished as much as possible, tending to the ideal of not having early reflections. Early reflections are very dangerous because if they arrive to the listener 50 ms after the direct source ray, the human ear is not capable of assimilate them as one sound and, therefore, echo appears. Echo creates a counterproductive effect in terms of intelligibility of an oral message (Carrión 1998).

![Figure 10. Scheme on how echo appears (Carrión 1998).](image)

2.3. **Reverb**

Digital reverberators have been used to recreate the reverberation of spaces in digital recordings. Consequently, the recreation of an environment can be settled without the need of recording the audio in the space desired. Digital reverberators make use of signal processing algorithms to create a reverb effect.

Simple techniques include applying several delay circuits - regenerative delay lines - to create a decay series of echoes. The most basic technique is shown in Figure 11.
Besides these simple techniques, more advanced digital reverb generators are used. This type also stimulate time and frequency domain response of a room, taking into account space and surface parameters such as room dimensions, absorption, among others. To create a convincing reverb, it is important to create a high degree of complexity and irregularity in the pattern and timing of delays in order to simulate reflective surfaces. In addition, most processors have a variety of filtering and equalisation options, so the approximation of frequency-dependent effects of various surfaces is possible (Fredrics 2009).

Finally, convolution reverb is also a very powerful tool inside the recreation of room acoustics. As explained in more detail in the chapter of Reverberation, this method consists in the convolution between the impulse response of the space - which can be from real recordings or generated digitally via software modelling such as CATT - and the audio desired to be reproduced in the room.

In order to recreate the acoustic characteristics of a space as naturally as possible, several parameters should be taken into account. Those are summed up in the following table.

<table>
<thead>
<tr>
<th>Reverb Parameters</th>
<th>Description / Observations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Room Size</td>
<td>Larger room sizes normally correlate to longer reverb times and a wider stereo image.</td>
</tr>
<tr>
<td>Early Reflections</td>
<td>Sets the level of the first group of sound repetitions. They tend to be more defined and sound more like ‘echo’ if they are too powerful.</td>
</tr>
<tr>
<td>Pre-delay</td>
<td>Amount of time it taked for a sound to leave its sound source and create a first reflection. Increasing this value creates a bigger room.</td>
</tr>
</tbody>
</table>
Table 1. Parameters commonly used to create and modify reverb (Cooper 2011).

<table>
<thead>
<tr>
<th>Reverb Parameters</th>
<th>Description / Observations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Decay Time</td>
<td>Determines how many time it takes for the reflections in the room lose all their energy. Small rooms do not have a long decay.</td>
</tr>
<tr>
<td>Damping</td>
<td>Sets the relative rate of reverb decay among high and low frequencies. Add damping for a warmer room sound.</td>
</tr>
<tr>
<td>High-frequency Attenuation</td>
<td>Attenuating high frequencies makes the sound being less metallic.</td>
</tr>
<tr>
<td>Low-frequency Attenuation</td>
<td>Attenuating low frequencies prevents a muddy sound, helping a better understanding of the audio message.</td>
</tr>
<tr>
<td>Width</td>
<td>Some reverbs allow expanding the stereo image.</td>
</tr>
<tr>
<td>Early Reflections Diffusion</td>
<td>Increasing the early reflections diffusion thickens the sound. Reducing diffusion creates more discrete sounds.</td>
</tr>
<tr>
<td>High-frequency Decay</td>
<td>A long high frequency decay can give a brighter and more ethereal reverb.</td>
</tr>
<tr>
<td>Low-frequency Decay</td>
<td>A long low frequency decay gives the impression of a bigger and larger space. If the decay is too long, the sound ends up being too sloppy.</td>
</tr>
<tr>
<td>Crossover Frequency</td>
<td>This parameter sets up the dividing point between the high and low frequencies.</td>
</tr>
</tbody>
</table>

2.5. Game Design

Nowadays, the Video Games’ market is a pretty important asset inside the Entertainment's business area. Concurrently to the the increasing amount of platforms we can find, the options and types of games available are also increasing. There are games for all types of people - depending on their age, the platform that they use, when they play and their interests.
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Since the creation of Video Games, all these changes and the expansion of types of games have developed to create different Genres and Game Mechanics.

Genre types are quite well-known nowadays, including Arcade, Platform, Shooter, Adventure, Strategy, Role-Playing, Beat them up, Puzzles, Action, Sports and Driving. However, the Game Mechanics concept is not widely known and it is important to take it into account while creating a video game. The different types of game mechanics can be used in any genre, even though there are some mechanics which fit more for one genre than another. Choosing the right game mechanic is key for the success of a video game, as its enjoyability is mostly bounded to the mechanic of the game and the originality/plot (Perotti 2016).

Consequently, it is very important to choose and develop game mechanics that entertain the player. This target can be reached by (1) encouraging the players' curiosity and surprising them, (2) creating a challenge for their abilities, and (3) rewarding the players depending on their actions. That is why it is necessary to choose the mechanics according to the player’s characteristics (Perotti 2016).

Mechanism types are created by choosing different parameters of the game and the interaction between the player and the environment. The most important features are the following (Perotti 2016):

- Game Areas: defining positions of the player, the objects of the game and limits of the game space.
- Game Objects: specifying their type (enemy, vehicle, …), attributes and status (values of the different attributes).
- Game Actions: containing the types of interactions between the player and the environment - simple actions such as run, jump and shoot or combined actions, where different actions and objects are needed.
- Abilities: including the capacities and experience asked to the player in order to success in the game. There are three main categories: physical abilities, cognitive abilities and social abilities.

To conclude, all these concepts are important for the project in order to create Game Mechanics which are enjoyable for an Audio Game. As all the information is sent via the auditory sense, the game should not be very fast-response; the player needs more time to process than when playing visuals. Furthermore, auditory objects are very important to let the player navigate around the game locations and collect objects.
3. Game Design and Development

This audio game has been designed to be an enjoyable manner of noticing the importance of room acoustics in the Game Development area and the better immersion that the player feels.

In the following chapters, the design of the game from scratch is explained and illustrated. During this process, the main objective has always been taken into account for a successful testing.

3.1. Game Type and Characteristics

The idea of the game has been centred in the importance of room acoustics for the player's experience. Consequently, the game is not focused on challenging the player or giving different rewards thorough the game; it tries to make the player enjoy of the journey ahead, with the only purpose of following a path and find the exit.

