Evaluation of Reverb with Eq as a Tool for Egocentric Distance Perception in Games

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Bachelor of Arts
Audio Engineering

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Department of Arts, Communication and Education
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Abstract

This bachelor investigates the possibilities for developing a technique that uses an eq to change the timbre of a reverb in a game, so that the egocentric distance perception changes. This technique, if it can be developed, might provide options for sound designers who want to imitate the sound of propagating waves. Reverb is an important and common tool for sound designers. This technique could be used in either pre-process, or alternatively in real-time, as a way of imitating sound propagation systems, changing the eq configuration dependent on character position. An experiment was performed in a game environment. Subjects listened to a stimuli at two distances from a wall in different rooms. The reverb was changed with eq at the further distances. Subjects were asked to prefer one room before the other and motivate that choice. A pilot study showed that a boosting the sound effect’s high frequencies into the reverb was perceived as farther away. But the results from the main experiment showed no clear patterns in subject’s preference.
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Introduction

The game industry is growing and the fast development of computer hardware and game software allows games to both look and sound better than before. Even if the clearest improvements are seen in the graphics, greater availability of disc space afforded by new computers and consoles also allows for the sound to have a higher quality and more advanced processing. But this is not being used as well as it might be. Virtual environments look more realistic and sound has to keep up, which is one reason why a big challenge is how to simulate acoustics realistically in virtual spaces. Until recently artificial reverbs are the most common tool used to simulate room acoustics in games, and it has been used ever since game platforms started incorporating tools for signal processing. Artificial reverbs are most commonly based on predefined algorithms. They can be computationally simple or very complex, depending on the algorithm. Reverbs are mostly built into game engines, so when developing a game, sound designers generally have little control over reverb configurations. No matter how good these artificial reverbs sound, they are not able to incorporate changing information about the game state dynamically in real time. Instead, the reverb is applied to sound files at startup. That means each sound file is always processed the same way, one way, regardless of when that sound is triggered during game play, and regardless of positioning and surface. This is not realistic. This bachelors will test the possibility to improve the use of standard reverbs to imitate the effect of sound propagation with eq.

Aim and purpose

Using an eq to change the reverbs output would need a development of a new system. That could be costly for game developers. It is always a risk to invest time in an idea that might not work. The idea was to use an eq on reverb to vary the egocentric perceived distance to reflective surfaces in first-person-shooter games (FPS). Later sections in the background will show that there are lack of literature that suggests that this idea has not been tested. It should not be hard for game programmers to implement an equalization that could be changed in real-time nor for a computer to process it. So if players find a spectral change from the reverb preferable, it could be a very quick and cheap step for sound design helping it to keep up with the graphics fast improvements, and it would be most likely implementable today. In the near future, a position based system could be developed where the eq changes in both frequency and amplitude depending on distance to- and type of the reflective surfaces. The research question is stated in the following section, the reasoning behind the formulation of the research question will be explained in later background sections.

Statement of the research question

Is it preferable to listeners, varying the timbre on the reverb input in games with an eq such that it attempts to simulates distance to reflective surfaces?

In order to create a method which could answer this question, understanding about sound propagation and reverb in real life and in games will be necessary.
Sound propagation in real life

When sound propagates in real life there are many factors that play a role in how we perceive it. As Everest & Pohlmann explains, reflections in a room gives us significant information about the room’s size, shape, and boundary composition. Different materials absorbs differently at different frequencies and shape of the surfaces is crucial for what direction the reflections paths will take. High frequencies are more absorbed in air than lower frequencies and therefore dies out quicker. Further away from a reflective surface there will therefore be less high frequency content in the reflected sound. If a wave front is interfered by another wave front, comb filter appears. It results in peaks and nulls in a regular series of frequencies and it will vary depending on the distance to the surface and the frequency content of the sound (Everest & Pohlmann 2009). Even if comb filter appears whenever sounds interfere with each other, it is most times not audible. In large reverbs the peaks and nulls are so numerous and packed closely together that they merge into a uniform response. But even if the comb filter is inaudible, it still impacts the timbre of the sound. When comb filter is audible, it is often described as thin and metallic sounding.

Sound intensity serves as the primary determinant of perceived distance (Sheeline 1982). But in a study written by Mershon & King (1975) it is shown that intensity only can serve as a relative cue while reverberation is an absolute cue, meaning that without reverberation it is difficult to hear loudness differences. This shows how important reverberation is to human auditory cues and how complex it is. A cathedral sounds large to a listener whether or not that listener enters the cathedral from a smaller room. A reflected sound reaching to the ear of the listener is always somewhat different from the direct sound. The amplitude and timing of the reflected sound is always different as well as the perception of the reflection compared to the direct sound.

Sound propagation in games

In the digital world, there are many different ways to simulate reverberation. But in order to make it sound realistic, many variables from real-life acoustics must be taken into account. Sound propagation systems try to do that as well as possible. In game sound this is a relatively new approach. Research has developed several sound propagation systems for games, which all do take player positioning and accurate reflections into account and all has slightly different techniques and approaches. However, there are few commercial products available.

The basic idea for all game-adaptive sound propagations systems are to calculate the sound wave propagation paths from the sound source to the listener, and do so in various directions. That way delays and spatial cues from reflective surfaces are generated realistically in real-time (Schissler & Manocha 2011; Chandak et al. 2008; Taylor, Chandak, Antani, & Manocha 2009; Heckbert & Hanrahan 1984), and are likely to be perceived as more realistic. To make these calculations, propagation systems use acoustical models. Acousticians have for a long time been using techniques for modeling acoustics in the real world environments (Schissler & Manocha 2011). Most of these techniques cannot be calculated in real-time, due to the large amount of processing power they need.

