Spatialisation of Binaural Audio With Head Tracking in First-Person Computer Games.

Patrik Bergsten

Mikita Kihan

Department of Computer
and Systems Sciences

Degree project: 15 HE credits
Bachelor Programme in Computer Game Development
Degree project at the bachelor level
Spring term 2023
Supervisor: Tobias Falk
Swedish title: Spatialisering av binauralt ljud med head tracking i förstapersonsdatorspel

Stockholm University

Abstract

Audio in today's first person computer games plays a vital role in informing players about their surroundings as well as general gameplay elements. Awareness of the direction, distance, and spatial placement of audio sources can be crucial for players in various contexts.

Spatialising audio through stereo panning can pose challenges to players when it comes to accurately localising sound sources in front, behind, below, or above the player. Binaural audio is another technique used for spatialising audio by simulating how sound interacts with the head and ears before reaching the eardrums from a specific direction before the signal is rendered through the headphones. While binaural audio attempts to alleviate the front-back confusion, the cues from binaural audio are lost when the listener moves their head if some form of head tracking solution is not incorporated. Hence, this study's research question is: *"How is localisation of audio sources in first-person computer games — while wearing headphones— helped by spatialising the soundscape in relation to head movement utilising head tracking technology?"*.

To be able to answer the research question a prototype of a game was developed following design science guidelines. The objective was to timely and accurately localise 14 invisible targets emitting sound in a virtual three-storey house. During one half of the test the spatilisation with head movements was inactive and the other half had it activated in order to compare the testers ability for localisation with and without the tool. The order for which half would have spatilisation activated was randomised for each test.

The research strategy consisted of two types of experiments, blind — with 20 participants, and open — with five testers, that were conducted to measure and evaluate the participants' head movement and performance in terms of accuracy and time of localising the targets by shooting them. For data collection this study used a mixed methods approach that included questionnaires with closed questions and semi-structured interviews. Data about the testers' performance was automatically logged during the test.

The results from the first, blind experiment showed little head movement and no significant impact on localisation performance from the spatialisation. Consequently an open follow-up experiment was performed to discover if the blind experiment design affected the results. The results demonstrated a higher degree of head movement but corroborated the first test in no substantial effect on the testers' accuracy or time when localising the targets.

In summary, there could be found no positive or negative impact on one's localisation of audio sources in first-person computer games —while wearing headphones— when spatialising the soundscape in relation to head movements by utilising head tracking technology. Additionally, some participants found the tool to be unfit for the genre that the prototype resembled and suggested that spatialisation of audio with head tracking could perhaps be better suited for other genres. This could serve as material for future research on the use of head tracking for spatialisation of audio in computer games.

Keywords: Sound localisation, head tracking, binaural, audio, computer games, experiences

Synopsis

BACKGROUND	Spatial audio in computer games is effective at communicating information to players about their surroundings. Binaural audio is sometimes used, which is a method of rendering sound to mimics how humans naturally experience sound, giving listeners more information about directionality than merely stereo panned spatialisation. This technique is still imperfect as some have difficulties with localisation of sound sources. Spatialising the game sounds to the player's head movements could allow for a more immersive experience and possibly increase player performance.
PROBLEM	Localisation of audio through stereo panning can prove difficult if the audio source is located in front, behind, below or above the player. Binaural audio attempts to solve this but the binaural audio cues are lost when the listener moves their head if no form of head tracking is incorporated.
RESEARCH QUESTION	How is localisation of audio sources in first-person computer games —while wearing headphones— helped by spatialising the soundscape in relation to head movement utilising head tracking technology?
METHOD	An artefact, a computer game, was created to assess the usefulness of spatialising audio, following design science guidelines. Blind and open experiments were conducted using mixed methods, including questionnaires and interviews. Quantitative data on testers' head movement and performance was collected. Qualitative data was analysed using thematic analysis, while statistical hypothesis testing were done for quantitative analysis. The experiments involved 25 participants; 20 in blind tests, and 5 in open tests.
RESULT	There is no positive or negative impact on one's localisation of audio sources in first-person computer games —while wearing headphones— when spatialising the soundscape in relation to head movements by utilising head tracking technology. The experience during the open test was considered to be unfamiliar and perhaps inappropriate for certain types of games that the prototype resembled but could perhaps be used more beneficially in other genres.
DISCUSSION	Limitations of this study are; a low sample size for the open experiment, minor inconsistencies in the test, the targets' sound profile, non-individualised spatial audio perception, and a high degree of interview note translation. The originality of the research is the novel combination of head tracking and audio for computer games, as well as the scarcity of studies conducted on this specific topic. Therefore, this thesis can serve as a resource for investigators and game developers interested in utilising or researching head tracking in computer games to enhance auditory performance, immersion, or support visually impaired individuals.

Acknowledgements

We would like to thank our thesis supervisor, Tobias Falk, for his confidence in our abilities throughout this project. We would also like to thank our friends and families for their support. Lastly we would like to thank David Söderström, Aware Mustafa Taher, Olov Karlsson, and our fellow students at the computer game development programme for their feedback and encouragement.

Table of Contents

List of Abbreviations

3D	Three Dimensional
CS:GO	Counter-strike: global offensive
CSV	Comma-separated values
DSV	Department of Computer and Systems Sciences, Stockholm University
FPS	First Person Shooter
HRTF	Head Related Transfer Functions
ITD	Interaural Time Difference
LED	Light Emitting Diode
UI	User Interface
VR	Virtual Reality

List of Figures

List of Tables

1 Introduction

1.1 Background

Many, if not most, of today's commercial computer games use audio to improve players' immersion and performance in the virtual environments. There are many *first person shooter* (FPS) games as well as games of other genres that strive for an informative and realistic audio system that can provide players with an accurate three dimensional auditory picture of their environment. In order to achieve this, games sometimes use binaural audio which is a method of reproducing sound that mimics the way humans naturally experience sound in real life (M. 2022). While spatial audio can be an important part in games certain types like competitive, team-based, FPS games such as *Counter-strike: global offensive* (2012), *Rainbow six: siege* (2015) and *Overwatch* (2016) prioritise it more as being able to know your enemy's position is vital. Another area that can benefit from binaural audio is immersion, as can be seen in the action-adventure game *Hellblade: Senua's Sacrifice* (2017). In addition to providing a realistic experience, the auditory elements of the game intentionally aim to evoke sensations of psychosis and hallucinations in the players, mimicing the main characters mental health challenges (Farkaš et al. 2018). Although binaural audio is sufficient in many games, there is still room for improvement as certain studies have shown that some players experience difficulties with localisation. By spatialising the sounds in a game to the player's head movements could allow for a more realistic and perhaps better performing experience, making this the focus of this study.

1.1.1 Spatialisation of Audio

Spatialisation is the procedure of generating a perception of spatial or three-dimensional (3D) audio experience. FPS games convey information to players mainly through visual displays that render the character's limited field of view. While visual displays are a fit medium for displaying a specific location, audio is capable of supplying information both within, as well as outside, of the player's peripheral (Hermann et al. 2011). Audio can also be helpful under conditions where the visual scene is dark, complex or cluttered (Zahorik 2002). Sound is in other words good for communicating information which changes over time and can be heard over a range of spatial locations whereas vision can only be observed at specific locations (Tannen 1998).

Spatial audio when conveying information from a computer to the user is also called an *auditory display* (Walker and Nees 2011). A strength of an auditory display is that it can be viewed as 'an extra set of eyes and ears' (Tran and Mynatt 2000). Hermann et al. (2011, p. 456) indicated that "the human auditory system does not need a directional fix on a sound source in order to perceive its presence". Results of a study done by Brock et al. (2002) support that statement by showing how 3D sound can improve the user experience through being a background process without disruptively affecting the primary focus of attention. The results of the study showed a significant improvement in performance on the visual search task when auditory displays were used as the users did not have to turn to look at the other screen for visual confirmation (ibid.).

Another strength of spatial audio and auditory displays is navigational decision making which Walker and Lindsay (2006) did a study on. Walker and Lindsay's study focused on leading visually impaired subjects through a three dimensional environment with solely non-speech beacons to see how sound timbre, waypoint capture radius, and practice affected performance. They demonstrated that with correct attributes, spatialised audio can be used to effectively help guide players in a virtual 3D environment

(Walker and Lindsay 2006).

1.1.2 Techniques for Spatialisation

In order to recreate a binaural audio experience the recording of the audio has to be carried out under the same conditions a listener would have in the recorded environment. Recording of binaural audio can be done by using human head analogues with microphones inside the ear cavities, also called dummy heads. (M. 2022)

Essential to the central concept of binaural audio is what is *head related transfer functions* (HRTF). HRTF is a way of modelling the individual differences of the sonic characteristics reaching each ear. The sonic characteristics modelled in a HRTF include the slight changes in frequency caused by the physical interaction with the ears, oral, and nasal cavities, and acoustic shadowing caused by the head and body geometry. The characteristic present in normal stereo recorded audio the *interaural time difference* (ITD) is present in binaural audio also. HRTFs are problematic in that they contribute to a high degree of variance in the perception of sound, however a generalised model can still be used. (Xie et al. 2007)

Recording with a dummy head gives a static rendition of binaural audio — to make it more interactive, for media such as video games, binaural audio can also be achieved by using digital filters on a mono source audio clip. The digital filtering reproduces the effects of a generalised HRTF by modulating the audio frequencies digitally depending on its position and distance in regards to the audio listener. (Widman 2021)

Previously mentioned ITD is "the result of differences in the acoustic paths from the sound source to left and right ears when sources are lateralized" (Blum et al. n.d.). ITD is important because it is the main reason for the so-called front-back confusion. Front-back confusion is when a source in front of the listener is being perceived as being to the back, at a symmetrical position toward the interaural axis, or vice versa, and thus presenting the same ITD (ibid.). A solution for this problem has been proposed more than 50 years ago by Wallach (1940) where he argued that even small head movements could provide information necessary to resolve front-back confusions. Though studies by Wightman and Kistler (1999) and Perrett and Noble (1997) focused on slightly different aspects of the problem of front-back confusions, they reported that head movements reduced localisation error.

A study by Brieger and Göthner (2011) used a group of HRTF presets that were made based on various proportions of human heads. By doing so the researchers let their participants choose a set of HRTFs that matched the testers' individual way of hearing the most and ran the game's sounds through that filter to personalise the experience. The investigators used the FPS action game Unreal Tournament 3 (Epic Games 1991) as their playground for examining the testers' opinions on the use of binaural audio in comparison with stereo sound. Majority of the participants thought that the HRTF technology would increase their performance and immersion and that it did facilitate their localisation of sound sources during the test, especially on the vertical axis. In spite of this, some players had difficulties with localisation experiencing front-back confusions as well as issues with the vertically positioned sound sources (Brieger and Göthner 2011).

1.1.3 Head Tracking

Head tracking has been one of the ways of interacting in virtual and augmented reality communities and has shown to be potentially useful for controlling specific gaming tasks (Bajura et al. 1992; Marks et al. 2010; Rekimoto 1995). The tool has also shown interesting discoveries when used with various head tracking supported modern computer games as demonstrated by (Kulshreshth and LaViola 2013). Though the study used head tracking to affect both visual and auditory displays the results indicated that the tool was useful in more slow paced games as well as shooting games such as FPS and flight combat simulators and was less useful or even potentially detrimental in fast paced games like racing games.

Although previously mentioned FPS games *Counter-strike: global offensive* (2012), *Rainbow six: siege* (2015) and *Overwatch* (2016) provide a relatively good level of sound localisation, head tracking technology could still contribute to the spatialisation of audio. Today's binaural audio in virtual environments diverge from the real human hearing in that the soundscape does not follow along the head movements as in real life. As a consequence, this influences the user's immersion and perception of sound because they cannot interact with the audio through head motion. All the cues given by binaural audio for the localisation are therefore lost without some form of head tracking (Widman 2021).

It is understandable that in dynamic FPS games like Overwatch, that provide a sufficient level of localisation, one would most likely not risk time and attention to any intentional head movements. However, as Kulshreshth and LaViola (2013) pointed out slow paced games and certain FPS shooters could benefit from the tool. In addition, when a player is engaged in the activity of playing to the level of flow (Nakamura and Csikszentmihalyi 2014) —being absorbed by an activity— they may hypothetically do some unconscious body or head movements. Whether head motion is done unconsciously or intentionally it could still prove to be helpful for players since it, being a dynamic cue, could increase the accuracy of sound localisation. Furthermore, not all FPS games possess advanced tools and technologies for spatialising audio like Overwatch. The inclusion of head tracking technology could therefore be of value for games that have room for misinterpretation of the acoustic cues for localisation. In addition, using head tracking for spatialisation of binaural audio is advantageous in that it can be implemented at a relatively low cost, using a webcam and facial recognition software as done by (Ludovico et al. 2010).

1.2 Research Problem

The general interest of this investigation is the improvement of spatial audio in computer games. One of today's problems is that localisation of audio through stereo panning alone can prove difficult due to the front-back confusions problem (Gustafson and Cancar 2020). Binaural audio attempts to solve this issue, as investigated by Gustafson and Cancar (ibid.) and (Brieger and Göthner 2011) but like Widman (2021) states; the cues from binaural audio are lost when the listener moves their head if some form of head tracking solution is not incorporated. Virtual reality systems have head tracking technology integrated, however, as stated by (Munafo et al. 2017), many experience motion sickness, which as a result makes it an incomplete solution to the problem.

Hence, the study's primary purpose is to investigate how localisation of sound sources in a binaural 3D environment can be influenced through the use of head tracking technology. By finding an answer to how head tracking influences localisation of audio sources in a binaural 3D environment we hope to shed light on whether the technology solves the above mentioned issues. It was interesting to observe the users' impressions of the head tracking technology and its' impact on their experience and gameplay.

This study could perhaps be of value to the game developers who attempt to make audio in video games as realistic, immersive and informative as possible. Hopefully other researchers could benefit from the results in the future.

1.3 Research Question

How is localisation of audio sources in first-person computer games —while wearing headphones— helped by spatialising the soundscape in relation to head movement utilising head tracking technology?

2 Methodology

2.1 Choice of Method

2.1.1 Design Science

Design science according to Johannesson and Perjons (2014) is a scientific strategy for solving problems by creating scientifically and technically supported artefacts. The method framework for this process consists of five activities:

- Explicate Problem
- Define Requirements
- Design and Develop Artefact
- Demonstrate Artefact
- Evaluate Artefact

Explicate Problem activity "is about investigating and analysing a practical problem. The problem needs to be precisely formulated and justified by showing that it is significant for some practice." (ibid.).

Define Requirements activity suggests an artefact that will solve the explicated problem and elicits the requirements related to the artefact (ibid.).

Design and Develop Artefact is the process of creating an artefact which "addresses the explicated problem and fulfils the defined requirements" (ibid.).

Demonstrate Artefact is the activity where the artefact is being used in an illustrative or real-life condition to prove its' feasibility and ability to solve the explicated problem (ibid.).

Evaluate Artefact activity "determines how well the artefact fulfils the requirements and to what extent it can solve, or alleviate, the practical problem that motivated the research" (ibid.).

This framework is an constantly iterative process and the purpose of a design science research is to not only create artefacts but to also learn about them by answering questions related to the artefacts. While each design science activity has its' own commonly used research strategies and methods, because different activities may require different approaches, any research strategy can be used in any activity. When explicating a problem or defining requirements instruments such as surveys, case studies, and action research can be used. For the demonstration and evaluation of an artefact one can use experiments, case studies and action research. Whereas the designing and developing of an artefact requires creative methods instead, as research strategies are often less important during this activity (ibid.).