Nevertheless, a lot of changes in the categorisation of games has been held lately. The game type genre has widen since it was created. Challenge and reward have always been the most powerful tool for game design, as these two methods encourage and engage the player (Wang and Sun 2012).

Even though challenge and reward are still the most common patterns to design video games, the concept of gaming has also broadened its horizons. Creation, Exploration, Discovery, Difficulty, Competition, Danger, Captivation, Sensation, Sympathy, Simulation, Fantasy, Camaraderie and Subversion are nowadays explored for the creation of new video games, and considered as a genre. A video game just based on the discovery of the environment is possible and considered as a game. For example, there are also video games that require a feeling of anger or frustration while playing, and that is their purpose. This type of player reactions towards the game were not accepted for games some time ago, leading to think that the game was badly designed (Korhonen et al 2009).

In this project, this wider idea of the game genre is explored and encouraged. There are some games on the market of these characteristics, but more focused on a visual experience for the player. The most famous one is Journey, an audiovisual and pleasant journey through different surroundings, with a very open story that the user can interpret differently. This project's idea has the same concept but being audio the most important feature on it.
3.2. Game Script

As exposed in the previous chapter, the game is based on different aural targets that creates a path for the player to follow. The path creates an auditory immersive experience that, besides engaging the player, creates a sensory adventure just using the hearing sense. The player has to train a new skill to navigate through different environments, as he or she depends only on the hearing.

The Audio Game does not include a proper storyline or information background. Only by reaching targets, the game is engaging enough to stand by itself. Moreover, different types of parameters are applied to recreate different rooms and environments, obtaining a more realistic experience.

In particular, the player starts the game in a dry room. From this initial room, a voice of a man saying ‘Hey you, yeah you, come here’ can be heard from the adjacent space. Once reached the target, the player starts listening to some bells coming from the next room, a corridor to the church. Inside the corridor, the output sound is echoed and with a high wet gain parameter value, resembling a long and empty hallway. At the end of the hall, the player arrives to a big space, where an organ is playing. The room is designed to resemble a church, with a very wet and echoed sound. Finally, when the player achieves the target - the organ playing -, it stops playing a new sound comes from the previous entrance. The new sounds - some keys opening a door, some claps on a table and a game-style beeping sound - opens a way back to the initial room. Once there, a new door has been unlocked and the player can go towards a corridor, which leads to a mountainous path where a clapping sound source is playing. This new path is an outside road, meaning that no reverb is applied as only the direct sound hits the player. At the end of the way, the player arrives to a cave, where a new clapping source is playing but, in this case, the sound that the player receives is very echoed and wet. When the player arrives to the end of the cave, the end of the game is achieved.

In Figure 12, the map previously explained can be observed. Furthermore, in Figure 13, the audio sources are located.
3.3. Materials

The final prototype – third prototype - does not require many physical materials. Besides the software that the game is created on – Unity 5 -, the physical objects needed are a controller and stereo headphones.

In order to increase the playability of the game, the control of the player relies on a PS3 controller. The left joystick corresponds to the movement around the game area; the right joystick lets the player move the head and body of the character, an important feature to locate sources; finally, pressing the X button makes the character jump.

Finally, the audio output can be played with a pair of stereo headphones, as the audio output is spatialised by using stereo panning technique, defined by the following cite.
"Panning is the distribution of a sound signal (either monaural or stereophonic pairs) into a new stereo or multi-channel sound field determined by a pan control setting." (Wikipedia 2017).

3.4. **First Prototype: Convolution of Impulse Responses**

In the first prototype, the reverberation of different locations with a Pure Data patch is used and combined with a Unity3D Virtual Environment. This connection between both softwares is carried out with the package *libpd4unity*, which creates a wrapper to use LibPD inside Unity's audio engine. As a consequence, Pure Data patches can be called from C# scripts used in Unity. In the following paragraphs, the reverberation patch and the creation of the environment is fully explained.

First of all, with Unity3D, a small environment has been set up. Visuals are included to know the location of objects and walls easily - in the Audio Game, none of these visual structures are shown. That is why the environments are just box rooms with different shapes. There is also a mountainous outside area and a cave.

![Figure 14. Environment of the prototype game.](image)

As shown in Figure 14, the environment is composed by:
- Two small rooms.
- Two corridors. They will have a very echoed sound.
- An outdoor area (mountainous path).
- One big room. It will simulate the sound in a church.
- One cavernous path.

Finally, a First Person Controller has been added to the scene in order to move around the game and interact with the environment. Some views of the gameplay are shown in Figure 15.
On the other hand, the audio of the game is created convolving Impulse Responses of different spaces with sounds of the game in order to listen to realistic environments. The patch used is called convolve.

As we can observe in Figure 16, the convolve patch analyses different impulse responses and convolves them with an audio file, ideally recorded in an anechoic chamber. Moreover,
as it convolves in real-time, a microphone can also be used for the user to speak ‘inside the game’.

This patch has to be edited in order to work within the Unity3D environment. It is necessary to add send and receive objects in order to establish the connection Unity - PD patch.

Nevertheless, before starting with the edition of the patch, the connection between Unity and Pure Data has to be established. First of all, a connection between Unity 5 and Pd has been tried to settle, although with no success as libpd4unity is not further updated. For that reason, the project has been set up in Unity 4.

Libpd4unity, as said previously, works with Unity 4.x pro and free versions. Adding the document LibPdFilterRead.cs to the main camera, this script opens the Pd software and runs the chosen patch from ProjectFolder/Assets/StreamingAssets/PdAssets.

Once all the environment was set up, the game experimented some clicking during its testing. After 30 seconds playing the game, the audio starts clicking no matter where you are located – until the Unity crashes. After some time of debugging and trying to solve the problem, we concluded that the main issue is from Unity's buffers. The buffer is not emptying fast enough so the environment looses data, creating the clicking and, eventually, crashing the game.

Considering that the software is not updated and that quite a lot of time was being spent in fixing the clicking matter, a second different prototype was developed. The next chapter explains the changes and software used for the Second Prototype.

### 3.5. Second Prototype: Application of reverb in audio

In the second prototype, a reverb mixer is used to apply the desired room reverberation to an audio recording. This reverb mixer uses different parameters - such as wet gain, dry gain and feedback - to recreate the desired environments.