Sound propagation systems can be divided into two main groups, numerical and geometrical. Numerical methods solve wave equation problems with numerical analysis. They can often make sound propagation simulation accurately than geometrical but are much slower in its calculations. Geometrical methods solve
the wave equation problems analytically using geometry in the environment, assuming that the sound propagates in straight lines (Drake, Likhachev & Safonova, 2014). It uses algorithms from graphics to simulate how sound propagates (Schissler & Manocha, 2011). Numerical methods tend to be more suitable for realistic 3D room simulations where only the listener's position can vary not the sound sources (Schissler & Manocha, 2011). According to Schissler and Manocha (2011), geometrical methods are generally more tractable than numerical because they usually allow for moving sources and dynamic scenes. This is what makes the geometrical methods more attractive for games. Geometrical methods can also be divided into different groups because it varies what techniques different developer use to calculate the geometrics. The most common ones are ray tracing, beam tracing and frustum tracing.

Ray tracing is another technique that allows for exploring the environment and possible reflection sequences. A ray is a line/path in computer graphics that generates an image and simulates the effects of encountering virtual objects. In a sound propagation system, it is used to be generated from a sound source and graphically reflect on virtual objects. Depending on how many rays that are used and recursion depth each ray is programmed to for the calculations can vary in magnitude. The basic idea is that rays are generated from the sound sources, in all directions randomly and only the rays that reaches the listener are calculated based on geometrical algorithms (Schissler & Manocha, 2011).

Beam tracing is similar to ray tracing, but instead of generating rays, that has no thickness, beams are shaped like unbounded pyramids (Heckbert & Hanrahan, 1984). The reason for this is that because of the rays shape it can miss important features of the environment if the amount of rays are too small. Beam samples areas continuous of the environment with every cast beam. The beams are split if the beam intersects discontinuities. This way the risk of missing important features of the environment is largely decreased (Drake, Likhachev & Safonova, 2014).

Frustum tracing is a third one with a similar approach. ADFrustum is a system that traces rectangular frustums from a sound source through the scene to see if the listener is contained in any of the frustum, if so the listener hears the sound (Chandak, Lauterbach, Taylor, Ren, & Manocha, 2008). Both beam tracing and frustum tracing are created to improve ray tracing and even if both these systems work well, performance issues come with the complexity of the geometrics (Schissler & Manocha 2011).

Even if these techniques are being adapted for games today, most of them are not implemented in commercial games because they often require more processing power than the game can spare. In order to make sound propagation systems operate in today's games in real-time, the quality of the processing must be compromised. With less accuracy, less like how sound propagates in real life, it is possible to use a real time sound propagation system for games. But some games allocate as little as 5 to 10 % of the CPU usage to sound, so there is still a big challenge to develop a real-time system that can compete with artificial reverbs in terms of sound quality and computational cost (Schissler & Manocha, 2011). Game engines, however, do process reverb.
Reverb in games

In a game engine the most common type of reverberation is still an algorithmic reverb. They are based on a predefined algorithm that process different signal parameters in multiple ways. Algorithmic reverbs can be both very simple and very complex depending on the algorithm. Algorithmic reverbs have no limits when it comes to parameters, everything is programmable since it is only an algorithm. The advantage of algorithmic reverbs is that if you only need one for a whole game if the parameters allows you to create all the different spaces by saving presets for the different environments.

Many game developers have their own in house game engine which they have developed for themselves as a tool to make games. Unreal engine 4 [UE4] (Epic Games, 2016) is a open and free professional game engine developed by EPIC Games and are in many ways equal to other game engines proprietary used by game developers. UE 4 has an application called Reverb Effect which is the only reverb available in the engine. It is an algorithmic reverb limited to 12 parameters, density, diffusion, gain, gain high frequencies, decay time, decay high frequency-ratio, reflections gain, reflections delay, late gain, late delay, air absorption gain hf and room roll off factor. Reverbs like these are very normal when it comes to game engine reverbs. See UE4: s reverb effect in figure 1 below.

![Reverb Parameters](image)

*Figure 1: Shows the parameters of the built-in reverb in UE4.*
Imitating sound propagation in games

Artificial reverb is not the only sound processing tool in game engines. They also provide equalization, which may help sound designers to imitate sound propagation in games. Propagating sound in the real world is detected by both temporal and spectral cues. Reflections, comb filter and sound attenuation creates sounds that are familiar to listeners, and similar spectral qualities might be imitated with an eq. High frequencies that are more absorbed than lower frequencies is something that could be simulated with an equalizer. According to Coleman (1968) a stimuli with reduced high frequency content will be judged to be further away than the original unprocessed sound. Comb filter generates a special sound, which also could be imitated with eq. Even if a simple eq configuration might not be fully accurate, our human perception might associate the effect with the natural phenomenon. That association may make for a preferable sonic experience in a game environment. These associations are the basis for this research project. An experiment was conducted to see if an eq can be used to imitate these natural phenomena, and if listeners make the expected associations.

Attributes

To get a sense of if an eq could imitate these natural phenomena, the listener’s evaluation of audio quality will be important. It can be hard to express an auditory experience in words, but using attributes to describe sound can help. Nunnally and Bernstein (1994) defines attribute as an evaluation of a particular feature of objects, in this case sound objects, and that you cannot measure objects only their attributes. In a study by Letowski (1989), sound quality are categorized in four groups. Timbral, spatial, technical and miscellaneous quality. The sense of location, distance and spaciousness etc. goes under the category spatial quality, which is the most relevant quality for this research. Attributes will be used to analyze the results from an experiment that was performed for this thesis.

The design process for this study

The experiment was a first person shooter (FPS) game was played by subjects. Only sound and distance were taken into consideration. In this case, sound reflecting from surfaces was imitated with eq. The eq changed depending on a character's distance to surfaces. The sounds were preprocessed, but variations were triggered depending on player’s position. If the change in the reverbs frequency balance closer or farther to reflective surfaces such as walls shows to be preferable, it might result in a cost-efficient technique that allows the system to respond to the players movements. It might not be as realistic as a sound propagation system could be, but it could take artificial reverbs one step further with real-time processing features, which would improve sound design even as new techniques for modeling sound propagation are developed.