However, not all design science researches concentrate on all of the five activities of the method framework in depth as it depends primarily on the study's focus. For example, there is at least five typical cases of design science research to which a project can belong: *Problem-Focused*, *Requirements-Focused*, *Requirements- and Development-Focused*, *Development- and Evaluation-Focused* and *Evaluation-Focused* (ibid.). In this study every design science activity was planned to be given a fair amount of attention but more focus lay on the designing and developing, demonstrating, and evaluating the artefact. It is also important to underline that during the designing and developing stage a prototype of a game was created in order to be used as a ground for using, demonstrating and evaluating the main artefact and focus of the investigation - head tracking. The plan was in other words to create an artefact - a prototype, together with which an already existing artefact - head tracking, would be used in order to be investigated.

The explication of the problem was presented in the Background and Research Problem chapters where sufficient amount of information using scientific literature related to the formulated issue was provided. With regard to definition of the requirements, and design and development of the prototype an in depth description was granted under Application of Method chapter. While the activity of demonstrating and evaluating the artefact - head tracking, was performed using research strategies and methods specified in the following sections below.

2.1.2 Research Strategy

Research strategy is a general plan for how a study should be conducted through planning, execution and monitoring (Johannesson and Perjons 2014). A number of different research strategies exists where each has unique advantages and disadvantages depending on the character of the study.

An experiment is an empirical investigation under controlled conditions which focuses on studying relationships between specific factors (Denscombe 2014). As Johannesson and Perjons (2014) stated, investigating relationships can be done by formulating a *hypothesis* which consists of dependent and independent factors. Since the focus and purpose of an experiment is to prove or disprove the impact of one factor on another; experiment was chosen to be the primary data research strategy for this study. The decision was based on the fact that spatialising audio with head tracking in computer games was the causal factor, and player's ability to localise audio sources was the consequent factor. In addition, as it was previously mentioned, experiment is a commonly used research strategy during the design science activities such as demonstration and evaluation of the artefact (ibid.). The formulated hypotheses were thus:

> Null hypothesis 1: "Spatialisation of audio through head tracking in FPS computer games has no influence on one's precision in localising sound sources".
>
> Alternative hypothesis 1: "Spatialisation of audio through head tracking in FPS computer games has an influence on one's precision in localising sound sources".
>
> Null hypothesis 2: "Spatialisation of audio through head tracking in FPS computer games has no influence on one's ability in localising sound sources vertically".
>
> Alternative hypothesis 2: "Spatialisation of audio through head tracking in FPS computer games has an influence on one's ability in localising sound sources vertically".
>
> Null hypothesis 3: "Spatialisation of audio through head tracking in FPS computer games has no influence on one's time in localising sound sources".
>
> Alternative hypothesis 3: "Spatialisation of audio through head tracking in FPS computer games has an influence on one's time in localising sound sources".

An advantage with experiment is that it is regarded by many people, as well as some social scientists, to be the most scientific and credible approach to research (Denscombe 2014). Experimental research also permits high level of precision and consistency, is capable of identifying and explaining the exact cause of the observed effect, and is repeatable in certain types of experiments (ibid.). When it comes to disadvantages with experiments there is always a risk that other factors may intrude and affect the results, which imposes additional attentiveness and preparation on the researcher (Johannesson and Perjons 2014). This disadvantage, however, can be mitigated by using laboratory experiments that enable researchers to control various factors by carrying out experiment in an artificial environment (ibid.). In return, this leads to another problem being the settings of the laboratory experiment could be so artificial that the conclusions drawn are not applicable in the 'real-life' scenarios. Other disadvantages are related to ethical and practical problems in controlling relevant variables and treating control or experimental groups (Denscombe 2014).

2.1.3 Research Method

While research strategies provide high-level guidance, research methods work as a tool for performing a concrete task (Johannesson and Perjons 2014). Research methods can be quantitative, to gather numeric data, or qualitative to gather data including text, sound, images and video. There is a number of data collection methods some of which have been associated with specific research strategies because of their usefulness and efficiency. Nevertheless, any data collection method can be usable for a given strategy and while it is common to only use one data collection method more can be employed. In fact, it can be advantageous to use different methods as they can complement each other and provide a more complete picture of the study. "The approach of combining research strategies and methods (not only data collection methods) is called the *mixed methods* approach" (ibid., p. 55).

This study made use of mixed methods by using both quantitative and qualitative methods as it was desirable to investigate the problem from different perspectives. Quantitative data was firstly gathered through measuring testers' head movements, time of finding the objectives - *ghosts*, and the accuracy of shooting them. These properties were used as variables to see if e.g. increased head movement under the use of head tracking had an effect on the time of finding a ghost or on the accuracy of shooting one.

The second method for collecting quantitative data was questionnaires with closed questions. A questionnaire is a list of typically brief and unambiguous questions (ibid.). Every respondent answers an identical set of questions which directly ask about the points concerned with the research (Denscombe 2014). This makes questionnaires effective in providing consistent and precise results as well as also being easy to arrange (ibid.). Additionally, Johannesson and Perjons (2014, p. 57) point out that questionnaires are inexpensive and "offer standardised data when closed questions are used, which eliminates the need for interpretation of answers and thereby simplifies data analysis". However, closed questions run the risk of influencing the respondents' answers towards being biased as the available answer-options are set by the researchers (ibid.). Another disadvantage with questionnaires is that they "offer little opportunity for the researcher to check the truthfulness of the answers given by the respondents" (Denscombe 2014, p. 182).

The method for collecting qualitative data was semi-structured interviews. An interview, similarly to questionnaires, provides the researcher with data that comes directly from the respondent (ibid.). However, one of the main differences is that this data collection method happens physically face-to-face which allows for some advantages as well as disadvantages. The first advantage of interviews is the depth of information and the insights that can be gained. Interviews also respect informants' priorities as they give them the opportunity to expand ideas and views. Lastly, interviews have high validity of data and are flexible in that the researcher with semi-structured and unstructured interviews can make adjustments during the enquiry (ibid.). Semi-structured interviews differ from regular interviews in that "the respondents are allowed to formulate the answers in their own words" (Johannesson and Perjons 2014, p. 57) and let the respondents express themselves in a more unrestricted way. Speaking of the disadvantages, interviews are time-consuming, may invade the respondent's privacy and have an uncertain reliability as the data collected is, to some degree, affected by the context and individuals involved (Denscombe 2014). More importantly, the validity of the data is put at risk because the data are based on the informants' words and not actions which may not coincide. Another disadvantage is the *interviewer effect* where the identity of the researcher could influence the answers of the interviewee (ibid.).

Lastly, the set sample size was planned to be 20. The intention was to get a good data saturation (Fusch and Ness 2015) while being able to collect and analyse data in time.

2.1.4 Data Analysis

Raw data does not speak for itself and needs to be prepared, interpreted, analysed and presented in order to be ready for the drawing of conclusions (Johannesson and Perjons 2014). While quantitative data analysis works on quantitative data like numbers; qualitative data analysis works on qualitative data like words, images and video (ibid.). Since this study involved the mixed methods approach it required that qualitative and quantitative data were treated accordingly.

2.1.4.1 Quantitative Data Analysis

To ensure reliability it is important to use appropriate statistical methods on high-quality data. For validity it is important to gather data pertinent to the research question, to minimize bias, and to exclude confounding variables unrelated to the examined variable. For analyzing quantitative data one can use descriptive or inferential statistics. While descriptive statistics is used for describing a sample of data, inferential statistics intends to draw conclusions about a population that the sample represents by investigating relationships between measured variables. (ibid.)

Data gathered through questionnaires gives ordinal data, meaning that data can be ordered but the differences cannot be clearly quantified. An example of ordinal data is the Likert scale where the options might be ”strongly disagree” with incremental steps up to ”strongly agree” (ibid.).

In order to discern if there is significant evidence to support or reject a specific claim there exists hypothesis testing (Hjerm et al. 2014). The Wilcoxon signed-rank is such a test and is utilised to asses how likely the observed means are due to chance when two sets of observations are related in some way (Borg and Westerlund 2020). Two sets of observations could be said to be related when the same participants are measured but at different times or under different conditions, such as before and after receiving a medical treatment. Other hypothesis tests such as t-tests require the measurements to follow a normal distribution (ibid.).

The Wilcoxon signed-rank test, however, does not require a normal distribution. Since the Wilcoxon signed-rank test sorts the absolute differences in the samples into ranks and discards ties the results become inaccurate if measurements are not continuous. Therefore the data being continuous, or accurate to a number of decimal places, is therefore a requirement for utilising the Wilcoxon signed-rank test. (*Social Science Statistics* 2018)

Also, the Wilcoxon signed-rank can either be one-tailed or two-tailed. In one-tailed tests the alternative hypothesis is set before the experiment to either be that the data shows a greater of a lesser mean, but not both. For two-tailed tests the alternative hypothesis is that there will be a difference between the means, without specifying in which direction. For all test calculations of this study, one-tailed calculations were used. (Borg and Westerlund 2020)

In the Wilcoxon signed-rank test, the test statistic W-value is calculated as the sum of ranks of the positive or negative differences between the paired observations. The W-value indicates the strength of the differences, ranging between 0 and $N(N + 1)/2$, where N is the number of paired samples (*Social Science Statistics* 2018). The W-value is used to determine the magnitude of the observed differences in the populations, larger values indicating a larger difference.

In addition, the Wilcoxon signed-rank test yields a p-value, which is the probability that the differences in the measurements are from chance. Significance level, or α-value, is a chosen limit that the p-value must fall below to be accepted. Commonly chosen α-values are .05 (5%) or .01 (1%). Thus, if the p-value is less than the chosen significance level, $p < \alpha$, then the null hypothesis can be rejected. (Borg and Westerlund 2020)

As a consequence, the significance level chosen for this study was .05, meaning that if there would be shown a less than a five percent chance of the observed positive result in the data stemming from random chance alone, it would have be enough to reject the null hypothesis.

When data is collected from independent samples, meaning from another set of participants or conditions entirely, the Wilcoxon signed-rank test becomes unsuitable and instead the Wilcoxon rank-sum test is more appropriate. The Wilcoxon rank-sum test gives a U statistic which quantifies the direction and size of the difference in ranks between the samples, meaning that the sample sizes do not need to match for comparisons to be made. A z-score is calculated from dividing the difference of the the U statistic and the expected value, $E(U)$, and dividing by the standard deviation of U, σ_U. (ibid.)

$$z = \frac{U - E(U)}{\sigma_U}$$

The p-value can then be obtained for the Wilcoxon rank-sum test by comparing the z-score to the normal distribution of the U statistics. (ibid.)

Statistical analysis for ordinal data, such as Likert scale survey responses, the split-half reliability test can be done. To perform the split-half reliability test, the data is randomly divided into two equal halves, and the results are compared. If there is a high degree of similarity between the halves, it can provide higher confidence in the measurement's reliability. (Denscombe 2014)

2.1.4.2 Qualitative Data Analysis

When analyzing qualitative data like text there is a number of methods to choose from, five common approaches described by Denscombe (ibid.) are: content analysis, grounded theory, discourse analysis, conversation analysis, and narrative analysis. Content analysis focuses on the quantification of the text whether it is in the form writing, sounds or pictures. Grounded theory aims at creating theories and concepts that capture the meaning located in the data. Discourse analysis focuses on the implied meaning of the data rather than its' explicit content. Conversation analysis concentrates on the underlying rules of everyday talk. Finally, narrative analysis aims at creating a personal story containing a plot line and a specific purpose (ibid.). The most appropriate method of the mentioned ones would be grounded theory, however, this method is demanding in that it relies on the iterative addition of new data and constant comparison as a means of analyzing the data (Johannesson and Perjons 2014).

Another commonly used method, which was chosen for this study's qualitative data, is thematic analysis, which as stated by (Braun and Clarke 2006, p. 79), "is a method for identifying, analysing and reporting patterns, or *themes*, within data". While there are no exact limits to what can count as a theme there are some key points. A theme would ideally have a number of instances across the data set, which would also show importance towards the overall research question, meaning that the frequency of instances on its' own does not necessarily increase a theme's value. Another key point of what can count as a theme is related to the type of approach one adheres when conducting a thematic analysis - inductive or theoretical (ibid.).

An inductive approach means that the identified themes are heavily linked to the data (Patton 1990) and are not driven by the researcher's theoretical interest in the area (Braun and Clarke 2006). As Thomas (2006, p. 238) claims "the primary purpose of the inductive approach is to allow research findings to emerge from the frequent, dominant, or significant themes inherent in raw data". Whereas a theoretical approach, also known as deductive, "would tend to be driven by the researcher's theoretical or analytic interest in the area, and is thus more explicitly analyst-driven" (Braun and Clarke 2006). Deductive analysis, unlike inductive, is used to test whether data are consistent with an investigator's identified or constructed assumptions, theories or hypotheses (Thomas 2006).

The choice between the two approaches is thus dependent on whether one is coding for a specific research question - theoretical approach, or whether the specific research question can evolve through the coding process - inductive approach (Braun and Clarke 2006). Although these two methods are evidently different from each other, in practice, many evaluation projects use both inductive and deductive analysis (Thomas 2006). As the research question was quite specific and hypotheses were formulated it was clear that the study was driven by the investigators' interest in the area and should therefore have utilised a deductive analysis. However, because it was also curious to see what themes would emerge from the data without a particular goal in mind, it appealed to us to use an inductive analysis as well. The combination of these approaches would consequently serve as a complement to each other and lead to a richer analysis of the data set.

2.1.5 Alternative Methods

2.1.5.1 Alternative Strategy

Case studies could be an alternative research strategy as they focus on providing a deep and detailed understanding of a phenomenon. While an experiment must strive to control for and eliminate factors that interfere with the results, a case study does the opposite. Case studies take all factors in regard and analyse how they affect the phenomenon as they do in real life. Especially exploratory case studies try to identify cause and effect relationships that explain what affects events (Johannesson and Perjons 2014).

The fact that a case study can focus on a small number of instances or a single instance would make it suitable for the scope of this study, since the instance could be studied in detail it would still give a large amount of information. The very nature of a case study though, is to observe the instance in its ordinary context to be able to gain a deep understanding of it (ibid.). Altering it in any way speaks against the suitability of it as a case study. There exist many games, if not made specifically for head tracking technology, at least compatible with it. Unfortunately, not many games using head tracking technology does so without including visual elements. Since the question being studied pertains to audio alone case study is deemed unsuitable for this research.

2.1.5.2 Alternative Methods

Structured interviews could be used instead of semi-structured in order to keep the interviewee restrained to the fixed set of questions as to gather specific information. However that would keep the informant from telling any potentially useful information about their experience and impression outside of the questions' boundaries that could relate to aspects of the problem or factors that influenced the results.

Another alternative data collection method that could be used is systematic observation. Systematic observation has the advantage of the researcher being able to observe what the respondents do instead of say (ibid.). Since systematic observations strive to make observations more objective they constantly keep researchers informed about what they should focus on (ibid.). This could, to some extent, increase the validity of the data because researchers would pay attention to the most important parts of the investigation (ibid.) and be confident that the received data is based on the informant's actions (Denscombe 2014). However, the data collected may be superficial and lack the context that could have affected the observed (Johannesson and Perjons 2014). Hence, this method also would not fit the context of the study as it involved an artificially created setting which obviously violates the naturalness of the environment.