First of all, it is needed a connection between Unity and Pure Data that does not produce clicking, so libpd4unity has been discarded. Afterwards, updating the software back to Unity 5, a LibPD wrapper called Heavy is used for the prototype. This new type of connection between both softwares prevent the clicking in the output audio. Moreover, as the software is updated, real-time support is available.

Heavy creates a plugin from the patches you want to use in your game. This plugin acts as a wrapper, which establishes a connection between Unity scripting and Pure Data patches. Nevertheless, Heavy only supports some Pure Data objects\(^3\), and that is the main reason why it has been discarded the use of the convolve patch. As an alternative, Heavy has a

\(^3\) full list can be found: [https://enzienaudio.com/docs/pdobjects.html](https://enzienaudio.com/docs/pdobjects.html)
library available - called heavylib (Enzien Audio 2016) - that includes a reverb patch that is accepted on Heavy. This patch, as explained previously, plays with parameters such as wet gain, dry gain, feedback and frequency cut-offs. Comparing to the convolve patch, this new method creates less realistic audio environments, as it does not use real impulse responses.

Once the plugin is created - the plugin has to be created every time there is a change in the Pure Data patch -, it should be installed into the Unity project. Finally, as the connection is set up, patch parameters can be controlled from C# scripting inside the different rooms if the plugin is added to each Game Object. As an advantage, this method allows more than one source playing at the same time, enhancing the performance and opening the playability and game techniques.

In order to make the parameters and patch events visible, send and receive objects have to be added to the Pure Data patch. For example, \[ r \text{wetgain} @\text{hv_param} 0 1 0.5 \] will show the parameter wetgain on Unity, with a minimum value of 0, a maximum value of 1, and a default value of 0.5. The same idea is applied to sending events and parameters back to the Pure Data patch. The patch used for the project can be observed in Figure 17.

![Figure 17. Heavylib reverb patch modified for Unity prototype (Enzien Audio 2016).](image)

The game keeps the same structure as in the first prototype, with the same type of rooms: one church, two corridors, two dry-sound rooms, one mountainous path and a cave. As in the first prototype, a PS3 controller is used to move the first person player around.
Even though the clicking has disappeared, the naturalness of the room environment is not as good as in the previous prototype. That is the main reason why it has been decided to find another alternative to the previous two prototypes. In the next chapter the third and definitive prototype is explained thoroughly.

3.6. Third Prototype. Application of Unity’s Audio Mixers

Due to the drop of naturalness experimented in the second prototype, a third idea has been implemented in order to obtain better results. Specifically, in spite of finding a connection between a Pure Data patch and Unity 3D, a quite new set of 3D Unity Audio Mixers has been tested.

Lately, Unity has been improving their audio settings, including 3D spatialisation and stereo panning. Additionally, with the audio mixers they have developed, a lot of new features can be implemented. For this project, the Audio Mixer ‘spatializer reverb’ has been used. This mixer applies the same technique as the convolve patch from the first prototype - it uses the convolution of an impulse response. However, real impulse responses are not used - they are generated by different parameters, such as wet gain, dry gain, feedback, resonance, volume, among others. Moreover, an echo plugin is added to add more effect in the Church, Corridor and Cave environments.
Each Audio Source includes the desired mixer - spatializer reverb -, even though it is a common for all of them. That is the reason why the parameters have to be changed by C# scripting. The whole project has been programmed with colliders - when the player hits the collider, the sound parameters change to coincide with the acoustic of the desired room. That way, the change of parameters is pretty natural and goes along with the movement of the player.

As shown in Figure 20, the audio generated is propagated as a sphere. Inside this sphere, the volume decay curve can be customised to obtain the desired volume and effect on the room. Nevertheless, this sphere is spatialised with stereo panning, leading to no apparent difference between being in front or back the source. Moreover, as the sound propagates as an sphere, the volume is equal on the same radial difference at any point of the propagation area. Finally, this technique does not apply occlusion from the geometry of the space - it does not cover sound when there is a wall between the player and the source.

Figure 19. Parameters and Characteristics of the ‘Spatializer Reverb’ Audio Mixer.
To conclude, the third prototype has been chosen to be tested with four case studies, explained in Chapter 4. The main reasons to choose the Unity Audio Mixers are that (1) the audio output is easier to control as everything is within Unity, (2) the sound is more natural than in the second prototype and echo can be applied, and (3) the stereo panning and spatialisation lead to a better prototype even though there is no sound occlusion and not HRTF filtered (back and front differentiated). Even though HRTF would improve the performance and playability of the audio game, the technology used for the prototype only allows stereo output audio. Nevertheless, the result is quite accurate and the location of sources is possible.
4. Testing

4.1. Description and Parameters Evaluated

The prototype chosen to be tested is the third prototype - using Unity’s audio mixers - as it shows the best trade-off between realism and spatialisation among the other designs. However, the objective of this project is to evaluate the importance of Room Acoustics in Audio Games. In order to obtain a comparison, the game is tested with and without reverb, each version to different subjects. That way, the performance applying Room Acoustics or not can be observed.

Two different types of parameters are evaluated in the experiment. First of all, a more quantitative area is studied, where the impact of the reverberation on the players' performance is evaluated. On the other hand, a qualitative study has also been carried out, focused on how the player feels, and his or her impression of the game.

On the quantitative study part, the time and path followed are evaluated. The path followed by the player is key in his or her overall performance, and it determines how well the user understands the locations and dimensions of the different rooms.

On the other hand, the qualitative study attempts to understand the player's reactions towards the game. First of all, a small questionnaire about their perceptions through the game is asked once the game is tested. Furthermore, a drawing of the mental map is asked to the user in order to compare with the real one. Consequently, it can be analysed how the room acoustics play a role in the user's performance and their perception of the environment.

The study is composed by four case studies - two of them playing the with-reverb game, and the other two playing the non-reverb game. Furthermore, in order to analyse if the performance of the player is influenced by their gaming experience, one subject of each group is a very occasional player.

Finally, it should be clear that the exposed study does not lead to conclusive results, as only four subjects have been tested. Nevertheless, the results shown in the next chapter are the methodology proposed to do a more extensive testing and be able to extract conclusions.
4.2. Results and Discussion

As said in the previous chapter, the study is composed by four case studies. The results include an interview per subject, with the following questions.