A FPS games have been chosen because they are often filled with action and dynamic scenes. The game developers often want the gaming experience to be as realistic as possible, just as if the player was the character in the world the game depicts. If the player could hear a difference in the sounds he/she generates being close to a wall or not could add to the realism of the gaming experience. Imagine a scene where the
player has to sneak past guards in a dark room and if the player could hear the difference in the characters breathing and footsteps depending on if he/she is close or far from a wall. It could add thrill to the task and also help the player find spots where he/she is undetectable by the guards. Another scenario could be on a battlefield and the sounds change depending on if you are hiding behind an object or standing up shooting towards the enemies. The player might feel more protected behind the object thanks to a more intimate and realistic sound.

For the experiment a stimuli had to be designed. Even with these scientific principles in mind, the creation of the stimuli was approached from a sound designer's perspective. A sound effect was processed with an eq and a reverb in various ways in order to find the best sounding option, which would be the processing settings that create the most realistic movement closer to/farther from a wall. The most realistic method in this case would be the one who appear to be most similar to how sound propagates in real life as described earlier, or at least leads listeners to make that association.

Practically speaking, the choices available to a designer are, process the eq inside the game engine, having the eq change in real-time, or pre-process assets outside the game engine, import them and trigger them depending on the player position. The placement of the eq-processing could either be set pre or post the reverb. Placing the eq before the reverb would mean that the eq processes the sound effect and then send it to the reverb. Placing it after the reverb would mean that you send the sound effect to a reverb and then process the reverb with an eq. The first way to do it changes the timbre of the sound effect before being sent to the reverb. This method change nothing about the reverbs processing, but the actual sound effect that is being sent to the reverb gets a different timbre. The other way is doing nothing to the actual sound effect, only eqing the reverbs output. The results could be similar, but never the same and neither procedure accurately represent sound propagation or perception in real-world listening. In a game however, either might enhance the experience. The sound designer would have to conclude which fits best for the task.

During the design process, while trying to create appropriate stimuli for this research, many options were tested. The eq was not only applied both before and after the reverb. It was also applied only on the dry sound only and on the whole mix (wet and dry). This was necessary since it wasn’t known how the different processing's would be perceived. It stood between having the eq before or after the reverb. Eqing the dry sound or the whole mix both affected the dry sound in a way that wasn’t contributing to any perceived change in distance to the ears of the author. The difference between applying eq before and after the reverb was not big, but there was a difference. Applying the eq after the reverb, the actual eq processing was a bit more audible. This was seen as unnatural due to the fact that sound propagation in real life is complex, it travels multi-directional and wouldn’t treat the amplitude of a certain frequency in a consistent way. With the eq before the reverb, it sounded less consistent but still very close to the same spectral balance as applying the eq after the reverb. It gave the impression that eqing before the reverb gave the impression that it was more natural. The difference were small but big enough to make the decision to apply the eq before the reverb when designing the stimulus. In this research, putting the eq before the reverb has therefore been evaluated.

With a programmer’s help, an eq could be implemented in a game engine before or after sounds are processed by the built-in reverb. When implemented, the eq could be controlled by a sound designer and be configured differently based on the environment and the character's distance to reflective surfaces.
However, for this experiment, the decision was taken to pre-process the stimuli. This removed any possibility of in-engine processing adding unexpected complications to the experiment.
Method

An experiment was designed in which subjects would play a first person shooter (FPS) game. In the game, subjects were able to listen to sound excerpts both close and far from a wall in similar rooms. The rooms used eq in different ways to process the excerpts in attempt to change the perceived distance to a wall. Each subject also heard a room with no eq as a control. The subject’s task were to decide which room they preferred the most.

Pilot study

In order to decide a configuration of the eq for the main experiment, a pilot study was made in a non-game environment. A stimuli and 7 different eq-curves was designed with Fabfilters Pro-Q (Fabfilter, 2012), which is a software equalizer, they contained both cuts and boosts across the whole audible frequency spectrum. They were selected by the author. A mono stimuli was designed to sound like an automatic weapon that is being reloaded. It was made sure that the stimuli contained a wide frequency spectrum so that no eq-processing would be inaudible. The configuration for eq 1 was, 10 dB @ 70 Hz, -10 dB @ 100 Hz, +14 dB @ 140 Hz, -14 dB @ 200 Hz, +10 dB @ 280 Hz, -14 dB @ 400 Hz, +9 dB @ 560 Hz, -15 dB @ 800 Hz, +7 dB @ 1120 Hz, -16 dB @ 1600 Hz, +6 dB @ 2240 Hz, -16 dB @ 3200 Hz. This design was made from a sound designer perspective so there was no theory supporting the configuration of the eqs. Except for eq 1, which was an attempt to simulate the sound of comb filter, all other eq bands had a q-value of 1 and a gain of ±8 dB, table 1 (below) shows the configuration of eq 2 - eq 7. Figure 2 below is a graphical representation of the designed eq-curves.