2.2 Application of Method

2.2.1 Application of Design Science

To test and investigate spatialisation with head tracking a prototype of a game similar to those of FPS genre was chosen to be created with the Unity game engine (Unity Technologies 2004).

Previous research has stated that localisation of audio sources proved easier for subjects if the sound had objects to reverberate against instead of being set in a free field (Walker and Lindsay 2006). Since audio localisation—although helped by binaural audio—still can prove more difficult for some, the environment should therefore be designed to facilitate in localising audio sources as much as possible. An indoor setting was therefore deemed appropriate. When reverberation plays such a significant part in audio localisation it is advantageous to have an environment with enough visual fidelity capable of conveying the material properties. If a material reflects sound like tile or polished concrete it is of help if it can easily be identified as the material it is meant to represent.

When testing for localisation of audio sources above and below the listener it is appropriate that the building would also be multi storied since this gives more opportunity for the audio source to be above or below the player. For these reasons, a building with good visual fidelity, with modular walls and staircases was chosen to have as a setting for the game.

2.2.1.1 Head Tracking

The system for head tracking uses three infrared light emitting diodes (LED) mounted with a clip to the testers' headphones. The positions of the lights are registered by an infrared camera mounted on top of the testers' monitor and then the accompanying software triangulates the position in 3D space, giving the relative position of the wearer's head to the monitor.

The audio listener is a separate game object, a *child* to the game camera. Briefly; the Unity game engine uses a hierarchy of game objects where they have a parent-child relationship if one is nested under the other. If a parent moves or rotates, it moves and/or rotates its child with it, but the child does not affect its' parent. With head tracking engaged we used the relative position of the head to alter the audio listener's local position and rotation within the parent — the camera. When turned off, the audio listener's position was set to the camera's position, following the camera as the players would move or rotate it.

The equipment used, TrackIR by NaturalPoint Inc. (n.d.), is a commercial product used for head tracking in video games. Most common gaming applications for head tracking are military simulation shooters and flight simulators where it is used to move the player's view on the screen with their head movements (Kulshreshth and LaViola 2013).

2.2.1.2 Game Design

The testers start with their player character within the house and are given a short introduction to how the controls work and can familiarise themselves briefly with the environment. The challenge is presented as a game where the players are hunting ghosts. The ghosts are invisible but give off an audible sonar like pulse (Tran and Mynatt 2000), a modulated heartbeat sound. 14 ghosts in total are present within the house and the player must find and eliminate as many of them as possible to complete the challenge. At any given time, only one ghost is active within the house to avoid confusion.

It is communicated to the players that the ghost hunting weapon does not go through walls so they have to move to the same room as the ghost. The players aim their reticle at where they believe they hear the ghost from.

If the player misses and the ghost had line of sight to the player character; the ghost 'gets scared' and shows themselves for a brief moment before turning invisible again and changing its' location. If the ghost was off the screen when the player missed, an on screen indicator shows the direction to the ghost, giving the player a chance to turn to see where the target was. To prevent the players from resorting to trial and error the player cannot fire nor hit the ghost before it disappears and relocates and must try their best to hit the ghost at their first try.

To prevent the ghost's location from being easily determined by analyzing the logarithmic falloff of the audio volume as they move closer or farther away from the audio source, the logarithmic falloff curve was modified. The curve levels off closer to the audio source, resulting in a consistent volume level within five metres from the ghost. Thus the player cannot *probe* to discern where the ghost is by moving the player character around or through it.

If the player manages to hit the ghost, the ghost becomes visible and dissolves in a flash to confirm a successful shot. The challenge is over after either hitting or missing the ghosts 14 times.

2.2.1.3 Audio Design

Audio can be utilised in a myriad of different ways in video games. To familiarise testers with the realistic rendering of audio in the prototype, ambient audio sources are used throughout the house. One such ambient sound source is the 50-60Hz hum given off from the electric grid that we place at each incandescent light bulb. The light fixtures modeled in the game are older makes, less efficient than modern lights, associated with giving off more heat and sound. In the house are placed a number of wall fixtures at head height emanating this electrical hum. Such sounds are routinely ignored in every day life but here serves to resemble a reality normally abstracted away in video games and to anchor the sound for the listener at a location. Training them to associate sound directionality with location.

When the player moves the player character step sounds are played according to the material that the character is treading on. The floor materials in the house are either hardwood floors or tile. To reflect the dilapidated visuals (see Figures 2.1a and 2.1b) of the house there is a chance of a wood creek sound being played every step taken on the hardwood floor.

(a) Basement (b) Ground floor

Figure 2.1: Examples of the visuals and the general lighting of the house

The sonar like pulse emitted by the invisible ghost is comprised of the attributes described by (Tran and Mynatt 2000). The pulse has a broad frequency spectrum, encompassing both lower and higher frequencies for easier localisation (ibid.). The pulse is played roughly every two seconds. In between each time it is played the volume is varied 10%, making it more difficult to locate by the logarithmic rise in volume as the listener gets closer.

The purpose of the footsteps and the variance in volume of the pulse is to encourage the testers to stop and listen for the direction of the sound and not rely on walking blindly in the direction that sounds louder.

2.2.1.4 Level Design

The level design was relied upon for drawing the testers forward during the test with minimal interference from the test leaders. Totten (2014) describes in his book, *An Architectural Approach to Level Design*, that light and shadow can be used to draw the player forward. ”Lighting conditions and negative space are both useful methods of not only putting players in interesting survival scenarios where their enemies are unknown, but also enticing players with withheld information or atmospheric ambiguity.” (ibid., p. 229). The house has contrasting dark and light spaces the player must navigate through to proceed. Totten states that a player feels an ancestral sense of safety from being in a dark space, out of view from predators, but feels hesitance moving from a lit area into a darker area. Creating contrasting islands of dark and light can help create what the author describes as a *rhythm* which pulls the player along. ”Shadows’ harmful association should also be noted. Shadows work against humans when viewed from the light. They create the perception that they are hiding danger, which may very well be true in video games." (ibid., p. 227).

The basement floor of the building, Figure 2.2, is darkly lit with islands of light coming from pendant lights. Large sections of the basement can be seen from any other point of the basement but some nooks have to be explored more closely to be viewed.

The ground floor seen in Figure 2.3, connects with a stair to the basement and has several rooms with double and single glass doors dividing them. Closed doors help differentiate uncharted rooms with visited ones for players needing to orient themselves. The rooms are distinct and are easily recognised from their functions; kitchen, dining room, living room, television room and bathroom. Most rooms are well lit, some are dominated by shadows. Between darker areas are better lit corridors and between well lit areas are dark corridors, trying to achieve Totten's *rhythm*. Two doors open to the outside but remain locked for the players. Note that windows are present throughout the house above ground floors but are not marked on the floor plans.

The upstairs floor in Figure 2.4 is connected to the ground floor with two distinct staircases. Three bedrooms, an office, washing room, wardrobe and bathroom make up the rooms on this floor with corridors connecting them.

The sonar like sound is dampened by walls and ceilings but can travel from one floor to another and between rooms. The ghosts' spawn volume choosing algorithm is set up to lead the players in varied paths through the house from room to room and between floors. The visual distinctness of each room should help players orient themselves even though the space is unfamiliar to them.

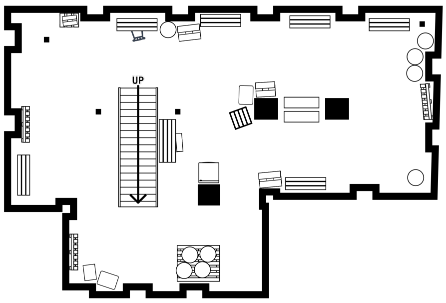


Figure 2.2: Basement floor plan

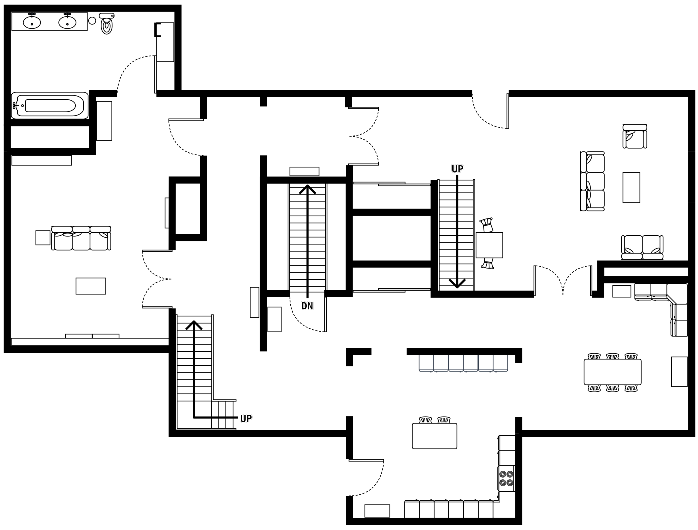


Figure 2.3: Ground floor plan

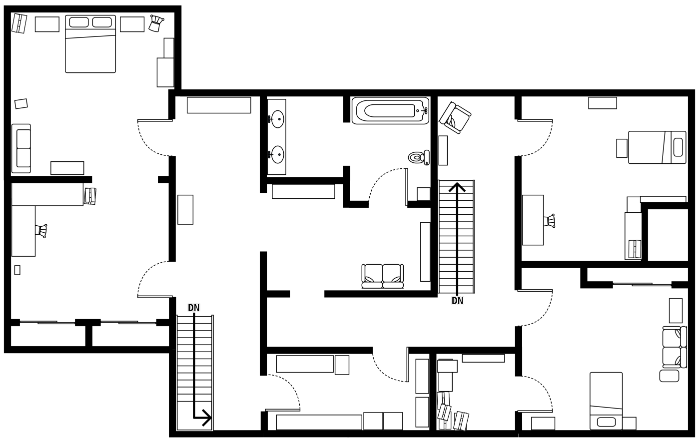


Figure 2.4: Upstairs floor plan

2.2.1.5 Resonance Audio

For spatialisation in an indoor environment it can be helpful to have a realistic sounding environment that closely mimics how audio naturally reverberates off walls, ceiling and floors.

Resonance Audio by Google LLC (1998) is an audio plug-in compatible with several game engines that aims to reproduce realistic acoustic qualities in rooms and binaural sound rendering. With the Unity game engine it adds upon functionality of Unity's already existing audio source and audio listener components. The developer can bake the resonance qualities of a room from the acoustic properties of the materials that the developer sets. The Resonance Audio room component allows the reflectivity and reverberation qualities of a room to be customised to allow the system to simulate how sound reflects off walls in a room. Resonance Audio's audio source component lets developers customise the *listener directivity*, the *source directivity* and *occlusion intensity*.

Listener directivity allows to set how much an audio source sounds depending on the relative direction from the audio listener. Meaning sound can be set to be heard more loudly if the listener views it *head on* or hears it equally from the front, sides or back.

The audio listener component takes the audio frequencies projected from the audio source and modulates them from the appropriate reverberations that the audio sources and the audio listener components are located in. It also uses an algorithm to modulate the audio to resemble how it would sound naturally from the given direction through a generalized HRTF.

The result is a more realistic sounding environment than what is supplied by Unity's built in audio components which do not take into affect materials' acoustic properties or if objects block audio sources. This to give better spatialisation and thus endeavour to control for that factor when testing for the difference between having head tracking active or not.

2.2.1.6 Test Design

The testers' started with a progressive tutorial where they were asked to shoot three sequential practice targets, the last two being invisible, all audibly giving off the same sonar like audio as the ghost targets. Later in the 14 rounds of testing, seven of the rounds spatialise the audio with the players' head movements and seven spatialise the audio as normally in video games — locked to the camera.

Engaging the head tracking in the first or second half was determined randomly by the game as to mitigate trends of players getting better with practice and the effect that would have had for the subsequent data comparison. The testers were informed that we measured head movement for data collection purposes. However, they were not informed about the games spatialisation of audio through the head tracking as to not introduce any confirmation bias in the results.

Since a near miss from a great distance could mean more than a direct hit close up —while a hit or miss is presented to the players as a binary state— precision was measured as alignment values between zero and one on both lateral (x) and vertical (y) axis. The separate axes was to be able to get data for specifically vertical localisation of audio and the effects head tracking might have had on it. A direct hit would give a value of 1.0 for both x and y-axis, and the player firing in the complete opposite direction would give 0.0 for them both. The player aiming $45°$ too high or too low would result in y = 0.75, but will still result in $x = 1.0$, if the lateral direction is dead on.

The alignment value $\propto$ is calculated from the dot-product of the perpendicular complement of the projected and normalised aim direction v, and the normalised target direction u, which gives a value between -1.0 and 1.0, then moved to within the 0.0 to 1.0 range by adding 1 before dividing by 2.

$$\propto = \frac{\hat{v}^{\perp} \cdot \hat{u} + 1}{2}$$

Other data that was logged were the regular dot product between aim direction and target direction, distance to the target and time it took to hit the ghost.

Spawn locations are designated *volumes* manually placed within rooms. A weighted random for choosing between the spawn locations will be used to not influence the results by inadvertently introducing variance in the difficulty by setting a bespoke sequence of spawn locations.

The weighted random is calculated from the cubic volume of the spawn volumes — giving equal chance for every cubic metres of spawn volumes in the house to spawn a ghost. Since the time taken between every ghost is recorded it is important that the distance between each new spawn volume does not vary too greatly. The validity of the chosen spawn volume's distance is, therefore, checked by pathfinding from the player's location to the spawn volume. If too close or too far, another volume is chosen. The A* pathfinding algorithm is used to validate the length of the walking distance. A* with an *admissible* heuristic guarantees the shortest path (Russell and Norvig 2010). For an admissible heuristic it is important that a new node's cost, or distance in this case, is never overestimated (ibid.). Since A* is a *greedy* algorithm, trying to take the most direct path while searching as few nodes in the graph as possible, it might miss the shortest path if a node on the path were to present itself as less promising than it actually is (Russell and Norvig 2010). The exact distance from a node to the goal is used for the heuristic calculation, thus guaranteeing it not to overestimate the cost of choosing that node. To ensure a high degree of variance in the random choice it is checked so the newly chosen volume was not one of the two previous spawn volumes, if it is, the volume is deemed invalid and the random choice continues until a valid volume is found. The spawn point *within* the chosen spawn volume is randomised, if inside any object or furniture a new random location within the volume is chosen and checked until a valid one is found. The volumes are placed and scaled so that they span from floor to ceiling within a room, giving equal variance of height in the unblocked area inside the volume.

2.2.1.7 Pilot Tests

A round of pilot testing was conducted after the prototype was near completion with 7 fellow game developers. This to allow for iterations on the prototype, and on details in the testing procedure. Changes were made to the ghosts' audio volume as it proved to be too easy to localise the ghosts by judging the distance to the audio source. More specifically, the logarithmic falloff curve of the volume was modified to give a consistent volume level within five metres from the ghost. Special attention was given to ensuring statistical validity and to how data was collected. The pilot testers were also asked about the interview and survey questions to see if they could be improved. How the test was presented to the testers was scrutinised for not influencing the testers' interview and survey responses after the playing session.