1) What is your playing experience?
2) Do you find this type of game (only-audio) interesting?
3) Positive aspects about it? Do you think that the experience can be improved in any way?
4) Do you feel that the games played previous to the proper game have helped you in any way? If so, why?
5) How many rooms have you noticed thorough the game?
6) How would you describe the different rooms you remember? If they were big, small, echoed, even which type of room do you think they resemble.
7) How have you felt while playing the game? Do you think it is entertaining?
8) If these type of games were commercialised, would you recommend them?
9) Thank you for your answers. To finish, could you please draw the room map you think you have been through the game? As accurate as you remember.

Moreover, the path followed by the subjects has been recorded in order to extract the time spent playing and the time spent to find the next room. Finally, other information such as the amount of times that the subject needed assistance during the test has also been kept. All the results and the transcription of the interview can be checked in the Appendix Chapter. The recordings are also attached as media support, along with the code of each prototype and the application of the final game.

Case Studies

The first subject (Case Study 1) has tested the with-reverb prototype. The tester has a strong gaming background, more frequent when younger. The subject has played the demos created to learn how the controller works and how the stereo panning works without adding reverberation.

The second subject (Case Study 2) has tested the non-reverb prototype. The player has a extended gaming background since very young, specifically in PC platform. Both demos have been played by the tester.

The third subject (Case Study 3) has tested the non-reverb prototype. The tester does not have any experience playing. Both demos have been played by the player.

Finally, the fourth subject (Case Study 4) has tested the with-reverb prototype. The tester does not have any experience playing. Both demos have been played by the player.
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Duration of the Game Experience

The amount of time spent by the subject playing the prototype is an essential parameter to take into account, as it is very related to the grade of difficulty experienced by the subject. As we can observe in Graph 1, subjects 1 and 3 have taken less time to complete the task. Nevertheless, subject 1 played the with-reverb version of the game; subject 3 the non-reverb version. Consequently, this parameter does not indicate that using room acoustics improve or not the performance of the player.

On the other hand, subject 1 has trained skills in spatialised audio hearing. That could be an indicative of why the first tester was the fastest to finish the game. Despite that, subject 3 does not have any background in audio and music technologies and, without training, the game is more complicate to finish. More tests should be run in order to find a pattern and obtain a definitive conclusion in this area.

<table>
<thead>
<tr>
<th>Total Time Spent (min)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Case Study 1</td>
<td>8.75</td>
</tr>
<tr>
<td>Case Study 2</td>
<td>13.7</td>
</tr>
<tr>
<td>Case Study 3</td>
<td>9.32</td>
</tr>
<tr>
<td>Case Study 4</td>
<td>12.4</td>
</tr>
</tbody>
</table>

Graph 1. Total time spent playing the prototype by each subject in minutes.

Time spent to change rooms

Another important factor to consider to evaluate the player’s performance is the amount of time spent to change from one room to the next one. Evaluating these measurements, the hardest spots for the user’s performance can be detected.

Graphs 2, 3, 4 and 5 show the percentage of time spent at each room from the total playing time of each player. As we can observe in them, the first subject has a quite equitable division of the time spent at each room. Besides, the second subject spent more time coming back from the Church to the Hallway to Room 2 and in the Cave than in other parts of the game. It is notable that subjects 3 and 4 - with no previous gaming experience - took more time than the average in different points. The third subject spent a 40% of the time from the Hallway to the Church; the fourth subject spent more time than the average
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at the last part of the game (Hallway to Cave and the Cave). This might indicate that subjects with playing experience are less prone to get stuck at some parts of the game. However, more tests have to be done in order to assure this conclusion.

Graph 2. Time spent by subject 1 to find the next room (%).
Graph 3. Time spent by subject 2 to find the next room (%).

Graph 4. Time spent by subject 3 to find the next room (%).
Graph 5. Time spent by subject 4 to find the next room (%).

Graph 6. Comparison of time (in seconds) between all subjects.
Finally, Graph 6 shows a comparison of the amount of time, in seconds, spent by each player from one room to the following one. As we can observe, the third subject found the path from the Hallway to the Church specially difficult. Moreover, the second subject found the journey from the Church to the Hallway and the road from the Room 2 to the Initial Room harder than the other subjects. Besides that, it can be seen that the fourth subject took more time than the average from the Initial Room to the Hallway and from the Hallway to the Cave. Finally, it is also noticeable that the second and fourth subjects spent a lot of time in the Cave, trying to find the exit. As each subject - second and fourth - have played two different versions of the game, no hypothesis can be extracted from that matter. Furthermore, every subject has had difficulties at different points of the game; that leads to think that there is no specifically difficult part of the game; it depends on the subject.

**Number of times the subject needed assistance while playing**

During the testings, all subjects had difficulties while playing, in general because of the lack of sound occlusion of the prototype. All audio sources were not masked by walls and surfaces, creating a problem to distinguish whether there is a wall or not. Consequently, that created confusion for the subjects at some points of the game. Nevertheless, the game was still completely playable and all subjects successfully completed it. However, if the player was stuck for quite some time, a small clue was given in order for them to proceed playing. In Graph 7, the amount of times that the subject needed assistance is shown. As it can be observed, the second subject needed three times more help than the other three testers. Nevertheless, no conclusions could be extracted as, for example, the third subject does not have any background in playing or audio technologies, and he or she still only needs one tip to finish the game.

The assistance provided to the player consists on small verbal clues such as ‘There is a wall in front of you’ or ‘Move a bit around’. Specifically, all subjects needed assistance at very different points of the game - the first subject was stuck on a wall between the Initial Room and the Room 2; the second subject, stuck on walls at the Hallway to the Church, leaving the Church, between the Initial Room and Room 2, and the Cave; the third subject, finding the path at the Hallway to the Church; finally, the fourth subject, finding the exit at the Cave.
Graph 7. Number of Times the subjects needed assistance during the game.

Information compiled from personal interviews

As mentioned above, the most important information extracted from the testings are the interviews. As the project attempts to understand the importance of Room Acoustics for the player’s experience, the opinion of them is vital for the experiment. In Table 2, a summary of the subjects’ thoughts and ideas is included. Table 2 is extracted from the interviews shown at the Appendix. The map drawings are shown in a bigger size at the Appendix.