<table>
<thead>
<tr>
<th>Eq</th>
<th>Gain</th>
<th>Frequency</th>
<th>Filtertype</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eq 2</td>
<td>+8dB, +8dB</td>
<td>100 Hz, 2500 Hz</td>
<td>Bell, Bell</td>
</tr>
<tr>
<td>Eq 3</td>
<td>+8dB, -8dB</td>
<td>900 Hz, 4500 Hz</td>
<td>Low shelf, High shelf</td>
</tr>
<tr>
<td>Eq 4</td>
<td>-8dB</td>
<td>4500 Hz</td>
<td>LPF 24db/Oct</td>
</tr>
<tr>
<td>Eq 5</td>
<td>-8dB</td>
<td>650 Hz</td>
<td>Bell</td>
</tr>
<tr>
<td>Eq 6</td>
<td>+8dB</td>
<td>2800 Hz</td>
<td>High shelf</td>
</tr>
<tr>
<td>Eq 7</td>
<td>+8dB</td>
<td>700 Hz</td>
<td>Bell</td>
</tr>
</tbody>
</table>

Table 1: Shows the parameter settings on eq 2 – eq 7
4 subjects participated in the pilot study. They were third year students in LTU’s audio engineering program. Subjects listened to auditory stimuli only. There was no game environment. They had to compare every eq-processing with a reference stimuli and decide if the eq:ed excerpt was perceived as closer, farther away or at the same distance as the reference. The reference stimuli was identical to the excerpts except it had no eq applied to it. The 7 different eqs were tested on both an indoor reverb and an outdoor reverb in order to look for consistency in effectiveness between the indoor and outdoor environments. The pilot study was performed in Pro Tools 10 (Avid, 2016) using Izotope Ozone 5 Reverb (Izotope, 2012) as indoor reverb Lexicon LexRoom (Lexicon, 2009) as outdoor reverb and Fabfilter’s Pro-Q as eq. The eq-processing was made before the reverb in the processing chain and all sounds in mono. The stimuli was in mono so that the width of the stimuli wouldn’t affect the perceived distance. The focus of this study was the distance perceived to a wall in front of the player, a stimuli in stereo would risk distract the listener. All excerpts were loudness-normalized so that the amplitude of certain excerpts would affect the outcome of the study.

The results from the pilot study showed that the subjects had different perception when it came to estimate the distances. For the indoor reverb, 3 out of 4 perceived eq 1 and eq 4 as closer and 4 out of 4 perceived eq 6 and eq 7 as farther away. The outdoor reverb showed either weak or no tendencies at all in the results. The data from the outdoor reverb had no clear pattern in preferences. Stronger support was needed in order to choose an eq and move on for the main experiment. Therefore the pilot study was run a second time with the same subjects to check their consistency. If they were consistent, the data would become more reliable.
Regardless, the second pilot still focused mainly on the indoor reverb since it had patterns, and this suggested further study was justified. To help clarify the results, a refined version of the pilot study was performed. Only the eq 1, 4, 6 and 7 was tested a second time, for the indoor reverb the subjects was handed a short questionnaire to get some more details out of the results. The questionnaire for the second pilot study asked just as the first pilot study, if the excerpts was perceived as closer, farther or at the same distance as the reference. But this time, if they perceived it as closer or farther they were asked to estimate the difference from the reference in meters. This was to get a better understanding of how much closer or how much farther away the excerpts were perceived which could be helpful in designing the main experiment. They were also asked to highlight which attributes that correspond with each excerpts. The attributes they could choose from was, clear, unclear, natural, unnatural, bright, dark, wet and dry. They were also asked how hard it was to determine the distance on each indoor excerpts. In the end of the pilot study they could write their own thoughts about the experiment. The results from the second pilot study showed that the subjects weren’t consistent on most excerpts. But the indoor eq 6 and indoor eq 7, all subjects perceived as farther away than the reference even the second time. This led to the choice of using both eq 6 and eq 7 for the main experiment.

The main focus in the second pilot study was the indoor reverb, but the outdoor reverb was also tested a second time. The reason for this was to still be open for patterns with the outdoor reverb so that it wouldn’t be excluded too early in the process. The exact same stimuli were presented and the same questions were asked as the first pilot study. But the outdoor excerpts still did not show any clear patterns, therefore it was decided to not follow through with the outdoor reverb to the main experiment. Instead of using an outdoor reverb, another indoor reverb was designed. The indoor reverb from the pilot study was kept and unchanged, the second indoor reverb was created with Izotope Ozone 5 and had a shorter decay time. The reason for that was to see if the subjects would be consistent or not in their preference with different decay times.

Main experiment

For the main experiment, two different rooms were designed in the game engine Unreal Engine 4. Content from a free access map called Sci-Fi Hallway developed by Epic Games was used to create two different indoor environments. That content was used because it was developed by professional level designers from Epic Games, which maintained ecological validity regarding a game environment. The two environments had similar aesthetics, furnishings, layout, etc. but were differed in volume. The reason for using two rooms with different volumes was to find out how well the eq-curves worked in different environments. If one eq would show to be preferred in both rooms, it would be an attractive choice of eq configuration for sound designers. Figure 3,4,5 and 6 below, are screenshots from the experiment.
Figure 3 & 4 shows the large room blue from the closer and farther distance as the subjects saw it during the experiment.

Figure 5 & 6 shows the small room green from the closer and farther distance as the subjects saw it during the experiment.

Three copies of both environments were made so that one room would only contain the reference and the two other contained each of the eq-curves. In each room the player could move back and forth between two positions, one closer and one farther from a wall. Since the pilot study showed that eq 6 and eq 7 was perceived as farther away than the reference, the processed excerpts were only applied on the position that was farther away from the wall. On the position close to the wall the reference was applied in all rooms. In order to distinguish the rooms from one another a unique framed picture was placed on the wall in every room. For the large rooms animated cats were placed on the walls, each room with a unique color of the cat. For the small rooms, animated dogs was placed on the walls also with unique colors so that the subject could identify which room the subject was in. The colors were red, blue and green in both the big and small rooms. From now on, the rooms with cats will be called large rooms and the rooms with dogs will be called small rooms. Visually, the 3 large rooms were almost identical. The only difference except for the color of the cat, was the positioning of the plants. In the small rooms the only difference except the color of the dogs were the positioning of a table fan. In appendix 1, 2 screenshots from each room type is shown. The stimuli used was the same as for the pilot study. The character in the game were holding an automatic weapon which the character normally does in an FPS shooting game, so the stimuli was still ecologically valid to be used in the experiment. Some silent ambiences were added on each room as well. In the large rooms there were ambience of an office and the moving robot in the roof (which clearly can be seen in figure 7 in
the appendix), had a silent electrical elevator sound that were synced with the robot’s movements. In the small rooms, there were fans that were sound designed and a very silent room ambience.