2.2.2 Authors' Backgrounds

Both authors at the time of the study studied Computer Game Development at Stockholm University's Department of Computer and Systems Sciences (DSV). The program teaches various areas within computer game creation such as; programming, game design, level design, sound design, 3D modelling and others, which influenced the choice of the research question. Since an interest lay in players' interaction with sound in computer games, it was desired to investigate how head tracking could add value to spatial game audio.

2.2.3 Experiment Setting

The environment of the experiment was the DSV's laboratory of computer game development. The laboratory was, at the time of testing, often filled to capacity with students, resulting in a loud background din. To combat this issue a pair of Sony WH-1000XM3 headphones with active noise cancelling were used, to reduce distracting background noise during the test.

2.2.4 Data Collection Procedure

At the start of each test, participants were asked for their consent and provided with limited information on the study's background and instructions on how to navigate the prototype. In order to not bias the testers' answers they were told that the head tracking equipment was used to measure head movements during play without revealing the actual focus. After playing the prototype participants were asked to answer a questionnaire and then interviewed. The participants were chosen mainly through reachability and availability, but some testers were chosen specifically because of their low familiarity with FPS games in order to get data from a broader selection of experience levels. The participants were also informed about the approximate time that the test would take, approximately 25-30 minutes.

2.2.4.1 Quantitative Data Collection Procedure

Data was logged automatically at the time of each shot and written to a comma-separated values file format (CSV). Ordinal data, including precision and time taken, were measured, also information on what floor the audio source and player were on, and if it registered a hit or not.

When designing a questionnaire the questions asked should be concise, clear, specific and unbiased (Lee 2006). The questions should not suggest an answer and should be relevant towards answering the research question (Peterson 2000). Johannesson and Perjons (2014) proposed that the number of questions should be concise to not discourage the participants from completing the questionnaire. This study has followed the guidelines and formulated most of the questions as *closed questions* in order to simplify the response and analysis processes.

The survey started with a question regarding the respondent's average time spent on playing first person shooter games in order to understand their familiarity with such video games. All of the following questions focused on the person's ability to audibly localise the ghosts on different axes and floors. All six questions were ordinal data where five focused on the perceived ability of localising the ghosts and one question pertained to the tester's first person shooter gaming habits. The reasoning behind the question about person's gaming habits was to see whether there was a correlation between the regularity of playing FPS games and one's ability to localise sound sources in the games of such genre. The rest of the questions were used to acquire each participant's short and clear subjective assessment of how well they could understand the ghosts' positions.

Because the surveys were followed by interview questions the questionnaires did not include any questions involving head tracking as that would possibly bias the answers given during the interviews before the aim of the study was revealed and discussed. Lastly, the questions were formulated in English and since there were not any open questions the participants would not have to consider what language to answer in.

2.2.4.2 Qualitative Data Collection Procedure

Due to the individualized nature of the experiment, *group interviews* and *focus groups* were not considered suitable. Considering that both interview options require the number of interviewees to exceed one none of them could be useful and, therefore, a *one-to-one* interview was used (Denscombe 2014). Although the disadvantage of one-to-one interviews is that they capture only one person's opinion (ibid.) it was suitable for this study's data collection procedure as it focused on one participant at a time.

The first half of the interview contained questions similar to the ones from the survey as the aim was to gather a more detailed and in depth information about the respondents' answers. The second half of the questions was aimed towards ascertaining if the testers understood if head tracking was utilised for spatialisation during the experiment and if they benefited from it. The order of questions was to avoid bias.

As Johannesson and Perjons (2014) stated the answers provided by a respondent should be recorded, however, considering that the study's experimental environment was often noisy it was difficult to record the answers and only field notes were taken. Similarly to the survey the interview questions were formulated and asked in English.

2.2.4.3 Data Collection Results

In total 20 people participated in the experiment which hit the set sample size. All participants were students at Stockholm University's Department of Computer and Systems Sciences. Pertinent to mention is that one participant (1.5), post-test reported a preexisting hearing impairment on their right ear. The experiment was conducted over a period of approximately one week. The survey questions were answered by using Google Forms. During the interviews participants were free to answer in either Swedish or

English. Consequently, notes on the interview answers provided by respondents in Swedish were later translated into English.

2.2.5 Data Analysis

2.2.5.1 Quantitative Data Analysis

The qualitative data from the tests were copied onto a spreadsheet and processed in Google Sheets, an online spreadsheet program.

Descriptive statistics such as head movement and precision were analysed through bar charts and scatter plots. Responses from questionnaires were also analysed for frequencies as suggested by Johannesson and Perjons (2014). Proportions of questionnaire responses were analysed and presented with pie charts also suggested as appropriate by Johannesson and Perjons. Head movement data from testers that showed abnormally high readings during the tests were excluded from comparisons pertaining to head movement. While the discrepancy could stem from larger than average head movements—errors in the measurement could not be wholly excluded.

Inferential statistics were done using statistical tests on the precision data with reliability tests done using an online program *Social Science Statistics* (2018) for statistics and hypothesis testing.

A Wilcoxon signed-rank was used on the blind test, where the means of the result with spatialisation enabled and disabled were compared within the same group.

The initial experiment was conducted as a blind experiment to minimize bias. Subsequently, a follow-up open experiment, which will be discussed below, was conducted to validate the hypotheses formulated based on the data obtained from the first experiment. When comparing the means of the results between the open experiment and the blind experiment the Wilcoxon rank-sum test was used.

2.2.5.2 Qualitative Data Analysis

To answer the research question inductive and deductive thematic analyses were used. In order to perform an inductive analysis a step-by-step approach comprised of six phases by Braun and Clarke (2006) was followed:

1. Familiarizing yourself with your data
2. Generating initial codes
3. Searching for themes
4. Reviewing themes
5. Defining and naming themes
6. Producing the report

Since the data did not have to be transcribed, the analysis started with reading the interview data. This helped experimenters get familiar with the data set and make notes about any ideas. During the next step a number of initial codes was generated as the aim was to mark interesting features of the data in a systematic fashion (ibid.). At this stage and until the end of the analysis a website Metro Retro was utilised in order to have a better overview of the codes and themes. Afterwards, a set of initial themes was created to group the codes and give them a sense of structure. During this, as well as other phases of the analysis procedure, the whole data set was reread multiple times and some codes were added, reformulated and deleted to better fit the overarching research question and themes. Then, the themes were reviewed and iterated on to develop definition and clarity. Finally, the results from this analysis, which can be found in the Results chapter, were produced.

In addition, to analyse data deductively we approached the data with specific questions in mind that we wished to code around (ibid.), for example: ”Does the spatialisation of soundscape in relation to head movements utilising head tracking technology impact one's immersion or ability to localise audio sources?”. This led to the creation of a number of codes related to this analytic approach.

2.2.6 Follow-up Experiment

Follow-up tests were conducted since during the main experiment, as the results showed, head tracking was left unnoticed by most, if not all, of the participants. Since the first test was a blind experiment, meaning that the testers did not know what was being tested, it was curious to see if participants would have different results when they were consciously using the head tracking feature. The follow-up experiment was carried out in mostly the same manner as the first but with a few differences. Firstly, the follow-up experiment was an open experiment, meaning participants were informed about the head tracking's purpose before the beginning of the test and a user interface (UI) element that indicated if head tracking was activated or not during the test. Secondly, the questionnaire and interview questions focused primarily and explicitly on the use and impact of head tracking. Thirdly, the sample size was smaller with only five testers. Apart from that the data collection and analysis procedures were performed in an identical way to the blind test.

2.2.7 Research Ethics

2.2.7.1 Informed Consent

Ethical issues that need to be addressed in this study can be summarised as the four principal demands laid out by *Forskningsetiska principer inom humanistisksamhällsvetenskaplig forskning* (2002); the information requirement, the consent requirement, the confidentiality requirement, and the usage requirement. The information requirement, where subjects must be informed about what data is collected and how the data collected will be used (ibid.). The subjects must also be informed that their cooperation is completely voluntary and that they can discontinue the experiment at any time (ibid.). To uphold the consent requirement, informed consent must be received from the subjects before conducting any survey or test with them (ibid.). The confidentiality requirement (ibid.) was upheld by anonymising the respondents test data, interview, and survey responses so as to not be able to identify any individuals. To ensure the usage requirement (ibid.) no data was collected about individuals that could be used commercially or for other non-scientific purposes.

2.2.7.2 Credibility

”The credibility of quantitative data depends on how good the research methods are at producing data that are accurate and consistent” (Denscombe 2014, p. 271). This implies that the criteria of such concepts as validity, reliability, generalisability and objectivity are fulfilled (ibid.).

Validity ”refers to the accuracy and precision of the data” (ibid., p. 271) as well as the appropriateness of the data in relation to the research question. In order to measure a study's validity one can ”use 'check questions' within a questionnaire to see whether people's responses are the same to a very similar question” (ibid.). Another thing a researcher can do is ”check for consistency in the profile of answers within the data set, based on the assumption that similar respondents should provide the same kind of answers to similar questions” (ibid.).

Reliability refers to whether a research instrument is free from bias in its' effect and is consistent throughout multiple occasions of its' use (ibid.). To check data on reliability one can use the test-retest approach, which involves using the research tool on a later occasion to compare the results with previous ones. Another way of checking the level of consistency in the data is by using the split-half approach. It is the process of dividing the dataset into two halves and comparing their findings.

Generalisability, or external validity, ”refers to the prospect of applying the findings from research to other examples of the phenomenon” (Denscombe 2014, p. 272). In other words, how well can the findings be generalized externally. Usually, a large representative sample lays good ground for generalizing from the findings (ibid.).

Objectivity concerns the absence of bias in the researcher's impact on data collection, analysis, and outcome of the investigation. This can be addressed by fairly treating the data, giving due consideration to competing theories and alternative views, giving details of any sponsors of the research, and declaring any vested interests in the outcomes of the study (ibid.).

Similarly, when conducting a qualitative research, in order to achieve a good credibility, one needs to make sure that the research heeds the requirements of validity, reliability, generalizability and objectivity (ibid.).

Validity refers to ”the extent to which qualitative researchers can demonstrate that their data are accurate and appropriate” (ibid., p. 297). Three common ways of arguing for validity are respondent validation, grounded data and triangulation.

Reliability addresses the question of whether a research instrument would have produced the same results and led to the same conclusions if it had been used by different researchers. The principal way of arguing for the reliability is explicit documentation of an investigator's methods, analysis and decision-making (ibid.).

Generalisability, or transferability, addresses the question of how representative the studied cases are and how likely it is that the findings will be found in similar cases elsewhere. To argue for a study's transferability one needs to provide relevant information, especially about the respondents, that will make it possible to think of the instances to which the findings could be transferred (ibid.).

Objectivity ”concerns the extent to which qualitative research can produce findings that are free from the influence of the researcher who conducted the enquiry” (ibid., p. 300). Though no research is ever free from the influence of its' conductor a few things can be kept in mind when performing interviews. Firstly, the investigator can ”distance themselves from their normal, everyday beliefs and to suspend judgements on social issues for the duration of their research” (ibid.). Second alternative is that the researcher can ”come clean about the way their research agenda has been shaped by personal experiences and social backgrounds” (ibid.). The latter can clarify to the reader how and why the investigator's self might be intertwined with the research as he or she might have a valuable insight into the issue. Lastly, the researcher should ”avoid neglecting data that do not fit the analysis” (ibid., p. 301) and should ”check rival explanations” (ibid., p. 302).

The quality criteria described above were used during the research to assure the thesis' credibility.

3 Results

3.1 Artefact

The developed artefact, 'Ghost Hunt', incorporated various components (Figure 3.1). To enhance the audio experience and supply the foundation for testing the spatialisation, the artefact utilised the audio plug-in Resonance Audio, providing a realistic binaural audio experience. A basic UI was created to supply feedback and information to the testers. The modular building asset downloaded from *Unity Asset Store* (n.d.) provided foundation for the game's environment and level design.

(a) Hallway.

(b) Dining room.

(c) Basement. The ghost is revealed after a missed shot. The opaque white UI headphone symbol indicating that spatialisation is active.

Figure 3.1: Images showing the artefact as used during the open experiment.

A custom ghost model was created to serve as visual feedback and positive reinforcement for the testers (Figure 3.1c). A collection of sound effects was downloaded and processed to give audible feedback to the testers, including the pulsating heartbeat-like audio that guided players towards the targets as recommended by Tran and Mynatt (2000). The AI synthesised instructional voice for the tutorial was obtained from *ElevenLabs Inc.* (n.d.). Code for enabling head tracking through NaturalPoint Inc. (n.d.) TrackIR was implemented to measure head movements and to spatialise the audio according to the testers' head movements during the tests. The different components served well together to facilitate the testing of spatialisation. The final artefact as was used for the tests can also be seen in Figures 3.1a and 3.1b.

Artefact can be downloaded at: https://github.com/CaretSoftware/Spatialised-Audio.git (Bergsten and Kihan 2023).

3.2 Quantitative Experiment Results

3.2.0.1 Blind Experiment Questionnaire Results

The proportion of participants' reported gaming habits gathered through questionnaires during the blind experiment can be seen in Figure 3.2 and showed even proportions of gaming habits.

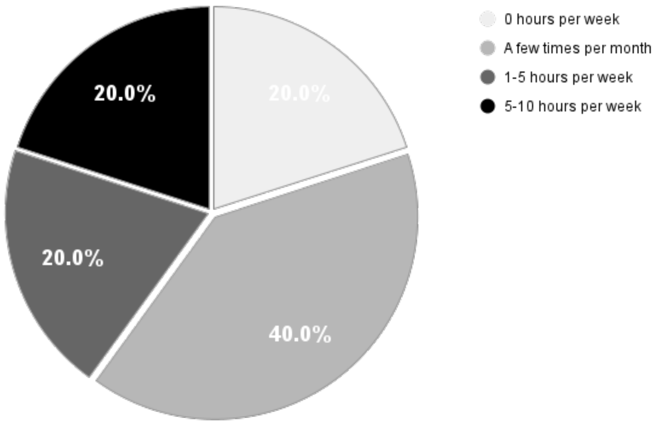


Figure 3.2: Percentage of participants' self reported FPS experience

The rest of the answers given by the respondents proved to be of little value in relation to the head tracking considering that no questions mentioned it and were thus not included here.

3.2.0.2 Open Experiment Questionnaire Results

According to the respondents' answers head tracking had a noticeable impact on their localisation of targets as can been seen in Figure 3.3.

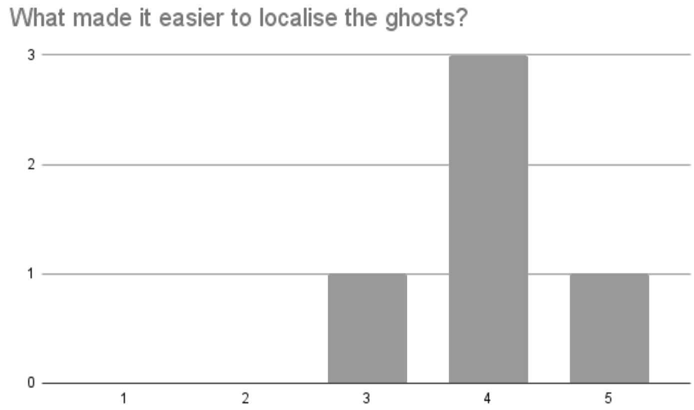


Figure 3.3: Respondents’ answers to ”What made it easier to localise the ghosts”. Options were 1-5, (Without head tracking - With head tracking).