<table>
<thead>
<tr>
<th>Case Study 1</th>
<th>Opinion and experience with the game</th>
<th>Positive aspects</th>
<th>Improvements</th>
<th>Number of Rooms in the game</th>
<th>Drawing of the game map</th>
</tr>
</thead>
</table>
|                                       | - Felt lost but intrigued while playing.  
- Interesting idea.                     | - New kind of feeling.  
- More difficulty than other games.       | - Sound tips when you are lost in the game.         
- Skip the up and down vision joystick movement. 
- Notice when the source is in front of you or behind you (apply HRTF). | 7 or 8                                       | ![Case Study 1 Map] |
| Case Study 2                          | - Frustrated at points.  
- Difficult type of game.  
- Engaging game.                      | - Engages your brain more than other games.           | - Notice when a source is in front of you or behind you.  
- Straightforward room design.         | 2 or 3                                      | ![Case Study 2 Map] |
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Table 2. Summary of the information compiled from the subjects’ interviews.

<table>
<thead>
<tr>
<th>Case Study</th>
<th>Opinion and experience with the game</th>
<th>Positive aspects</th>
<th>Improvements</th>
<th>Number of Rooms in the game</th>
<th>Drawing of the game map</th>
</tr>
</thead>
</table>
| Case Study 3 | - Different type of game.  
- Engaging; you have to focus a lot.  
- Confused while playing. | - Fun to play.  
- Liked the idea of finding where is the source. | - More story on it. | 3 | ![Drawing](image) |
| Case Study 4 | - Implies that you have to be more inside the game than other games.  
- Felt interested and stressed at some points. | - Different experience.  
- More intriguing and thrilling. | - Other types of sounds might be easier to find.  
- Difference between front and back audio.  
- Have the option of using buttons, not only joysticks.  
- Sound or vibration when you touch a wall or you arrive to the audio source. | 3 or 4 | ![Drawing](image) |

As a common pattern, all subjects have felt lost and engaged while playing the game. The feeling of being lost is induced by the loss of the visual sense. That is the reason why all subjects have felt very focused and inside the game while playing - they needed their whole attention to move forward.

The four subjects have found positive that the game is different. Moreover, the subjects with playing experience have acknowledged the fact that this new type of games are more difficult than current video games, creating a new dimension in the market.

Almost all subjects agree that applying HRTF filtering - differentiating front and back sounds - would have definitely improved the experience. Furthermore, two subjects agreed that a few minor changes in the controller setup would have made their experience easier. Besides that, they have also agreed on the fact that some auditive tips inside the game would help to make the experience easier.

Finally, it should be noticed that the two subjects playing the reverb version of the game answered that there are more rooms than the two subjects playing the non-reverb version. Besides that, the drawings also corroborate their answers. Consequently, all subjects have noticed the changes of reverb parameters while testing the game.
5. Conclusion and Future Work

The project attempted to understand the effects of Room Acoustics on the players' performance in Audio Games. In other words, how players interact with the environment and the degree of immersion created by different spaces with different aural characteristics. For that reason, three different prototypes were created - the first idea tried to maximize the naturalness of sounds by using real impulse responses and convolving them with anechoic recordings. Because of buffering overload problems, a second prototype had to be developed, where avoiding buffering issues was the principal objective. With this second project, the software was updated and the buffering problems disappeared. Nevertheless, the naturalness of the output sound was diminished because of the reverb parameters applied to the audio signal. Trying to find a trade-off between naturalness and buffering space, a third prototype was designed. This last one applies Unity audio mixers to spatialize audio - using stereo panning - and apply reverb parameters. Even though the naturalness of the sound is not as good as in the first prototype, it improves the overall performance of the previous two ideas. That is the main reason why it has been chosen as the final prototype and prepared for testing.

As thoroughly explained in Chapter 4, the testing process was used in four different subjects, two of them with gaming experience. The results obtained by the four case studies are not conclusive, as more subjects would be needed to find a pattern of reaction towards the game. Nevertheless, it can be assured that the testing process developed for the game is valid to obtain conclusions with a bigger amount of subjects.

During the testing, it has been acknowledged the importance of playing the controller and audio demos. All subjects found it very useful, no matter their experience on playing and on audio technologies. A previous training is fundamental to understand the game and be ready for the task. On the other hand, every subject has reacted differently towards the gameplay, even though their emotions while playing were pretty similar. This means that the player was feeling immersed in the game, although it was very difficult for them in some parts, leading to a frustration feeling.

On the other hand, some subjects remarked that some tips during the game would improve the playability of it. For example, subject four explained that it would have been very useful to sense controller vibration when the character was touching a wall. Adding haptic information to the prototype would improve its playability and solve, in a way, the sound occlusion issue that all subjects were concerned about. Haptic technology is being developed to complement and upgrade the gaming experience. Surround Haptics are a novel research area. Israr et al (2012) have designed a video-tactile-audio gaming environments using this technology, that delivers real-time tactile sensations, matching with the audiovisual experience.
Even though the haptic technology to apply to the project is more basic than Surround Haptics, this demonstrates the importance of haptics to enhance the player experience and immersion in the game.

As it might seem by the opinions of the different subjects, easy navigation and realism fight against each other. In one hand, direct sources are easy to detect by the player, if the geometry of the room is not very complex. If the complexity of the room increases, then direct sources would turn into a handicap as walls and rooms corners could not be detected. Nevertheless, taking into account that the room geometry of the prototype is not very complex, direct sources are the key for easy navigation thorough the game. On the other hand, the application of reverb parameters create a loss in the perception of the location of the source, due to the echo and sound propagation of the environment. All that said, the real question here is: what is more important, realism in acoustics or easy navigation from source to source? Realism is important up to a point, as depending on the genre and the story it may be worth to loose some of this realism to create another aural atmosphere. However, easy navigation leads to the diminishment of the difficulty, which can also turn into the player being bored. That is the reason why I would say that a good game design implies to find a balance on all those aspects. Moreover, localisation with reverb can be helped by adding haptic information or another type of auditive tip.

Also concluding from the testers’ ideas to improve the prototype, a technology using HRTF filter should be found. As future work, a prototype with a newer technology could be developed and the spatialisation results of the player might improve. After this project was started, a new plugin for Unity and Unreal Engine was released, called Steam Audio.