Every stimulus excerpt for all 6 rooms was exported from Pro Tools 10 with a sample rate at 48 kHz and a bit rate of 16 bit which is the highest possible bit rate that is importable in Unreal engine 4 (Epic games 2015). Once imported to unreal engine 4, the compression quality was set to 100 which is highest possible sound quality available in the engine and is equal to 288 kbps Ogg Vorbis, which is a lossy compression audio format.

The experiment was designed so that the character in the game couldn’t move except close and far, nor could the character look around. It was important that it looked right at the wall and at the right distance when playing the stimuli. The subjects could only use 4 buttons, they could toggle between the two distances in the present room, switch room within the same environment and switch environment to the second environment. On the fourth button the subjects could play the reload sound. It was playable at any time, but was different depending on the position and room. It was randomized which room the subjects started in. The following table is showing what excerpt could be play at what position in the experiment. The processed sounds were only playable at the further position due to the results from the pilot study which showed that both eqs was perceived as farther than the reference. So the reference stimuli had a reverb that sounded suitable for the close position and the farther position had different processing’s to see if the eq:s made any preferable changes to the sound.

As it is shown in the table 2 below, eq 7 was always the playable excerpt at the farther distance in the red rooms. In the green rooms there were no change in the stimuli no matter what distance it was played from. The Blue rooms always had eq 6 processed at the farther distance.

<table>
<thead>
<tr>
<th>Table 2: Shows what sound that was playable at the different positions</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Large Room</strong></td>
</tr>
<tr>
<td>Red</td>
</tr>
<tr>
<td>Blue</td>
</tr>
<tr>
<td>Green</td>
</tr>
<tr>
<td><strong>Small Room</strong></td>
</tr>
<tr>
<td>Red</td>
</tr>
<tr>
<td>Blue</td>
</tr>
<tr>
<td>Green</td>
</tr>
</tbody>
</table>

27 subjects participated in the main experiment. All except for one subject were first- and second year audio engineer students from LTU. The one who wasn’t was a third year composition student who also claimed to be an experienced listener. The reason for mainly choosing audio engineer students was because they’re...
all used to listen critically. Having experienced listeners performing the test made it more likely to get more useful and accurate data than inexperienced listeners probably would have. Everyone used the same equipment and got the same instructions. They were handed a questionnaire which they were asked to read before starting the experiment. Instructions about their task were included in the questionnaire. They were free to ask questions during the experiment. Most often the experiment took around 10 minutes. 3 subjects were tested at the same time at the most, on 3 PC computers with the same specs, they run with Windows 7, Intel i5 4570 3.2 GHz quad-core processor and had a GeForce GTX 705 graphics card. In the cases where three subjects participated at the same time, they were placed not to see each other’s screens. All subjects used Beyer dynamic DT 770 headphones and at the same playback amplitude which was set by the experimenter. According to Goodwin (2009), most players use headphones when gaming, so using headphones for the experiment seemed to be the most ecologically valid playback tool.

All subjects saw themselves as experienced listeners, their gaming experience is shown in figure 7 below.

![Gaming experience](https://example.com/gaming_experience.png)

*Figure 7: Shows the subjects gaming experience according to their own estimation.*

**Questionnaire**

The questionnaire for the main experiment began with instructions about the subject’s task and the controls to navigate through the experiment. On each level they were asked three questions and after finishing the experiment they answered two questions about their listening and gaming experience. The questionnaire and the subjects answers was written in Swedish, and can be seen in appendix 2, but are translated here for convenience.

**Instructions**

*This experiment is about game sound.*

You will play two levels, whereof every level contains three rooms. One level has a picture of a cat, the other has a picture of a dog. Each room has a unique color of the picture so you can distinguish between them. Your task is to listen for differences in the sound in the rooms and afterwards choose one room that
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you prefer the most. You cannot look around, nor move. What you can do is to play a sound and toggle between two positions in every room. It is necessary to listen from both positions before making any decisions. There is no time limit.

For each level

1. a) Did you perceive any difference in the sound between the rooms?
   b) If yes, which of the rooms did you prefer? The Red, the Green or the Blue?
2. What in the sound made you prefer that room before the others?

Experience

1. Do you study audio engineering and/or see yourself as an experienced listener?
2. Highlight which of the following three options that describes you best.
   I play games often
   I play games sometimes
   I play games rarely

The responds from the question 1b (If yes, which of the rooms did you prefer?) from the subject was later quantized into different attributes in order to see if any patterns in the subjects preferences was shown. This could show for example that one room was chosen because of a certain attribute that was preferable. It could either show that the subjects chose a certain room based on the same attribute or if subjects heard different attributes that made them prefer a room. The attributes were chosen based on patterns in the data from the experiment. The chosen attributes were naturalness, realism, clarity, muffledness, pleasantness, and the last category were “other” which included all answers that did not fit the mentioned attributes.
Results

In this section the results are presented. Out of the 27 subjects, 22 will be presented in the results due to 5 cases of misinterpretation of the task from the main experiment. The 5 excluded subjects had included all audible sounds in the rooms. They had put a lot of focus on the sound of the fan in the small room, which could be seen in the answers of the second question. One example was subject 11 who chose the green small room with the reason that the fan sounded best in that room. Out of the 22 presented subjects, two subjects did not perceive any difference in the stimuli in the small room and one subject did not perceive any difference in the large room.

Figure 8 shows the results of which of the rooms in both levels the subjects preferred. The colors of the bars represents the colors of the cats and dogs, so the red bar from the large room is the value of how many preferred the red large room. As the diagram shows, all rooms except for the red large room, are almost evenly distributed. The most preferable room from the large rooms was the blue room which was the room processed with eq 6. From the small rooms, the green and red rooms were the most preferable, by one subject. The blue room had only one subject less.