Concerning question about the participants’ vertical localisation while using head tracking showed mixed results leaning more towards being hard than without the use of the tool, see Figure (3.4).

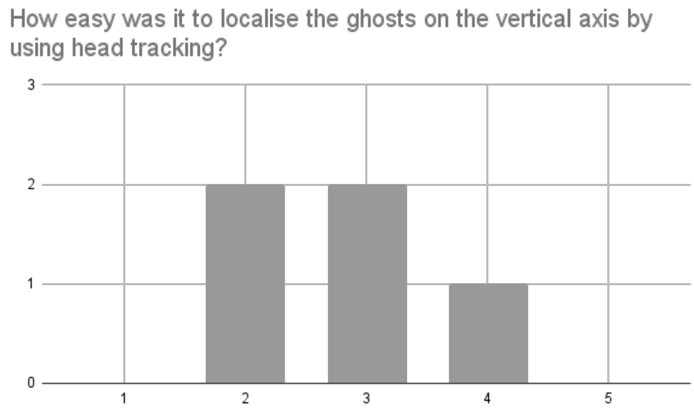


Figure 3.4: Respondents’ answers to ”How easy was it to localise the ghosts on the vertical axis by using head tracking”. Options were 1-5, (Very hard - Very easy).

While to the question about localisation on the horizontal axis while using head tracking testers gave both positive and negative responses as can be viewed in Figure 3.5.

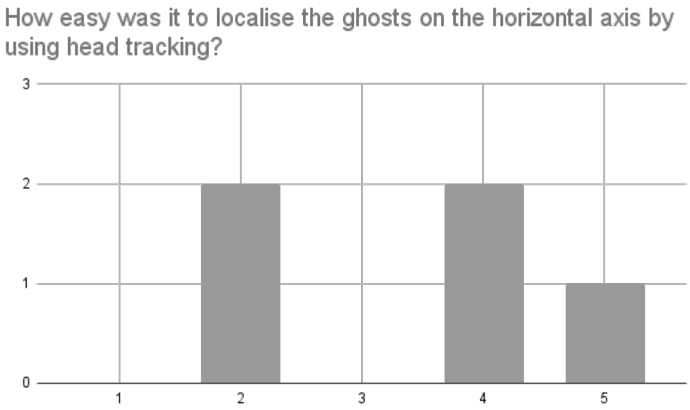
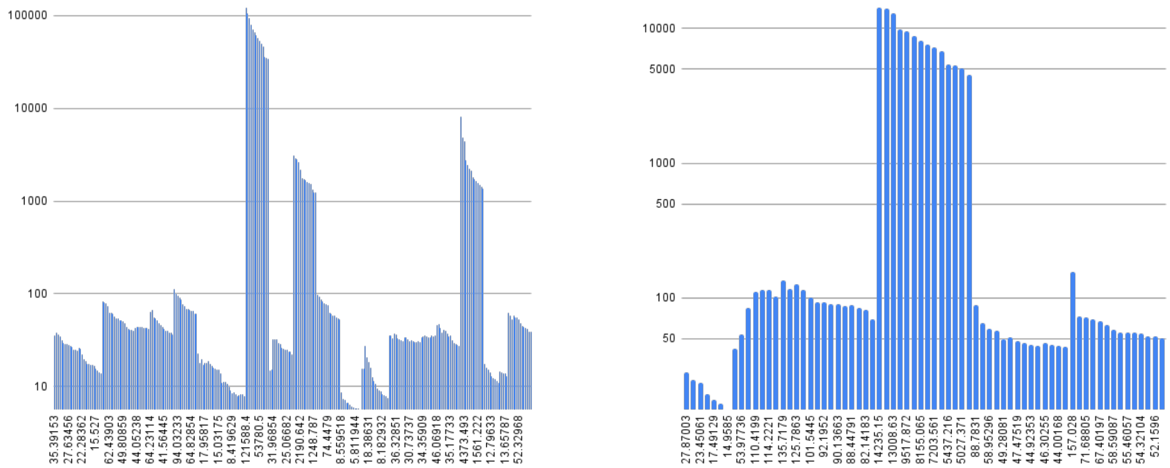


Figure 3.5: Respondents' answers to "How easy was it to localise the ghosts on the horizontal axis by using head tracking". Options were 1-5, (Very hard - Very easy).

3.2.1 Head Movement

Average head movement per round can be seen in the bar chart in Figure 3.6. The scale for the chart is logarithmic, the measurements are in pixels per second. Each bar on the chart is a single round, each tester playing 14 rounds. Average values above 100 per round were excluded from the calculations as they could potentially stem from measurement errors. The persistent trend of higher average head movement at the beginning of each round is observed in both the blind experiment and the open experiment. As a result, making direct comparisons between average head movement for spatialisation active and inactive becomes challenging due to the overwhelming consistent decline over time.



(a) Head movement average per round blind test.

(b) Head movement average per round open test.

Figure 3.6: Head Movement average per round for both blind and open test on a logarithmic scale.

3.2.2 Time Per Round

The average time per round with and without spatialisation during the blind test differed by only .1% at 35.33 seconds per round and 35.77 seconds per round. During the open test the average time increased to 48.86 seconds and 47.97 seconds, with and without head tracking. The average difference is deemed too small to reject the null hypothesis that spatialisation of audio with head tracking does not has no influence on one's precision for localising sound sources.

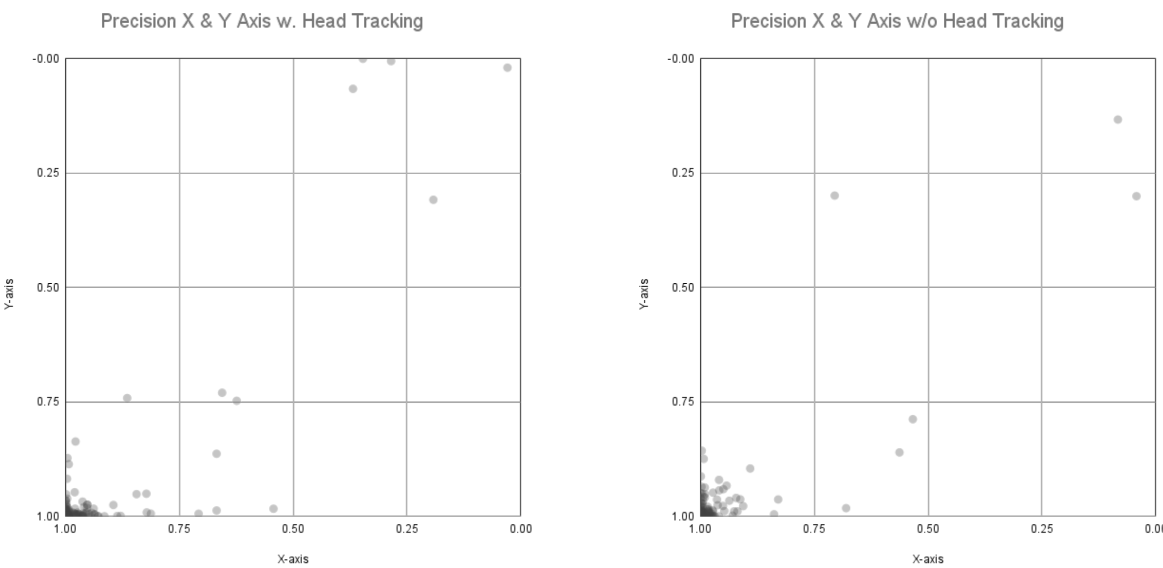
3.2.3 Precision Results

3.2.3.1 Blind Experiment Precision

A one tailed Wilcoxon Signed-Ranks test was conducted to compare the means for total precision with head tracking enabled and disabled. The comparison had a degree of freedom of $= 140$. The value of z is -1.4498. The p-value is .07353. Since the p-value is greater than the α level of .05, the result is not statistically significant. Therefore, we cannot reject the first null hypothesis; that spatialisation of audio through head tracking in FPS computer games has no influence on one's precision in localising sound sources.

Another one tailed Wilcoxon Signed-Ranks test was made for comparing the precision in the vertical axis with head tracking disabled and enabled. The comparison had a degree of freedom of $= 140$. The z-value was -0.9631 and the p-value was .16853. Since the p-value is greater than the α value of .05 we cannot reject the second null hypothesis; that spatialisation of audio through head tracking in FPS computer games has no influence on one's ability to localise sound sources vertically.

The diagrams in Figure 3.7 visually show the differences in total precision with and without spatialisation through head tracking for the blind experiment. Each point in the scatter plots represent a single shot, the y-axis is the vertical, and the x-axis is the horizontal. The scale goes from 1 to 0; 1 representing being perfectly aligned, 0 being 180 degrees opposite to the direction of the target. Note that for clarity the diagrams show absolute alignment values, not directionality.

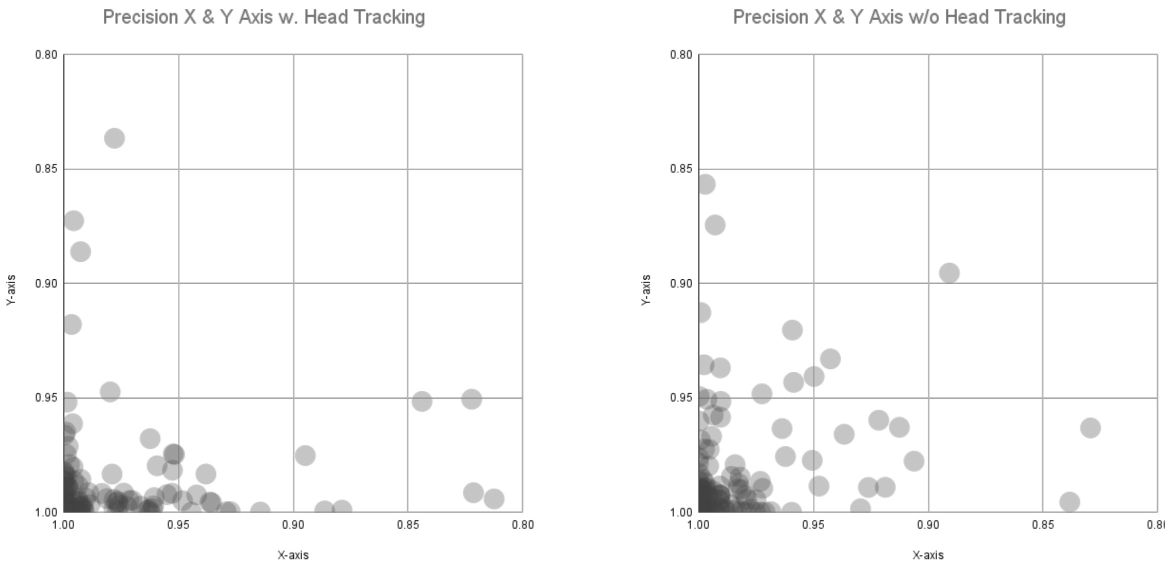


(a) Precision with head tracking.

(b) Precision without head tracking.

Figure 3.7: Total precision across all 20 participants of the blind experiment.

Another pair of diagrams 3.8 show the same data but focusing on the most aligned 20 percent part of the diagrams.



(a) Precision with head tracking

(b) Precision without head tracking.

Figure 3.8: Scatter plots showing the 80-100% precision range of the blind experiment.

3.2.3.2 Open Experiment Precision

The first test was conducted as a blind experiment, ensuring that the testers were unaware of the spatialisation of audio with head tracking. This was done to assess the impact of spatialisation on the results when it was enabled or disabled without inducing any biases.

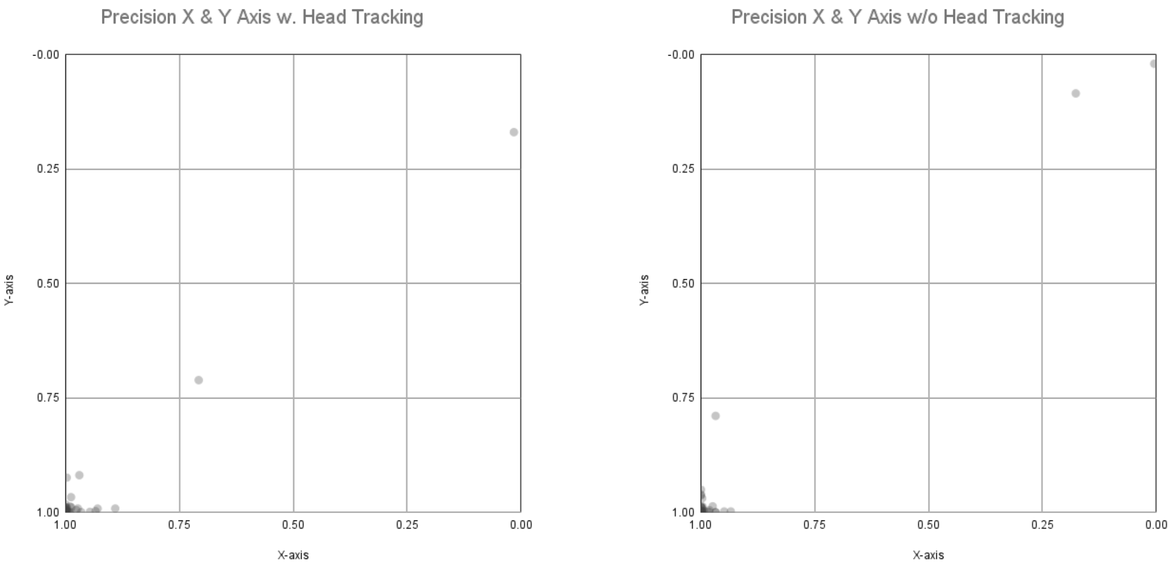
In the second test, the testers were informed about the spatialisation and made aware when it was enabled or disabled. By comparing the results from the rounds with spatialisation enabled from the two tests against each other, we aimed to investigate whether there are any discernible differences. The purpose was to determine if players need to be consciously aware of the spatialisation for it to provide any noticeable benefits.

- Null Hypothesis 4: There is no significant difference in precision with spatialisation enabled between players who are conscious of it and players who are not conscious of it.
- Hypothesis 4: There is a significant difference in precision with spatialisation enabled between players who are conscious of it and players who are not conscious of it.
- Null Hypothesis 5: There is no significant difference in precision in the vertical axis with spatialisation enabled between players who are conscious of it and players who are not conscious of it.
- Hypothesis 5: There is a significant difference in precision in the vertical axis with spatialisation enabled between players who are conscious of it and players who are not conscious of it.

A one-tailed Wilcoxon rank-sum test was made on the precision with spatialisation enabled between the blind test and the open test, with an approximated degree of freedom $= 174$. The z-score is -1.09482. The p-value is .13786. The result is not significant at $p < .05$. Since the p-value was larger than the α value of $.05$ there is a strong possibility the result is coincidental. Thus there is insufficient evidence for the null hypothesis to be rejected that there is no significant difference in precision with spatialisation enabled between players who are conscious of it and players who are not conscious of it.

Another one-tailed Wilcoxon rank-sum Test to compare between the same groups for precision in the vertical axis with head tracking enabled gave a z-score of -1.09482. The p-value was .13786. The result is not significant at $p < .05$. There is, therefore, a good chance the results are from chance alone with the α level at .05. Thus failing to reject the null hypothesis that there is no significant difference in precision in the vertical axis with spatialisation enabled between players who are conscious of it and players who are not conscious of it.

The diagrams in Figure 3.9 show the differences in total precision for the open experiment with and without spatialisation through head tracking.