Steam Audio currently offers the best solution for 3D audio in games. It is still in development, with a community behind trying to fix all the bugs that are currently appearing. The Steam Audio technology offers realtime sound propagation, computing how sounds interact in the environment created for the game. Moreover, it offers 3D audio based on real-time HRTF-binaural rendering, which provides different localisation cues for each ear. This plugin also considers the occlusion and reflection effect created by the existent geometry. Furthermore, it is compatible with virtual reality, allowing rotational and positional tracking and low-latency physics-based audio, which creates immersive VR. Finally, it also renders audio into first or higher order Ambisonics, and calculates static sound propagation for static scenes.

At the end of this project, a prototype using the Steam Audio technology has been started. Nevertheless, due to timelines and small bugs from the technology, the new prototype could not have been tested. Specifically, the absorption of materials at real time was not working for macOS systems. This has been reported to the creators of the software and they are trying to find a solution. Once this is fixed, a new prototype could be finished, using different absorption material rates, sound occlusion and HRTF filters. All the improvement ideas given by the subjects are included in this future work. In order to
understand how important HRTF filtering and sound occlusion is, a comparison between the testing already carried out and one of this new technology should be done.
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Appendix

Case Study 1

Testing details

- Testing with reverb

- Played AudioLearning

- Played ControllerLearning

- Time spent playing: 8 minutes 45 seconds

- How many times the tester needed help during the game? 1 (stuck on a wall for a while).

Transcription of the Interview

Interviewer: Which is your gaming experience?
CS1: I used to play a lot of video games, but not anymore. I played a lot until Year 2, like Xbox 360 and PS2. I’ve been gaming like 10 years, but not on the last year. When I was younger I played a lot.

Interviewer: But are you studying Game Design?
CS1: No, Music Tech. So I have more experience on sound than gaming.

Interviewer: Do you find this type of games interesting?
CS1: Yes, really interesting. I wanted to do stuff like this as well, spatialisation and this stuff. It’s really really cool.

Interviewer: Which positive aspects would you say about the game?
CS1: A positive aspect is the new kind of feeling, even more difficulty. I used to be a fan of a type of game that is very intriguing and it is made really really difficult so you get stuck in a place for like an hour. A lot of games nowadays are made to be easy, it’s like you get through it in 3 hours. I think there’s a new dimension there, where it’s really difficult to do something. So I kind of like that.

Interviewer: And do you think it can be improved in any way?
CS1: Well, I don’t know if this might be too big but if you have a button that would produce echo, that it sends a sound and the sound comes back to you and you hear, and they measure the distance from when it is sent and comes back, and then you know where objects are. If there were something like that, when you are stuck something like this to
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help you, and it will tell you where you are, you can kind of sense it, because sometimes you feel pretty lost. If you do that it could be more easy to play, I think? I don’t know, this is just an idea.

Interviewer: No, sure. I don’t know how much effort would it take that but it is a good idea nonetheless. It’s interesting.

Interviewer: And do you feel that the demos you played before have helped you in any way?
CS1: Yes, they did, definitely. The only thing I found is that it was hard to know where you are looking.

Interviewer: Yes, you were kind of looking at the ceiling like ninety percent of the time.
CS1: Yes, I kind of figured that out. Did it really change the audio depending on where you look?

Interviewer: I don’t really think it does, it is stereo panning.
CS1: Yes, and it is hard to do it that way, because actually vertically there is no change.

Interviewer: That’s right, maybe I should just skip that.
CS1: If you could just move right and left and skip the up and down part.

Interviewer: That would be easier.

CS1: Yes, it would be easier.

Interviewer: How many rooms do you think you’ve been through the game?
CS1: Is it one sound per room?

Interviewer: Not really.
CS1: And there is any hallways?

Interviewer: There were hallways, yes.

CS1: Do they count as rooms?

Interviewer: Yes, you can just tell me how many places you think you’ve while playing, like different types of rooms.

CS1: There were like four or five sounds with echo I think. And the dry ones as well, the echo represented a room that was bigger, right?

Interviewer: Yes.
CS1: And then, one sound that didn’t have echo was from a smaller room.

Interviewer: Which sounds do you think that they have echo?

CS1: The church bell, the organ afterwards, I would say the same room, .... I can’t really remember the other sounds, I think there was ping pong ball, I think it had echo on it, I’m not sure about that... There was a hallway maybe? After the church bell and the organ and I went into a small room.

Interviewer: Yes, you are right, you are right.
CS1: And I don’t know, I can’t remember the sounds. I think there was a hallway leading to a bigger room with echo. And maybe another hallway. I would seven or eight rooms, hallways included?

Interviewer: Ok, thanks, that answer is fine.
Interviewer: How have you felt while playing the game?
CS1: A little bit lost. But also intrigued.
Interviewer: So lost in a good way?
CS1: Yes! As I said, it was hard, but there is also a lot to do with that, like that feeling of being lost and you have to find an option to get out. And it’s interesting, because I was still at things, looking at the wall and... yes, it was interesting.

Interviewer: If these type of games were commercialised, I mean, fully developed and commercialised, would you recommend them?
CS1: Depends on how much further the game would go, you know?
Interviewer: Yes.
CS1: And what you would do with the screen aspect of it. Because you turned the screen away from me, but I’m not gonna do that. You need a black screen or something like that.
Interviewer: Yes.
CS1: Or you could have like an inventory or a menu that you can use but still it doesn’t help you to find the way out in the game, like beacons or something like that. But anyway, I’d definitely play it and, if it’s good, I’d definitely recommend it.

Interviewer: And to finish, can you draw a map of where you think you’ve been through the game?
CS1: That’s difficult but I’ll try.
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CS1: One more thing, actually. It’s hard to know where you are looking at, if the sound is in front of you or behind you. And I know that’s a massive problem with spatialisation, but it would really improve it.

Interviewer: Yes, I know. I wanted to use HRTF but I haven't found anything to work it out.

CS1: And you can’t make that in front it would be listened in a higher volume than in the back?

Interviewer: Not really... the audio sources are spheres, and you can’t really create different volumes at different places of the sphere.

CS1: Oh, so the closer you get, the louder it sounds.