The second question was what in the sound of the stimuli the subjects preferred from the room they chose. Here is a representation, in English, of the subjects own words. In the charts below, different words with similar meaning have been grouped together and are being categorized under the attributes natural, realistic, clear, muffled, pleasant and other. The color of the boxes represents the color of the cats and dogs in the different rooms.
**Table 3:** Shows the subjects own motivations why they preferred the red room in the small room level

<table>
<thead>
<tr>
<th>Natural</th>
<th>Realistic</th>
<th>Clear</th>
<th>Muffled</th>
<th>Pleasant</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>More natural</td>
<td>Warmer, reflected the visuals</td>
<td>Sounded damped in a preferred way</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Natural</td>
<td>Fitted the visuals best</td>
<td>The others felt too far away</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fitted the visuals best</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Table 4:** Shows the subjects own motivations why they preferred the blue room in the small room level

<table>
<thead>
<tr>
<th>Natural</th>
<th>Realistic</th>
<th>Clear</th>
<th>Muffled</th>
<th>Pleasant</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soothes the picture</td>
<td>Clearest change, fitted the visuals best</td>
<td>Wider sound</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Clearest change, fitted the visuals best</td>
<td>Clearer. Worked best with the fan</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>More realistic</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>More realistic, sharp</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Table 5:** Shows the subjects own motivations why they preferred the green room in the small room level

<table>
<thead>
<tr>
<th>Natural</th>
<th>Realistic</th>
<th>Clear</th>
<th>Muffled</th>
<th>Pleasant</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>More natural</td>
<td>Natural, Fitted the visuals best</td>
<td>Best soothing reverb</td>
<td>Something in the reverb</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Natural. Fitted the visuals best</td>
<td>Fitted the visuals best, hard surfaces “cold”</td>
<td>Had the right amount of sharpness</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>The others had exaggerated processing</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Table 6:** Shows the subjects own motivations why they preferred the red room in the large room level

<table>
<thead>
<tr>
<th>Natural</th>
<th>Realistic</th>
<th>Clear</th>
<th>Damped</th>
<th>Pleasant</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fitted the visuals best</td>
<td>Drier sound</td>
<td>Fuller sound</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Table 7:** Shows the subjects own motivations why they preferred the blue room in the large room level

<table>
<thead>
<tr>
<th>Natural</th>
<th>Realistic</th>
<th>Clear</th>
<th>Damped</th>
<th>Pleasant</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>More realistic</td>
<td>More clear</td>
<td>soothing treble</td>
<td>worked best with the reverb</td>
<td></td>
<td></td>
</tr>
<tr>
<td>more natural</td>
<td>Fitted the visuals best, Cold and hard</td>
<td>Good amount of reverb</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Fitted the visuals best, hard surfaces</td>
<td>The other felt too sharp</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Table 8:** Shows the subjects own motivations why they preferred the green room in the large room level

<table>
<thead>
<tr>
<th>Natural</th>
<th>Realistic</th>
<th>Clear</th>
<th>Damped</th>
<th>Pleasant</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fitted the visuals best</td>
<td>Hard surfaces</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

19
Evaluation of Reverb with Eq as a Tool for Egocentric Distance Perception in Games

<table>
<thead>
<tr>
<th>Natural</th>
<th>Realistic</th>
<th>Clear</th>
<th>Damped</th>
<th>Pleasant</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>More natural</td>
<td>More realistic</td>
<td></td>
<td></td>
<td>Less sharp</td>
<td>More depth</td>
</tr>
<tr>
<td>more natural, better timbre</td>
<td>Fitted the visuals best</td>
<td></td>
<td></td>
<td>The others had exaggerated processing</td>
<td></td>
</tr>
<tr>
<td>More realistic</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 3 to 8 shows all subjects motivation why they chose a specific room. Some comments fit more than one attribute, they are therefore presented more than once. Some subjects have commented on the other two rooms instead of the room they chose. For example that the other two rooms were too sharp or too exaggerated, in those cases it has been categorized under the most pleasing sound. In cases where subjects have commented that the sound fit the space or picture, it has been interpreted as realistic. A quantization and translation of the qualitative data has been made in order to compare the frequency of certain descriptions between the different excerpts.

![Attributes Small Room](chart.png)

*Figure 9: Shows the frequency of the grouped attributes from the small rooms.*

Figure 9 shows that most subjects made their decision in the small rooms based on realism. The attributes clear, muffled, pleasant and other only contains one bar. Words associated with the attribute clear was only brought up by subjects who preferred the blue small room. Subjects who chose the red small room were the only ones to comment words associated with muffled. Pleasant was an attribute that only was associated with comments from subjects preferring the green small room. No one choosing the blue small room wrote anything that could be associated with naturalness. Figure 10 below shows the reasons behind the subject’s choices in the large rooms.
Just as for the small rooms, realistic was the most commonly attribute associated with the subjects' comments for the large rooms as well. Clear and muffled only contained one bar for the large rooms as well, but only one subject on each. The attribute pleasant meanwhile, had comments from all three rooms associated with it.

Analysis

A chi-squared test was run on the main results from both rooms to see if they were statistically significant or not. The main results were the data from the subjects preferred rooms on each level. With 2 degrees of freedom the value had to exceed the critical value which is 5.991, in order to reject the null hypothesis. The value for the small room were 0.1001 and 3.714 for the large room. This meant that the null hypothesis was accepted in both cases, even if the blue large room was the most preferred room, the tendencies weren’t strong enough to be of any significance, according to the subjects' preferences. In appendix 3, the chi-squared calculation is presented.