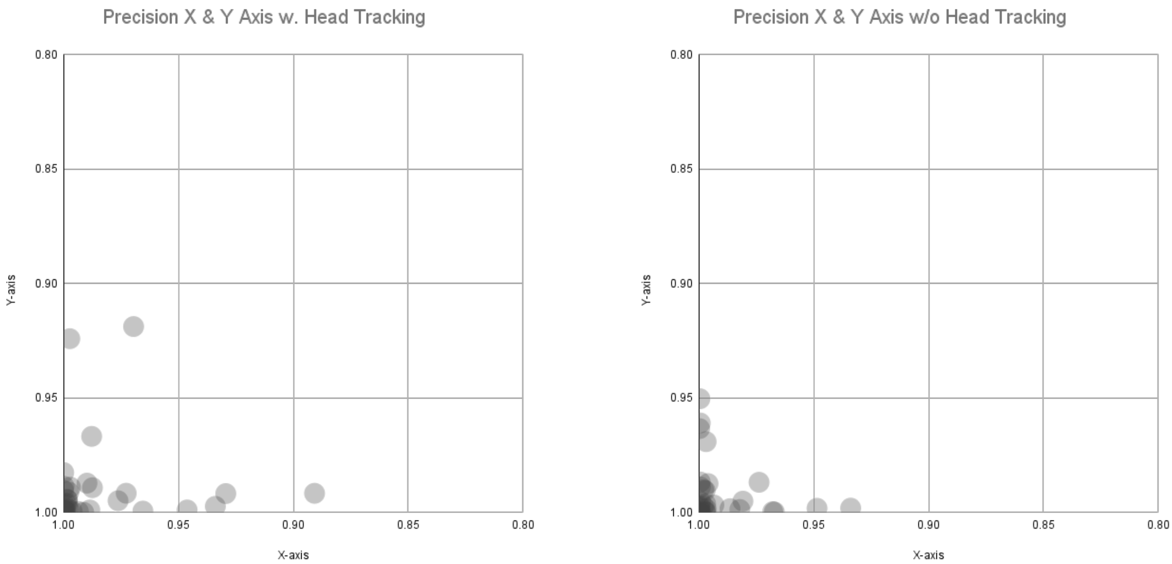


(a) Precision with head tracking.

(b) Precision without head tracking.

Figure 3.9: Total precision for the five open experiments.

Another pair of diagrams 3.10 show the same data for the open experiment focusing on the most aligned 20 percent of the diagrams.



(a) Precision with head tracking

(b) Precision without head tracking.

Figure 3.10: Scatter plots showing the 80-100% precision range of the open experiment.

3.3 Survey Blind Experiment Analysis Results

We calculated the average responses for each question to determine the overall sentiment of the respondents. The standard deviation was calculated to assess the level of consensus among the respondents. When interpreting the standard deviation, we considered the sample size, categorizing values below 0.5 as low, between 0.5 and 1.0 as moderate, and above 1.0 as high.

The split-half reliability test was done by dividing the data randomly into two and the averages compared to each other and the absolute difference was calculated between the two as the measurement for reliability. A smaller value pointing to that the data has a high degree of consistency and reliability. Sample size influenced the choice of values below 0.5 as high, between 0.5 and 1.0 as moderate, and values above 1.0 as poor reliability.

How well do you feel you could audibly localise the ghosts during the test? 1-5 , (Very hard - Very easy)

The average response was 3.75 with a standard deviation of 0.71, the split-half reliability test showing an absolute difference of 0.5.

Respondents were in moderate agreement that the ghost was easy to localise. The reliability of the result is moderate.

How well do you feel you could audibly localise the ghosts on the vertical axis in particular? 1-5 , (Very hard - Very easy)

The average response was 2.2 with a standard deviation of 0.83, the split-half reliability test showing and absolute difference of 0.8.

Respondents were in moderate agreement that localising the ghost on the vertical axis was neither very hard nor very easy. The reliability of the result is moderate.

How well do you feel you could audibly localise the ghosts on the horizontal axis in particular? 1-5 , (Very hard - Very easy)

The average response was 4.1 with a standard deviation of 0.79, the split-half reliability test showing an absolute difference of 0.4.

Respondents were in moderate agreement that the ghost was easy to localise on the horizontal axis. The reliability of the result is high.

Was it difficult to discern when the ghosts were on the floor above you? 1-5 , (Very hard - Very easy)

The average response was 2.7 with a standard deviation of 1.26, the split-half reliability test showing an absolute difference of 0.2.

Respondents were in some disagreement on that discerning if the ghost was on a floor above was neither very easy nor very hard. The reliability of the result is high.

Was it difficult to discern when the ghosts were on the floor below you? 1-5 , (Very hard - Very easy)

The average response was 2.65 with a standard deviation of 1.13, the split-half reliability test showing an absolute difference of 1.1.

Respondents were in some disagreement on that discerning if the ghost was on a floor below was neither very easy nor very hard. The reliability of the result is poor.

3.4 Survey Open Experiment Analysis Results

Making confident statements about reliability and consensus within survey responses with a sample size of 5 is fraught with uncertainty and limitations. No assessments of reliability and respondents consensus will be made.

What made it easier to localise the ghosts? 1-5 , (Without head tracking - With head tracking)

The average response was 4 with a standard deviation of 0.7. Respondents stating on average that localisation was somewhat easier with the localisation enabled.

How easy was it to localise the ghosts on the vertical axis by using head tracking? 1-5 , (Very hard - Very easy)

The average response was 2.8 with a standard deviation of 0.83. Respondents stating on average that it was moderately difficult to localise in the vertical axis with spatialisation enabled.

How easy was it to localise the ghosts on the vertical axis without head tracking? 1-5 , (Very hard - Very easy)

The average response was 2.2 with a standard deviation of 1.09. Respondents stating on average that it was moderately difficult to localise in the vertical axis with spatialisation disabled.

How easy was it to localise the ghosts on the horizontal axis by using head tracking? 1-5 , (Very hard - Very easy)

The average response was 3.4 with a standard deviation of 1.33. Respondents stating on average that it was easy to localise in the vertical axis with spatialisation enabled.

How easy was it to localise the ghosts on the horizontal axis without head tracking? 1-5 , (Very hard - Very easy)

The average response was 3.2 with a standard deviation of 1.09. Respondents stating on average that it was easy to localise in the horizontal axis with spatialisation disabled.

Did the use of head tracking help you discern when the ghosts were on different floors? 0 No, 1 Do not know, 2 Yes

The average response was 0.6 with a standard deviation of 0.89. Respondents more often saying No to spatialisation helping in discerning when the ghost was on different floors.

3.5 Qualitative Experiment Results

3.5.1 Blind Experiment Results

Thematic analysis of qualitative data from the main experiment ended in five distinct themes which can be seen in the Table 3.1.

Thematic Map Blind Experiment	
Personal method of localisation	Intentional camera movements. Closing in to the ghost to reduce the chance of missing. Probing around the sound source. Use of an exclusion method.
Improvement in localising by playing	Gradual improvement through playing. Realisation of distance-based sound differences. Realisation of floor-based sound differences. Knowledge of the house's layout.
Difficulties with vertical localisation	Localising ghosts vertically. Localising ghosts on different floors. Lack of crouch function. Guessing when shooting a ghost.
No impact from head tracking	Unaware of the head tracking. Unaffected of the head tracking.
Impact from head tracking	Impacted immersion. Impacted performance.
Prototype related	Experience unlike normal FPS games.

Table 3.1: Thematic Map Blind Experiment

Personal Method of Localisation

The first theme - personal method of localisation, was created on the grounds of frequently observed, individual ways of localising the ghosts. It showed that methods such as intentional camera movements, probing around the sound source, shortening the distance between the player and the ghost to decrease the chance of missing the shot, and process of elimination aided participants in their localisation. To exemplify this here is a quote from participant 0.8: “The hardest part was the middle, so learning to slowly turn helped.”.

Improvement in Localising by Playing

Participants’ improvement in locating the ghosts as they played was another strong theme that emerged. It was observed in many respondents’ views on their experience of playing that they felt more and more confident as they played, e.g. participant 1.5 said: ”I felt towards the end that I learned how to think more and more. Then I didn’t become accurate, but I got better at locating.”. The gradual improvement in the localisation showed itself in the participants’ realisation of distance-based sound differences, realisation of floor-based sound differences as well as knowledge of the house’s layout.

Difficulties With Vertical Localisation

The third theme - ”Difficulties with vertical localisation”, is about the vertical localisation issues that participants experienced during the test. Whether it was related to the localisation of a ghost on the vertical axis in a room or on a different floor an overwhelming number of testers experienced difficulties and many, like 1.9, considered that there were no tools of help: ”the vertical was hard because there was nothing that could help me localise it vertically”.

No Impact From Head Tracking

The theme “No impact from head tracking” emerged from participants stating being unaware and unaffected by the head tracking. For example 0.6 said: ”I didn’t know it was a thing, so I actively looked around with the mouse.”.

Impact From Head Tracking

Regardless of most participants’ being unaware of the head tracking, some thought that it did influence their immersion and performance, which hence, for the sake of inclusion of contradictory opinions, gave birth to the theme “Impact from head tracking”. For example 0.4 said: ”It felt like when I moved I could localise the sound better”; whilst 1.1 in response to whether head tracking impacted their immersion responded: ”Yes, I knew that head tracking had some function”.

Prototype Related

The final theme - “Prototype related”, reflects data related to the prototype. An example to this is a response from 1.2: ”It was a more realistic experience compared to CS because there you use instincts instead and the game would have been slower if there were any head movements.”.

3.5.2 Open Experiment Results

Thematic analysis of qualitative data from the follow-up experiment ended in three general themes that can be viewed in Table 3.2.

Thematic Map Open Experiment	
Positive effects from head tracking	Increase of immersion. Improved vertical localisation. Improved general localisation. Helpful for micro adjustments.
Negative effects from head tracking	Difficulties with vertical localisation. No impact on horizontal localisation. Ineffective for micro adjustments. Little difference with and without head tracking.
Head tracking's usability	Unusual and/or useless. Possibly useful for other genres. A matter of habit.

Table 3.2: Thematic Map Open Experiment

Positive Effects From Head Tracking

The first theme represents ways in which the head tracking positively impacted the participants' experience and localisation of ghosts. Apart from heightening the testers' performance in general and particularly vertical localisation it also increased immersion for some of the participants. For example tester from the follow-up experiment 2.2 said: "There was a difference when [head tracking] was on, I ended up much faster in the rooms the ghosts were in".

Negative Effects From Head Tracking

The theme "Negative effects from head tracking" reflects difficulties and downsides of using head tracking to localise the ghosts. Whether it was related to the vertical localisation or micro adjustments participants expressed having trouble and to exemplify this tester 2.1 told: "it was generally harder to hear vertical differences".

Head Tracking's Usability

The third theme was created based on the participants' views about the head tracking's usefulness and their experience of using it. For the most part the use of head tracking was perceived as unfamiliar and/or ineffective with statements about it possibly being more useful in games of other genres. For example participant 2.4 expressed themselves in the following way: "I can imagine in story games like the *The Last of Us* (2013) or *God of War* (2018) or some single player game, you would appreciate it more as it gives something to the immersiveness".

4 Discussion

The first rounds of tests were blind tests where the spatialisation was not revealed as a tool the testers had on hand. The purpose was to gather data on if spatialisation with head tracking could have inherent benefits during normal gameplay. Data collected during the first trials seemed to suggest that head movement during normal play of FPS games are not large enough to make the spatialisation noticeable.

4.1 Quantitative Experiment Discussion

4.1.1 Blind Experiment Discussion

Binaural audio is a more and more common way of heightening a player's experience, often most effective with the use of headphones. The cues from binaural audio are lost when the listener moves their head without some form of head tracking solution incorporated (Widman 2021). The use of head tracking equipment for spatialisation of audio in first person computer games is a rare occurrence — if not also altering the players viewpoint as in VR games.

The hypothesis proposed that the integration of head tracking and binaural audio to spatialise audio, more closely resembling normal human auditory perception, would enhance players' perception of the soundscape. As a result, this enhanced perception would enable players to more effectively discern the origin of audio sources, leading to a more intricate and immersive auditory experience.

The survey responses indicated a diverse range of familiarity with FPS games among the testers, which aligns with the ambition of achieving a broad spectrum of experience levels (see Figure 3.2). Since participants did not discover the utility purpose of the tool, their survey responses were not specifically related to head tracking and were consequently excluded from the analysis.

Some of the key findings during the tests were that the blind tests had very little discernible difference in measurements between the rounds that had the spatialisation enabled and disabled. During the test the players were not showing any heightened ability to localise the audio sources in either precision or time when spatialisation was enabled. Thus we could not reject the third null hypothesis that; spatialisation of audio through head tracking in FPS computer games has no influence on one's time to localise sound sources.

The average head movement per round exhibited a consistent downward trend across the tests in the blind experiment, indicating a gradual decrease the longer players played. The test starting with spatialisation had a 50% chance but with the sample size numbering only 20 the skew of rounds starting with spatialisation turned out to be 13 out of 20. Therefore it is suggested that an apparent correlation of increased head movement during rounds with spatialisation enabled might therefore be attributed to more rounds having started with spatialisation. This poses challenges in drawing conclusions regarding whether spatialisation enables increased head movement. Additionally, due to this, it remains inconclusive whether players who moved their head more during the spatialisation phase gained an advantage over those who moved their head less. One thing suggested by the data is that the average head movement was generally quite low, 35 pixels per second on average.

Measurements of general precision and precision on the vertical axis during the blind test indicated minimal impact from spatialisation. Drawing conclusions becomes challenging as it remains unclear whether this lack of effect stems from insufficient head movement by the players, rendering any appreciable effects of spatialisation inconsequential. Another possibility is that spatialisation itself does not yield significant effects in localising audio sources.

4.1.2 Open Experiment Discussion

Due to the lack of discernible differences in measurements during the blind experiment and the testers' inability to report any noticeable effects of spatialisation, a hypothesis emerged. It was suggested that this outcome might be attributed to the test being a blind experiment. In evaluating the effectiveness of a tool, it might be advantageous for the testers to be aware of its' existence to gauge its impact. Initially, it was hypothesised that even small head movements made by the players during gameplay could yield noticeable results, even if those effects were only subconscious. Now, with unbiased results obtained, further investigation was warranted to determine whether the lack of conscious utilisation of head tracking by the players contributed to the initial findings.

The findings of the following open experiment aligned with those of the blind experiment, as suggested by the data. When testers were aware of their ability to move their heads and listen for audio sources during spatialisation, minimal disparities in precision or round duration were observed between spatialisation being enabled or disabled.

Several hypotheses were put forth to explain the data indicating minimal differences in localising audio sources. In the natural perception of the world, we typically turn our heads, and the audio direction remains stationary relative to us. However, when using headphones, the directionality of the audio unnaturally follows the rotation of our heads. Therefore, it was theorized that spatialising the audio's directionality would alleviate confusion for the listener. However, it seems that spatialisation fails to achieve this goal. The statistical tests showed that there was insufficient evidence to disprove that there was no significant difference in precision between players aware of the spatialisation.