Interviewer: Yes, and you can actually control how you want the volume to decay in that sphere.

CS1: That’s cool.

Interviewer: Yes, but it can’t be different at the same radial distance.

Interviewer: Thank you very much for trying it.

CS1: Thank you for letting me try it.

Case Study 2

Testing details

- Testing without reverb

- Played AudioLearning

- Played ControllerLearning

- Time spent playing: 13 minutes 42 seconds

- How many times the tester needed help during the game? 4 times (stuck on walls at the Cave, the Church, the Hallway to the Church and between the Initial Room and Room 2).

Transcription of the Interview

Interviewer: Then you think that you’ve been playing the reverb or non-reverb one?

CS2: Definitely the reverb one.

Interviewer: Really? It was not.

CS2: Yeah, because it sound so different from the first one. Like the demo that you showed me, where there is only three sounds. It sounded really different to that. That’s why I would say it’s the reverb one.
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Interviewer: That’s interesting. I would show you the reverb project afterwards so you can see the difference.
CS2: Yes, sure.
Interviewer: Can I ask you some questions about what you have played before showing you the reverb project?
CS2: Sure.

Interviewer: Can you tell me your gaming experience?
CS2: Well, this is the first audio game I have ever played.
Interviewer: Yes, sure, I was meaning normal video games.
CS2: Ohh, what kind of games? Well, I’ve played a lot of games.
Interviewer: I can see that you are good with the PS3 Controller.
CS2: Yes, I don’t play a lot of Play Station. I normally play like PC games. Do you want to know what type of games and how long I’ve been playing?
Interviewer: No, just how long have you been playing.
CS2: Mmm, since I was 2 years old. So lots of experience.

Interviewer: Do you find these type of games interesting?
CS2: Well, if there would be more stories rather than going from sound to sound then yeah. I’d definitely find it interesting. It’s just that it needs to be a bit easier in my opinion? Because it was frustrating at points. Like I’ve felt that I was around the sounds a lot of the times, just walking around like that, over and over again. That’s how it felt like. Mmm, so it was a little bit frustrating. But if you could tell whether it is in front of you or back of you, I think that would make it way easier.
Interviewer: Ok, sure about that.

Interviewer: So, would you tell me some positive aspects about the game?
CS2: Yes! I think it really makes you think. It engages your brain much more than a normal game, because you really have to concentrate and try to figure out where the sound is. So yes, it engages your brain more. I’d say that’s a positive thing.
Interviewer: Yes, right now games are pretty easy to play, normally.
CS2: Yes, a lot of the games are very “hand-holdy”, like they show you everything, step-by-step, don’t let you fail anywhere. But this felt like it tells you ‘good luck’.

Interviewer: And do you think the experience can be improved in any way? Like some ideas or what do you think it can be improved?
CS2: Mm, yes let’s say the front and back thing would definitely help. But besides that, I’d say that games like these should probably have as little obstacles on its way as possible, like the room design should be as straight-forward as possible. If you can imagine a square room like this [shows visually]. The first sound is here [points out a place], and the second sound is here [points out another place], and se we are here [points another place], but the room goes like this [creates a room with a corner obstructing the sound]...
Importance of Room Acoustics in Audio Games

Ariadna Sanchez

propagation], so you have to walk around the corner. That’s stuff that would probably be very difficult to do.

_Interviewer:_ Yes.

CS2: So instead of do this design, you’d want a straight room that would lead you to the next sound.

_Interviewer:_ It is true that you haven’t played the reverb version, so maybe you could not notice if a room is a hallway or not. That makes a difference I would say…

CS2: Okay, yes, that might be true.

_Interviewer:_ Without the reverb, they are just direct sources playing, there is no echo applied on them. And I would say it’s more difficult to understand the type of room you are into.

CS2: So if there was reverb…

_Interviewer:_ I mean, what you said is difficult anyway, but you can understand better the space where you are.

CS2: Can we try afterwards?

_Interviewer:_ Yes, sure. So, how many rooms do you think there have been on the game?

CS2: I haven’t noticed any big change between sounds, just like that there were different audio sources.

_Interviewer:_ How have you felt playing the game? You previously said lost.

CS2: Frustrated, a lot… but yeah, it was a good experience to try out something like this. I would say frustrated and engaged, both of them.

_Interviewer:_ And if these games were commercialised, I mean more developed and commercialised, would you recommend them?

CS2: It would really depend on the game. I can’t tell you right now.

_Interviewer:_ Maybe it also depends on the type of games you like.

CS2: Yes, that’s true. If it would be a fun game, that wouldn’t be as frustrating, then I’d probably recommend it. Just because how engaging it is. And if you could tell some type of story in it, that way it would be much more immersive than a visual game.

_Interviewer:_ Well, actually the idea was more or less like the Journey game, to make an audio journey through different spaces.

CS2: Oh, right, okay. That’s cool.

_Interviewer:_ It’s only a prototype though.

CS2: I really enjoyed Journey.

_Interviewer:_ Me too.

CS2: It is one of my favourite Play Station games. What it does very well is setting up the whole atmosphere.

_Interviewer:_ Yes, in the game you don’t really have to do anything, just follow the path basically. It was pretty fun to play.

_Interviewer:_ And the last thing, could you draw a map of what you think you’ve done in the game?
CS2: [laughs] This is not gonna be right or anything, but let’s try.

Interviewer: Don’t worry about that.

Interviewer: That’s fine. Thank you very much.

Case Study 3

Testing details

- Testing without reverb

- Played AudioLearning

- Played ControllerLearning

- Time spent playing: 9 minutes 19 seconds

- How many times the tester needed help during the game? 1 time (stuck for a while in the Hallway between Room 2 and the Church).
Importance of Room Acoustics in Audio Games

Transcription of the Interview

Interviewer: First of all, I am going to ask you about your playing experience.
CS3: I don't really play much, sometimes at parties like Singstar and this type of stuff.
Interviewer: Great.

Interviewer: Do you find this type of audio games interesting?
CS3: Yes, I think so. It's interesting, it's something different like, I mean, I don't play games much but it sounds very different from the other games. It's like you are so focused on what you are seeing but this is a very different thing and a cool idea to try.
Interviewer: That you only have one sense helping you out.
CS3: Yes, it's really hard at first to get used to it. I really wanted to see all the time [laughs].