Even if the main results were close to random distribution, the attributes shows that the subjects in many cases perceived similar differences between the rooms. The subjects who preferred the blue small room did so because it had the clearest transformation in the sound between the closer and farther positions or/and they chose it because it sounded the most realistic. For all other rooms, the subject’s comments were grouped to more than two attributes which could tell that they had very spread out reasons for preferring the other rooms.
Discussion

To respond the research question, “Is it preferable to listeners to varying the timbre on the reverb input in games with an eq such that it simulates distance to reflective surfaces?” the answer is no. It is not significantly preferable compared to using no eq at all. Already from the beginning of the design process it proved difficult to apply eq as a convincing distance cue. The results from the pilot study showed that eq 6 and eq 7 were perceived as farther away than the reference by all participants. The results from the main experiment though, showed that subjects own preference were very different from one another. No patterns were found in the way they chose a room in relation to their gaming experience. Some attributes tended to be associated with certain rooms, but the subject’s preferences were still too different to show any statistical significance.

The pilot study was from the beginning an informal test that would investigate what kind of eq configuration or configurations that could change the perceived distance in the reverb. The seven eq configurations were designed by the author without consulting with anyone else. Even though the eqs were designed with confidence that they’d represented all critical band-widths based on theory and personal judgement, it might have been a good idea to let the subjects for the test pilot design their own eqs. For example, one that they perceived as closer and one as farther. This could have led to changes in the designing of the eqs, if the subjects found other band-widths more important for distance perception. That would result in even more confidence that the research was based on the eq configurations that might have been perceived similarly by many listeners.

When designing the pilot study, the stimuli, reverb and eq had to be fixed. The first thing that was designed was the stimuli. To maintain the ecological validity, the stimuli had to be a sound that a character in a FPS shooter game could have generated. Since the experiment would be about egocentric distance perception it had to be a self-generated sound from the character. A gunshot would be a natural choice as the stimuli since the weapons in a FPS shooter game is important for character identification and triggered by the character. A problem with a gunshot as stimuli though would be that it’s difficult to graphically illustrate the shots. It would be too time consuming in order to make it in an experiment, therefore it was decided to use a reload sound of a weapon instead. It wouldn’t necessarily need to be illustrated graphically and it is a type of sound that exists in all FPS shooter games. The stimuli was designed to sound like a really heavy weapon which enabled it to realistically have a wide frequency spectrum. The main experiment was designed in parallel with the pilot study. Before finalizing the stimuli, it was made sure that a suitable weapon in unreal engines provided assets. Also the rooms from the main experiment were designed before the specific reverbs were chosen for the pilot study. That enabled the reverbs to suit the rooms in the main experiment very well.

The eq configurations were very simple, in most cases only one or two frequency bands were manipulated. More complex eq configurations would maybe have given clearer results, but it would have been less controlled. It would be harder to know the reason for the outcome of the results and to have useful data for further research. The pilot study had room for improvements, maybe the outcome would have been different if they too were inside a game, seeing the room and player position. If they would have been able to position the character at the distance they perceived, maybe it would have been easier for them to evaluate the
different eqs. If they could both see the room and hear if the manipulation of the sound were fitting or not to the current position, the results might have been more accurate.

Choosing which eq/eqs to use for the main experiment was easy. Eq 6 and eq 7 were the only ones with clear results. They were both boosted in high frequencies and were perceived as farther away. That result was not expected since studies have shown that lower amount of high frequencies should be perceived as farther away. It is hard to say why that is, it could be that a boost in high frequencies might increase the perceived reverb time, which could be associated with distance. Another reason could be that a boost in high frequencies made the reverb sound like it had less low frequency content due to the fact that the stimulus were loudness normalized. It seemed much harder to perceive an eq configuration as closer than further away. Eq 1 and eq 4 showed some tendencies of being perceived as closer, but the subjects weren’t united.

Since the reverb already fitted the rooms and the reload sound matched the weapon in the main experiment, no changes in the stimuli were needed from the pilot study. Using a complete level from Epic Games saved a lot of time and made the experiment look professional. The interactivity and therefore the game play experience became very controlled, which ensured that every subject got the same experience. The negative side of that is that it wasn’t much like a game. If the subjects got more freedom, maybe they would evaluate the differences between the rooms in a way that suited them. It would be a greater risk of errors but maybe that would make it easier to have a preference. Freedom in this Case could mean that the subjects could walk around in the rooms and/or play more than one type of sound.

Another problem with the experiment was the chosen positions in the rooms in correlation with the EQ. Since both the distance between the two positions in the rooms and the amplitude of the eqs frequency bands was designed by the author, there were no guarantee that they were optimal. The subject’s preference would maybe look differently if that was changed. Some wrote in the questionnaire that the red and blue rooms were exaggerated, that could have been a reason for not choosing those rooms for many more subjects than the results reveals. Just as for designing the eqs in the pilot study, it would have been a good thing to test and evaluate the experiment on a small group before running the main experiment, just to make sure that the distances and amplitudes of the frequency bands on the eqs were optimal.

In order to make the rooms feel like a real space, some ambience were added. These ambiences were mixed very silent both so that they wouldn’t interfere with the stimuli and so that it would be clear that those sounds were just ambiences. Unfortunately some subject evaluated the ambience sounds instead of the stimuli, which of course affected their results. It was never a question whether or not they should be included in the results, they had interpreted the task incorrect, and therefore couldn’t they be included. This could have been prevented though, if the description in the questionnaire would have been clearer. The stimulus were in mono, this was a way to control what was being evaluated. If the reverb were in stereo there would be even more room for evaluating attributes in the sounds that weren’t part of the test. Since the character in the game weren’t able to move or look around, the ecological validity weren’t compromised that much by using a mono reverb.