One possible explanation for this discrepancy could be the mental coordination required when simultaneously being able to rotate the camera and one's head to alter the audio direction. This dual task may result in challenges in effectively processing the spatialised audio cues. Widman (2021) stated that the cues from binaural audio are lost when the listener moves their head if some form of head tracking solution is not incorporated, but it might be a possibility that the ques are again temporarily lost when turning the camera. Therefore, further investigation is needed to delve into the intricate interplay between head movements, camera control, and the listener's ability to decode and localise audio sources accurately.

4.2 Qualitative Experiment Discussion

4.2.1 Blind Experiment Discussion

The qualitative data from the blind experiment suggested no impact on performance or immersion from the spatialisation. It was hypothesised that the lack of apparent impact was from the testers not being able to utilise the spatialisation fully when not aware of it. Should the spatialisation have been revealed to the testers there would be no guarantee that the responses would be unbiased enough to give candid responses. Hence, participants reported no factual differences in their ability to localise sound sources when using spatialisation with head tracking unconsciously. Several participants mentioned that this was due to not having had a chance to consciously interact with it. Conversely, the qualitative results of the blind test also suggested that the presence of spatialisation did not negatively affect the participants either, perhaps allowing for its' passive use.

As it was discussed in Qualitative Data Collection Procedure the testers were asked questions about spatialisation with head tracking regardless of whether they were or were not aware of the tool during the test. After many participants gave hypothesising answers to what role the head tracking had for their abilities, it was emphasised that candid responses were sought and that if testers had not noticed head tracking with spatialisation they should respond as such. Some of the answers regarding the capabilities of head tracking were thus hypotheses put forth by the testers and not reflections of their own experiences during the test. For example participant 0.1 said: "I don't know, I think it helped because I noticed that I leaned my head."; while the answer given by 1.8 was: "I don't know if I noticed it, at some point I started to move my head and maybe instinctively I felt that there was a difference". However, some participants, which apparently believed it to be true, told that they did indeed feel a difference in their immersion and performance from head tracking with spatialisation, even though they initially reported not having noticed the spatialisation.

Apart from the testers' hypotheses about head tracking's impact on their experience of playing they also speculated about the use of the tool for games in general. The participant 1.2, even though they were unaware of the tool during the test, said that the game would have become slower if any head movements were involved. While there is no empirical data from this test that could support such a statement the idea makes sense considering that head movements would likely take more time compared to the camera movements made with a mouse. The respondent 0.5 also gave their opinion on the use of head tracking by saying that the eyes should be present on the screen and that looking away from the monitor when playing is not something they are used to. Another participant, 1.0, speculated that in order for the head tracking to be useful with computer games one would perhaps need a wider monitor, apparently to have more screen space for the eyes to stick to when making head movements. Interestingly, this relates back to the study by Kulshreshth and LaViola (2013) who noted that with head tracking based game camera controls the maximum amount of head tracking is dependent on the display screen size and distance of user from screen. Hence, because strong head rotations could lead to a user looking away from the monitor and experiencing discomfort, using a larger monitor could be one of the requirements for a more optimal use of head tracking.

4.2.2 Open Experiment Discussion

In the open test, while most participants who knowingly used head tracking found it to be unusual an without purpose, some testers found it helpful for sound localisation. More specifically, respondents said that it improved their general localisation of sound sources by helping them understand the approximate position of the target, like finding a room or a floor. Some participants also felt that head tracking aided them in micro adjustments when localising the targets and increased their level of immersion. However, there were some participants who thought otherwise and considered the tool to be unhelpful towards micro adjustments and vertical localisation. Interestingly, some testers also observed no impact from head tracking on the horizontal localisation and little difference with and without the use of the tool in general. Considering how contradicting many of these comments were it was difficult to draw any conclusions and perhaps if the number of participants during the open test was higher a more consistent pattern could be found.

The prevailing opinion throughout most of the participants was that head tracking was an unusual experience that did not serve any practical utility purpose. Some testers, like 2.4, emphasised the habit of using the standard tools considering that in FPS games like CS:GO head movements would take time. While it could be so, Kulshreshth and LaViola (2013) demonstrated that head tracking, and thus head movements, were useful in the FPS game Arma 2 (*Arma 2* 2009) and combat flight simulator Wings of Prey (*Wings of Prey* 2009), where players performed better with head tracking enabled. Kulshreshth and LaViola's conclusion could hypothetically be applicable towards highly paced games of other genres like CS:GO as well. Another opinion from the participants was a feeling of discomfort or unfamiliarity with turning away from the monitor when playing. Some testers felt that because the screen is static, the head tracking is not very effective in comparison to VR. To enhance its usability, one might require a larger monitor to expand the field of view. This comment, likewise those from the blind experiment, underlines the importance, pointed out by Kulshreshth and LaViola (2013), of being able to see the screen during head movements. Additionally, some participants found it unusual simply because it felt more natural to use the computer mouse instead of moving one's head as it achieved the same result.

Lastly, some participants proposed that while head tracking would likely not be useful in competitive FPS games it could heighten one's immersion in games of other genres such as horror games or single player story games. Related to this, one participant, 2.3, also speculated that in order for spatialisation of audio with head tracking to be useful, the game should be designed around it, for example a game for visually impaired. Kulshreshth and LaViola (2013) seemingly agree with 2.3's speculation, saying that not all games benefit from the use of head tracking. Finally, some of the testers viewed the use of head tracking as a matter of habit implying that it potentially could be used more effectively with time of practice.

4.3 Artefact Evaluation

4.3.1 Ghost Hunt

The developed prototype proved to be quite appropriate towards investigating the research question as it included all the necessary components. The necessary requirements for binaural audio to create a realistic experience properly matching the visual elements with their corresponding reverberation, multi-storey house, integrated head tracking, game loop, and more were fairly well implemented and appraised by the participants. The game was developed and tested iteratively to the extent the time budget allowed, though perhaps not to the extent suggested by Johannesson and Perjons (2014).

4.3.2 Head Tracking

Considering that the results showed no particular difference in the participants' localisation with and without the use of head tracking it appears that the tool may not be of much help to the localisation of audio sources in modern first-person computer games. This can also be supported by the respondents' comments on the use of the tool in general as physical head movements were described as inappropriate when playing FPS games. While the use of head tracking may not increase one's performance, according to some respondents the physical aspect of moving one's head could contribute to the increase of immersion in suitable game genres. Consequently, head tracking technology's usefulness appears to be dependent on the computer games' genre and playing style as there might not be room for any head movements in competitive and dynamic FPS games. More research is needed to say with certainty but immersive single player games might draw some potential benefit from the physical interaction with the sound.

4.4 Limitations

As a form of self-analysis and help to future researchers it is important to discuss this study's limitations and factors that could have influenced the results.

One of the issues could be the ghosts' spawning positions because randomising the targets' locations could be both positive and negative. By implementing a weighted random and ensuring that the new position was neither too close nor too far from the player at the beginning of each round, it was anticipated that, given a sufficiently large sample size, the averages would normalize and any potential bias resulting from a predetermined spawn location order would be mitigated. If spawn distance would have been logged, it could have been checked if it contributed to variability in the test. This might have lead to some inconsistencies and possible outliers in the data.

The fact that only five participants took part in the open tests also is a limitation. The amount of testers could have influenced the results and should have been higher to increase the findings' credibility.

The audio profile of the targets could possibly have influenced the participants' performance. The study by Walker and Lindsay (2006) demonstrated how the pink noise beacon, in comparison with pure tone and sonar ping, was the most easily localisable sound in terms of precision and time efficiency. Consequently, it could be one of this study's limitations that a pulsing tone was used instead of a steady pink noise.

The fact that a generalised HRTF profile was used also influences a participant's perception of the binaural audio. Because HRTFs are unique to every person the generalised values may not fit all individuals and may create confusions in the way sounds are perceived (Malham 1998). Hence, this factor cannot be omitted as it possibly could have an effect on the participants' performance.

Participants were informed at the start about their performance being timed with the UI displaying their current time. This could have impacted the participants' performance. One tester, 1.9, stated they did not know whether they should prioritise accuracy or time for 'best' performance. Testers should have been oblivious about being timed and instructed to fire when certain for more consistent and unbiased results.

Another limitation of this study is the choice of data collection method because questionnaires did not contribute with any particularly useful data. In hindsight had the investigation used observations a much more detailed and credible amount of information would be acquired as the data would be based on the participants' actions instead of words.

The interviews not being recorded is another limitation which directly influenced the data. Field notes were the only collected source of information for the analysis of qualitative data. Field notes implies that the investigator had to in real time selectively choose and note the parts of the participants' responses that were of primary importance to the asked question, which has an impact on what data is collected.

Considering that most of the respondents' answers from the interviews were given in Swedish this implied a lot of translation work and a risk of diminishing the responses' truth. When translating information from one language to another there exists a probability of losing details or meanings behind words that were said. Though considerate time and attention was paid to correct translation it could still have influenced the results.

4.5 Ethical and Societal Consequences

From a societal perspective this study's results could contribute to the integration of head tracking technology in commercial computer games to assist visually impaired individuals and perhaps allow for a wider range of players. From an ethical point of view no legal, physical or social harm should be a consequence of this study considering that the participants' safety and anonymity have been respected. We do not foresee the technology studied being used in offensive military applications, although it can not be completely ruled out.

4.6 Future Research

A number of participants viewed head tracking as an ineffective tool for competitive FPS games such as CS:GO and speculated that it could be a better fit for experience centered or story based games such as horror games. Some thought that story based games could benefit from head tracking more as it may increase immersion. Further investigation could, therefore, explore different game scenarios, user preferences, different camera perspectives and genres and any additional factors that may influence the effectiveness of head tracking in audio spatialisation.

Certain participants expressed that they did not feel they had sufficient time to acquaint themselves with head tracking as a tool. By allowing more extended exposure and opportunities for familiarisation, researchers could explore whether participants' experiences and perceptions of audio spatialisation are subject to habituation effects.

4.7 Conclusions

This study aimed to investigate how localisation of audio sources in first-person computer games —while wearing headphones— is helped by spatialising the soundscape in relation to head movement utilising head tracking technology.

The results could not show any significant impact on one's localisation of audio sources in first-person computer games. No substantial increase in accuracy or time could be seen when participants were unaware of the spatialisation. Neither did the data suggest increased performance with spatialisation enabled during the open experiments where the participants used it knowingly.

There was insufficient evidence for whether spatialisation needs to be used consciously or not to be beneficial. One possibility is that the sample size for the comparative open test was not large enough and more testing needs to be done to draw any definitive conclusions. The data suggests, however, that there is no discernible performance differences between being aware or unaware of spatialisation. In the open experiment, testers reported in the surveys that sound localisation was easier during the rounds with spatialisation. However, the measurements do not support their statements. According to the interviews, one possible explanation is that testers used spatialisation initially to get a general direction of the sound, but relied on the mouse to localise the audio as they got closer.

One of this study's contributions is its' observations on head tracking's effectiveness and usability for spatialisation in FPS games. These observations suggest that it may not be a very appropriate fit for the games that require constant attention and focus. This study's unique emphasis on the audio aspect of head tracking, can provide insights for future research in computer games involving immersive spatial tracking, encompassing VR and head tracking.

Some limitations of this study is the sample size of 20 participants in the blind experiment and five in the open experiment which might not be enough to draw definitive conclusions. A blind experiment, as it was conducted for this study, may not paint a full picture of any potentials or disadvantages that come from spatialisation with head tracking in computer games.

Since not many games utilise head tracking technology for spatialisation of audio a substantial number of testers reported being unfamiliar with listening in this way. Therefore, future research could delve deeper into the question of whether the experience of having a soundscape spatialised around the listener while wearing headphones is influenced by the level of familiarity. Another topic for future research is whether the first person perspective poses a limitation for how well players perceive spatialisation, and if other genres or perspectives would be more appropriate for this technology.

4.8 Research Quality

4.8.1 Quantitative Research Quality

The *validity* of the quantitative data collected through questionnaires during the first test showed to be accurate. However, with the blind setup of the first experiment, many survey questions were not appropriate to the research question. Regarding the open experiment's data from questionnaires all responses were accurately captured, though some questions could be consolidated into one or have slightly different response options. In the follow-up test all of the questions were pointed towards the use of head tracking and were therefore more relevant to the research question. The data gathered through the head tracking equipment was judged to be precise even though there were some possible outliers that were not included in calculations should they have arisen from measurement errors.

With regard to the study's *reliability*, the split-half approach (Denscombe 2014) was applied to the data from surveys. The blind tests survey responses showed a moderate level of reliability with the split-half approach. While the questionnaire responses from the open tests could not reliably be checked with the split-half approach because of the low sample size. Statistical tests such as Wilcoxon signed-rank test was done on data logged during the test to discern its reliability.

When it comes to *generalisability*, the first test can be better generalised on a population considering that the sample size was higher, but the generalised findings of which would be pointed towards players unaware of or passively using the spatialisation. Whereas the open test has worse generalisability because of the low number of participants, the findings would apply more to players aware of the spatialisation.

In terms of *objectivity*, we strove to avoid bias as much as possible by examining and discussing any contradicting or inconsistent data as well as providing information on the factors that could be perceived as an influence from the experimenters.

4.8.2 Qualitative Research Quality

In regard to *validity*, the study applied grounded data and triangulation. Grounded data was used through the interviews as one of the primary ways of collecting empirical data. Whereas triangulation was applied through use of mixed methods approach as a way of increasing a study's validity by analyzing the same phenomenon from different perspectives (Johannesson and Perjons 2014). The use of both quantitative and qualitative research strategies helped the analysis in that it allowed for a broader picture of the research problem and findings. Respondent validation, which involves revisiting the interviewees to validate their provided answers, was neglected in this research. This omission is a weakness in the study's overall validity.

When it comes to *reliability*, the experimenters, strove to pay much attention to the provision of an "explicit account of the methods, analysis and decision-making" (Denscombe 2014, p.298). It was sought to in detail describe the involved procedures and decisions as to make it easy for the readers to evaluate the dependability and quality of the research.

As for *generalisability*, the research provides readers with the participants' playing habits as an indicator for the type of instances the research findings could be transferred to as well as the description of the setting in which the experiments were performed.

Lastly, the study's *objectivity* was followed by including and discussing data that did not fit the analysis. Certain outliers which seemed to contradict the dominating trend were therefore mentioned and analysed. Further, since qualitative data analysis was involved it was impossible to entirely exclude subjectivity. Thus, a short summary of both experimenters' background and personal experience related to the research is provided to better clarify what impact the investigators' could have on the research.

References

Arma 2 (2009). [PC]. Czech Republic: Bohemia Interactive.

Bajura, M., Fuchs, H. Ohbuchi, R. (1992). ``Merging virtual objects with the real world: Seeing ultrasound imagery within the patient''. In: *ACM SIGGRAPH Computer Graphics* 26.2, pp. 203–210.

Bergsten, P. Kihan, M. (2023). *Ghost Hunt*. `https://github.com/CaretSoftware/Spatialised-Audio.git`. Accessed: 20-06-2023. GitHub.

Blum, A et al. (n.d.). *Navigating in a virtual audio environment*. `https://rs2007.limsi.fr/PS_Page_16.html`. Accessed: 27-02-2023.

Borg, E. Westerlund, J. (2020). *Statistik för beteendevetare Faktabok*. Fjärde upplagan. Stockholm: Liber.

Braun, V. Clarke, V. (2006). ``Using thematic analysis in psychology''. In: *Qualitative research in psychology* 3.2, pp. 77–101.