Interviewer: Could you tell me some positive aspects about it?
CS3: I think it's fun to play, like it was kind of cool to see where the next sound comes from, because sometimes you get kind of confused if it's not on the right or left side; with both sides (front and back) it was kind of confusing - but it was fun to play it. I liked the idea of finding out where the source comes from.

Interviewer: And do you think that it can be improved in any way? I know you are not in the game field but you can have your word on it.
CS3: Mmm, I don't know. Maybe I'd love it more if there was some story on it. Like some setup or basics of why we are here. Why are you playing, something like that.
Interviewer: This is a prototype, the idea is that it could be fully developed at some point and that could be add to be more engaging.

Interviewer: Do you feel that the games played previously - the one for the controller and the one for the audio - helped you through the game?
CS3: I don't know about the sounds, but the controller definitely helped.

Interviewer: How many rooms, spaces have you noticed during the game?
CS3: Three? I would really say three.
Interviewer: Okay.
CS3: There were definitely more sounds but...
Interviewer: Yes, sure.

Interviewer: Do you think you’ve played the reverb or non-reverb one?
CS3: The one with the reverb.
Interviewer: Are you sure about that?
CS3: Yes.
Interviewer: You’ve played the one without reverb. The bells for example are reverberant by themselves, that’s probably why you think that.
CS3: Oh, yes, that’s right. Maybe it’s just my imagination, that both claps were different.
Interviewer: How have you felt playing the game?
CS3: Mmm like the moments I was stuck it was kind of… I was confused because I didn't really know what to do, because I couldn't see anything. So I was like 'okay, this is weird, I don't know this'. At some point it didn't really worked the way I wanted it to, so I was kind of confused but when it worked it was cool (laughs). Like there were some sounds I got like, I got to them pretty fast, and that was fun.

Interviewer: So if this type of games were commercialised, I mean, fully developed and with different ideas or a story behind it, would you recommend them?
CS3: Probably.
Interviewer: And play it?
CS3: Sure. I'd definitely want to try because it's so different, so I'd definitely want to try playing that.

Interviewer: The last question. Could you please draw where you've think you've been during the game?
CS3: Yes, sure.

Interviewer: Thank you for your time!
Case Study 4

Testing details

- Testing with reverb

- Played AudioLearning

- Played ControllerLearning

- Time spent playing: **12 minutes 24 seconds**

- How many times the tester needed help during the game? **1 time (stuck at the Cave, confused by the position of the audio sources).**

Transcription of the Interview

*Interviewer*: What is your playing experience?
*CS4*: I never play. I’ve just tried to play a couple of times, but I am not a player.

*Interviewer*: Do you find these type of games, only-audio games, interesting?
*CS4*: Yes, very interesting.

*Interviewer*: Why?
*CS4*: I think it is a very different experience for the user. I mean, it implies that you have to be more in the game, not just outside of it, because you have to be aware of what’s happening around you by just listening. And that’s interesting.

*Interviewer*: Could you say some positive aspects about it?
*CS4*: Hmmm meaning what?
*Interviewer*: Actually whatever you want, like something that you actually liked about it, or something that you find positive about the fact of it being an only audio game…?
*CS4*: I think it’s a different experience, I mean it is positive that you don’t see where you are because it makes it more intriguing, and it’s more thrilling in a way.

*Interviewer*: Do you think that the experience can be improved in any way?
*CS4*: Yes. I think that one of the things that has to do a lot about how you receive the experience is what type of sounds you use. Different types of sounds might be easier or less easy to find in an audio game.

*Interviewer*: Did you find any audio specifically difficult?
*CS4*: Yes, there was one, but I don’t know how to describe it.

*Interviewer*: When was it? You can say in between which two sounds, for example?
*CS4*: Do you know when I got stuck with the clapping?
*Interviewer*: Yes, sure.
CS4: I was walking from the clapping to another sound. There was one with lots of reverb… I don’t know how to describe it.

Interviewer: Actually, it was another clapping sound with so much reverb.

CS4: Yes, so that was difficult to understand, because it was difficult to identify the left and right because of the reverb.

Interviewer: And would you say something else to improve it or…?

CS4: Hmm one thing that could be improved would be if you could tell the difference between front and back, because then you would know where it is and where you are. Also, for me, as I am not a player, it would be easier not to use the joysticks, but the buttons. I think that for people that doesn’t play a lot it’s easier for you to remember a path where you can only do straight lines. So it’s easy to know that you are going on a straight line if you are just clicking a button but if you are pushing a joystick your path can be curved. For me it would have been easier just with the buttons.

Interviewer: Do you think that the demos we have played before have helped you during the game?

CS4: Yes. I mean the first one…

Interviewer: The one of the controller?

CS4: Yes, that one. That one was just to test how to move around. It helped me but I am not a player so maybe other people doesn’t think it helps. But the other one, the sound one, was very helpful.

Interviewer: How many rooms have you noticed through the game? Taking into account the reverb, for example.

CS4: Is each sound a room or it doesn’t have to be?

Interviewer: No, it doesn’t have to be.

CS4: Ok, so I would say maybe three or four.

Interviewer: Ok, great.

Interviewer: How would you describe the rooms you’ve been? I mean, if they are big, small, echoed, …?

CS4: I would say, maybe, the first one was big. I don’t really know.

Interviewer: For example, you haven’t noticed differences between them?

CS4: No, not many. I think I was too focused on following the sound, more than understanding where I was. I wasn’t picturing a space, I was more like sensing the sound and trying to follow it.

Interviewer: How have you felt while playing the game?

CS4: I don’t know, I had to concentrate a lot. And it was interesting, stressful at some points, because when you don’t know what’s happening, for example if you hit a wall and you are not moving or find the direction to move it’s difficult because you get stuck. But, in general, I don’t know, it was interesting.

Interviewer: Do you think it is entertaining?
Interviewer: If this type of games were commercialised, I mean, fully developed and commercialised, would you recommend them? It doesn't have to be this game in particular, just the audio game idea.
CS4: Yes, sure. I mean, I am not a player, I would have to play a lot to actually get addicted to them. But I actually think it is a nice experience.

Interviewer: Finally, can you draw the path you think you’ve followed?
CS4: So difficult... I don't think I am going to draw anything useful... I'll try.

Interviewer: Thank you.