The experiment was about relatively small changes in the stimuli, so it seemed logical to use experienced listeners as subjects. There were also a higher probability, than inexperienced listeners, to get useful
Information out of the question “why” they preferred a certain room before the other. Audio engineering students at LTU are used to talk about sound and use attributes to describe features of sound. Due to the fact that no earlier research was found in this specific area, it was hard to know how difficult it would be to discriminate the different eq processing’s and to even have a preference. If the subjects would be inexperienced listeners, there would be a risk that the experiment would be too difficult for them, which could lead to unclear results. If the experiment would be too difficult even for experienced listeners, something about the design of the experiment would most likely be the problem. Therefore, experienced listeners minimized the risk that the subjects would be the bottleneck.

Gaming experience were first a high priority since this research is mainly about games. An experienced gamer would probably faster understand the experiment and have a greater idea of how games normally sounds. The best scenario would be if all subject were both experienced listeners and experienced players but unfortunately it that was difficult to find people that fulfilled those requirements. It was therefore decided that listening experience was more important for the experiment. But since gaming experience always were seen as an important demographic and might strongly affect the results, track was kept on the subjects gaming experience.

The experiment was about player’s preference, but the purpose for this thesis was to design a system that could change the reverb so that the egocentric perceived distance changes. The reason for this was that player’s preference is what’s most important when designing games. If the experiment would ask about the perceived distance and not preference the results would not show if this technique is attractive for game developers or not. The pilot study’s purpose was to gain information about perception so that the experiment could focus on preference.

Conclusions
The eq technique that has been investigated in this research could be used today. It is not a question of how to design a system like that, it is why a game developer would invest time in this technique. The results from the pilot study showed that boosting high frequencies was perceived as farther away. So it does actually work in that case. But even if it works, what really matters is what players think. As the main experiment showed, players had no united preference. In order for this technique to be used, stronger evidence that it is preferable must be shown. It must show to be good enough so that it is worth a game developer's time. In order to really know whether this technique would work or not, is to test it in real-time. If a player could walk around and really hear how the timbre of the reverb changes, only then this technique could be fully evaluated.

Further Research
Further research should be made in this area. Until sound propagation systems show to be practical and usable in commercial games, techniques like these should be tested. It might be good to test the difference between applying the eq before or after the reverb to be sure of what players think. And more research would also be necessary to find out why eq was not as effective together with an outdoor reverb. The next step in this research could be to enable the players to move freely, but only forward and backward in a room and having the eq change its configuration in real-time. If players find that change preferable, then this technique has good chances of actually work. If not, sound designers would know that it's not worth the effort to design a system like that.
Acknowledgements

I wish to express my sincere thanks to Nyssim Lefford, Assistant Professor at Luleå University of Technology, for being my supervisor.

I am also grateful to Gustaf Terneborg, Anton Ahlberg, Emilia Martin and Cecilia Johansson for participating in the pilot study, all studying audio engineering at Lulea University of Technology.

Special thanks to Gustaf Terneborg for loudness normalizing all stimulus for the experiments.
Evaluation of Reverb with Eq as a Tool for Egocentric Distance Perception in Games

References


Evaluation of Reverb with Eq as a Tool for Egocentric Distance Perception in Games

Appendix 1 - Screenshots of the rooms

Figure 11: Shows the blue large room from the farther distance as the subjects saw it during the experiment.

Figure 12: Shows the blue large room from the closer distance as the subjects saw it during the experiment.
Figure 13: Shows the green small room from the closer distance as the subjects saw it during the experiment.

Figure 14: Shows the green small room at the farther distance as the subjects saw it during the experiment.
Appendix 2 - Questionnaire (in Swedish)

Instruktioner

Kontroller i spelet

= spela upp ljudet

= skifta mellan positioner

[E] = Byt rum inom samma bana

[R] = Byt bana

Formulär Hund-banan
1. a) Upplevde du någon skillnad i ljuden i de olika rummen?

b) Om ja, vilket av rummen föredrar du ljudet i? Det gul, blå eller gröna?

2. Vad i ljudet fick dig att föredra just det rummet före de andra?

Formulär Katt-banan
1. a) Upplevde du någon skillnad i ljuden i de olika rummen?

b) Om ja, vilket av rummen föredrar du ljudet i? Det gul, blå eller röda?

2. Vad i ljudet fick dig att föredra just det rummet före de andra?

Experiment examensarbete - formulär
1. Går du ljudteknikutbildningen och/eller anser dig vara en van lyssnare?

2. Kryssa i vilket av följande tre alternativ som passar bäst in på dig:

Jag spelar dataspel ofta
Jag spelar dataspel då och då
Jag spelar dataspel välldigt sällan eller aldrig
## Appendix 3 - Analysis calculation

<table>
<thead>
<tr>
<th></th>
<th>Large Room</th>
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</tr>
</thead>
<tbody>
<tr>
<td>Total amount</td>
<td>21</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Critical value</td>
<td>5.991</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$E_i = \text{Expected value}$</td>
<td>7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$O_1 = \text{Observed Red}$</td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$O_2 = \text{Observed Green}$</td>
<td>8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$O_3 = \text{Observed Blue}$</td>
<td>10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$X_c^2 = \sum \frac{(O_i - E_i)^2}{E_i}$</td>
<td></td>
<td>$X_c^2 = \frac{(3 - 7)^2}{7} + \frac{(8 - 7)^2}{7} + \frac{(10 - 7)^2}{7} = 3.714$</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Small Room</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Total amount</td>
<td>20</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Critical value</td>
<td>5.991</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$E_i = \text{Expected value}$</td>
<td>6.66</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$O_1 = \text{Observed Red}$</td>
<td>7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$O_2 = \text{Observed Green}$</td>
<td>7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$O_3 = \text{Observed Blue}$</td>
<td>6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$X_c^2 = \sum \frac{(O_i - E_i)^2}{E_i}$</td>
<td></td>
<td>$X_c^2 = \frac{(7 - 6.66)^2}{6.66} + \frac{(7 - 6.66)^2}{6.66} + \frac{(6 - 6.66)^2}{6.66} = 0.100$</td>
<td></td>
</tr>
</tbody>
</table>