Brieger, S. Göthner, F. (2011). *Spelares inställning till HRTF-teknik i FPS-spel.*

Brock, D., Stroup, J. L. Ballas, J. A. (2002). ``Effects of 3D auditory display on dual task performance in a simulated multiscreen watchstation environment''. In: *Proceedings of the human factors and ergonomics society annual meeting*. Vol. 46. 17. SAGE Publications Sage CA: Los Angeles, CA, pp. 1570–1573.

Counter-strike: global offensive (2012). [PC]. Bellevue, WA: Valve.

Denscombe, M. (2014). *The Good Research Guide: For Small-Scale Social Research Projects*. 5th ed. Berkshire: Open University Press.

ElevenLabs Inc. (n.d.). `https://beta.elevenlabs.io/`. Accessed: 22-02-2023.

Epic Games (1991). *Unreal Engine 3*. Potomac, MD.

Farkaš, T. et al. (2018). ``Binaural and ambisonic sound as the future standard of digital games''. In: *Acta Ludologica* 1.2, pp. 34–46.

Forskningsetiska principer inom humanistisksamhällsvetenskaplig forskning (2002). Stockholm: The Swedish Research Council.

Fusch, P. I. Ness, L. R. (2015). ``Are we there yet? Data saturation in qualitative research''. In: *The Qualitative Report* 20.9, pp. 1408–1416.

God of War (2018). [PlayStation 4]. London, UK: Sony Interactive Entertainment Europe.

Google LLC (1998). *Resonance Audio*. `https://resonance-audio.github.io/resonance-audio/`. Accessed: 20-06-2023. Mountain View, CA.

Gustafson, H. Cancar, M. (2020). *Binaural ljudlokalisering i olika våningsplan i vertikala miljöer: En undersökning om binaural ljudlokalisering i FPS-spel*.

Hellblade: Senua's Sacrifice (2017). [PC, PlayStation 4]. Cambridge, UK: Ninja Theory.

Hermann, T., Hunt, A. Neuhoff, J. G. (2011). *The sonification handbook*. Vol. 1. Logos Verlag Berlin.

Hjerm, M., Lindgren, S. Nilsson, M. (2014). *Introduktion till samhällsvetenskaplig analys*. 2., [utök. och uppdaterade] uppl. Malmö: Gleerup.

Johannesson, P. Perjons, E. (2014). *An introduction to design science*. Vol. 10. Springer.

Kulshreshth, A. LaViola, J. (2013). ``Evaluating Performance Benefits of Head Tracking in Modern Video Games''. In: *Proceedings of the 1st Symposium on Spatial User Interaction*. SUI '13. Los Angeles, California, USA: Association for Computing Machinery, pp. 53–60. DOI: `10.1145/2491367.2491376`.

Lee, S. H. (2006). ``Constructing effective questionnaires''. In: *Handbook of human performance technology, Hoboken, NJ: Pfeiffer Wiley*, pp. 760–779.

Ludovico, L. A., Mauro, D. A. Pizzamiglio, D. (2010). ``Head in space: A head-tracking based binaural spatialization system''. In: Sound and Music Conference, pp. 369–376.

M., Matteo (2022). *What is binaural audio? How binaural recording works*. `https://splice.com/blog/what-is-binaural-audio/`. Accessed: 04-03-2023. Splice blog.

Malham, D. G. (1998). ``Approaches to spatialisation''. In: *Organised sound* 3.2, pp. 167–177.

Marks, S., Windsor, J. A. Wünsche, B. (2010). ``Evaluation of the effectiveness of head tracking for view and avatar control in virtual environments''. In: *2010 25th International Conference of Image and Vision Computing New Zealand*. IEEE, pp. 1–8.

Munafo, J., Diedrick, M. Stoffregen, T. A. (2017). ``The virtual reality head-mounted display Oculus Rift induces motion sickness and is sexist in its effects''. In: *Experimental brain research* 235 (3), pp. 889–901. DOI: `10.1007/s00221-016-4846-7`.

Nakamura, J. Csikszentmihalyi, M. (2014). ``The concept of flow''. In: *Flow and the foundations of positive psychology: The collected works of Mihaly Csikszentmihalyi*, pp. 239–263.

NaturalPoint Inc. (n.d.). *TrackIR*. `https://www.trackir.com`. Accessed: 20-06-2023. Cornvallis, OR.

Overwatch (2016). [PC, Playstation 4, Xbox One]. Irvine, California: Blizzard Entertainment.

Patton, M. Q. (1990). *Qualitative evaluation and research methods*. SAGE Publications, inc.

Perrett, S. Noble, W. (1997). ``The effect of head rotations on vertical plane sound localization''. In: *The Journal of the Acoustical Society of America* 102.4, pp. 2325–2332.

Peterson, R. A. (2000). ``Rating scales''. In: *Constructing effective questionnaires*, pp. 61–83. DOI: `10.4135/9781483349022`.

Rainbow six: siege (2015). [PC]. Montreuil Sous Bois: Ubisoft.

Rekimoto, J. (1995). ``A vision-based head tracker for fish tank virtual reality-VR without head gear''. In: *Proceedings Virtual Reality Annual International Symposium'95*. IEEE, pp. 94–100.

Russell, S. J. Norvig, P. (2010). *Artificial intelligence a modern approach*. Pearson Education, Inc.

Social Science Statistics (2018). `https://www.socscistatistics.com/tests/`. Accessed: 27-04-2023.

Tannen, R. S. (1998). ``Breaking the sound barrier: designing auditory displays for global usability''. In: *4th Conference on Human Factors & the Web, Basking Ridge, New Jersey*.

The Last of Us (2013). [PlayStation 4]. London, UK: Sony Computer Entertainment Europe.

Thomas, D. R. (2006). ``A general inductive approach for analyzing qualitative evaluation data''. In: *American journal of evaluation* 27.2, pp. 237–246.

Totten, C. W. (2014). *Architectural Approach to Level Design*. CRC Press.

Tran, Q. T. Mynatt, E. D. (2000). ``Music monitor: Ambient musical data for the home''. In: *Extended Proceedings of the HOIT*, pp. 85–92.

Unity Asset Store (n.d.). `https://assetstore.unity.com/`. Accessed: 05-02-2023.

Unity Technologies (2004). *Unity*. `https://unity.com`. Accessed: 20-06-2023. San Francisco, CA.

Walker, B. N. Lindsay, J. (2006). ``Navigation performance with a virtual auditory display: Effects of beacon sound, capture radius, and practice''. In: *Human factors* 48.2, pp. 265–278.

Walker, B. N. Nees, M. A. (2011). ``Theory of sonification''. In: *The sonification handbook* 1, pp. 9–39.

Wallach, H. (1940). ``The role of head movements and vestibular and visual cues in sound localization." In: *Journal of Experimental Psychology* 27.4, p. 339.

Widman, L. (2021). *Binaural versus Stereo Audio in Navigation in a 3D Game: Differences in Perception and Localization of Sound*.

Wightman, F. L. Kistler, D. J. (1999). ``Resolution of front--back ambiguity in spatial hearing by listener and source movement''. In: *The Journal of the Acoustical Society of America* 105.5, pp. 2841–2853.

Wings of Prey (2009). [PC, PlaytStation 3, Xbox 360]. Europe, North America: Microsoft Windows.

Xie, B. et al. (2007). ``Head-related transfer function database and its analyses''. In: *Science in China Series G: Physics, Mechanics and Astronomy* 50.3, pp. 267–280.

Zahorik, P. (2002). ``Auditory display of sound source distance''. In: *Proc. Int. Conf. on Auditory Display*, pp. 326–332.

A Quantitative Data Blind Experiment

1. Subject Number
2. Total Elapsed Time
3. Round Number
4. Spatialisation of Audio with Head Tracking
5. Time to Complete Round
6. Average Head Movement
7. Total Precision (0.0-1.0)
8. Precision on Horisontal (X) Axis (0.0-1.0)
9. Precision on Vertical (Y) Axis (0.0-1.0)
10. Distance to Target
11. Hit Target
12. Floor of Player at Time of Firing
13. Floor of Target at Time of Firing

Table A.1: Quantitative Data Blind Experiment

Quantitative Data Blind Experiment												
Nr.	**Time**	**Round**	**Head Track.**	**Round Time**	**Avg. Mov.**	**Precision**	**Precision X**	**Precision Y**	**Dist.**	**Hit**	**Fl. Player**	**Fl. Target**
1	119.5250	1	FALSE	119.5250	35.39153	0.9965127	0.9976556	0.9987718	2.331832	TRUE	1	1
1	200.6649	2	FALSE	81.13990	37.70773	0.9382306	0.9475667	0.9885391	4.034594	FALSE	1	1
1	216.2165	3	FALSE	15.55153	36.41221	0.9639944	0.9841163	0.9791963	2.433631	FALSE	1	1
1	239.4686	4	FALSE	23.25211	34.53858	0.9287794	0.9905418	0.9369094	2.240456	FALSE	1	1
1	298.7886	5	FALSE	59.32001	31.31282	0.9760260	0.9999782	0.9760466	2.616835	FALSE	2	2
1	331.2561	6	FALSE	32.46750	29.56973	0.8103635	0.8292516	0.9631490	2.494351	FALSE	2	2
1	348.0067	7	FALSE	16.75067	28.89056	0.9809168	0.9813948	0.9994531	2.087459	FALSE	2	2
1	359.8240	8	TRUE	11.81723	28.42711	0.9622793	0.9622798	0.9999932	3.117302	FALSE	2	2
1	377.7583	9	TRUE	17.93433	27.63456	0.9940674	0.9999304	0.9941343	2.297261	TRUE	2	2
1	393.7090	10	TRUE	15.95068	26.95061	0.9546266	0.9605117	0.9935713	1.810410	FALSE	2	2
1	415.2600	11	TRUE	21.55103	26.42510	0.9900953	0.9925278	0.9975108	4.203490	FALSE	1	1

Nr.	Time	Round	Head Track.	Round Time	Avg. Mov.	Precision	Precision X	Precision Y	Dist.	Hit	Fl. Player	Fl. Target
1	452.7948	12	TRUE	37.53479	25.06524	0.9641200	0.9664956	0.9972911	3.552678	FALSE	1	1
1	466.6295	13	TRUE	13.83472	24.72041	0.9910560	0.9927098	0.9983202	2.337305	TRUE	1	1
1	503.3144	14	TRUE	36.68488	24.29877	0.8751779	0.8947182	0.9752039	1.821184	FALSE	1	1
2	56.37147	1	TRUE	56.37147	25.85596	0.9953039	0.9999974	0.9953064	1.919082	TRUE	0	0
2	73.87222	2	TRUE	17.50074	25.14949	0.7996488	0.8222107	0.9505914	3.339553	FALSE	1	1
2	124.2583	3	TRUE	50.38608	22.28362	0.9933998	0.9998817	0.9935160	2.697754	TRUE	2	2
2	165.6938	4	TRUE	41.43552	19.79143	0.9939795	0.9989395	0.9950083	1.057029	TRUE	2	2
2	192.1957	5	TRUE	26.50188	18.49687	0.9889833	0.9937263	0.9951522	2.529766	FALSE	2	2
2	234.5158	6	TRUE	42.32007	17.54408	0.3615787	0.3684181	0.06644753	1.786817	FALSE	2	2
2	261.2010	7	TRUE	26.68523	17.58665	0.9947571	0.9948179	0.9999269	1.149546	TRUE	2	2
2	272.2019	8	FALSE	11.00092	17.18040	0.9335458	0.9976274	0.9355726	0.657686	TRUE	2	2
2	286.0690	9	FALSE	13.86707	17.10063	0.9925084	0.9993463	0.9931434	0.7791435	TRUE	2	2
2	299.3365	10	FALSE	13.26752	16.66230	0.8380485	0.8383046	0.9955245	3.360409	FALSE	2	2
2	338.0558	11	FALSE	38.71933	15.52700	0.8546678	0.9971036	0.8567337	0.9256423	FALSE	2	2
2	373.2413	12	FALSE	35.18546	14.74123	0.9950452	0.9997660	0.9952692	1.426567	TRUE	1	1
2	397.9253	13	FALSE	24.68399	14.14219	0.8692712	0.9928000	0.8744968	1.940174	FALSE	0	0
2	419.1258	14	FALSE	21.20056	13.87178	0.9994279	0.9999931	0.9994341	1.810467	TRUE	1	1
3	77.85535	1	TRUE	77.85535	81.58359	0.9452160	0.9443529	0.9998977	3.895616	FALSE	0	0
3	85.77249	2	TRUE	7.917145	80.25516	0.6714631	0.6679491	0.9872150	3.584501	FALSE	0	0
3	96.22315	3	TRUE	10.45066	78.41655	0.9489924	0.9549980	0.9922590	4.479577	FALSE	0	0
3	131.5920	4	TRUE	35.36883	74.10267	0.9966465	0.9971841	0.9993700	6.445928	FALSE	1	1
3	248.7333	5	TRUE	117.1413	62.43903	0.3756278	0.1918461	0.3087750	5.140469	FALSE	2	1
3	260.0173	6	TRUE	11.28400	61.39908	0.8243493	0.8438535	0.9515499	5.849251	FALSE	2	2
3	266.8341	7	TRUE	6.816833	60.91464	0.623296	0.6558743	0.7301075	2.849897	FALSE	2	2
3	335.0712	8	FALSE	68.23709	56.17715	0.9895542	0.9909549	0.9984474	2.016893	TRUE	2	2
3	364.6234	9	FALSE	29.55215	54.20636	0.9760767	0.9752537	0.9999794	5.277288	FALSE	2	2
3	388.5743	10	FALSE	23.95096	53.37193	0.3101618	0.04223716	0.3008503	0.8633433	FALSE	2	2
3	417.2925	11	FALSE	28.71817	51.90512	0.9120710	0.9990426	0.9127623	2.198791	FALSE	2	2
3	458.7103	12	FALSE	41.41779	51.10078	0.9796576	0.9794763	0.9998457	2.646657	FALSE	2	2
3	492.0280	13	FALSE	33.31775	49.80859	0.9136040	0.9186946	0.9890639	3.638352	FALSE	2	2
3	529.1614	14	FALSE	37.13342	47.88940	0.8917313	0.9591398	0.9204241	3.636269	FALSE	2	2
4	78.62350	1	TRUE	78.62350	43.18932	0.8875036	0.8862680	0.9993758	4.242819	FALSE	2	2

Nr.	Time	Round	Head Track.	Round Time	Avg. Mov.	Precision	Precision X	Precision Y	Dist.	Hit	Fl. Player	Fl. Target
4	155.8625	2	TRUE	77.23898	41.27041	0.9620954	0.9628783	0.9988864	4.007113	FALSE	2	2
4	229.9168	3	TRUE	74.05435	40.28546	0.9904116	0.9910295	0.9993688	3.943460	FALSE	2	2
4	277.4530	4	TRUE	47.53621	40.79207	0.8161466	0.8214526	0.9914397	3.722464	FALSE	1	1
4	314.4055	5	TRUE	36.95242	40.06994	0.9271589	0.9274098	0.9997019	3.731744	FALSE	1	1
4	520.7326	6	TRUE	206.3271	42.39586	0.6478083	0.6679721	0.8633181	1.144208	FALSE	2	2
4	614.7604	7	TRUE	94.02783	44.05238	0.7104341	0.7074889	0.9942833	3.418582	FALSE	2	2
4	654.9747	8	FALSE	40.21423	43.73914	0.5768259	0.5627718	0.8604076	3.078181	FALSE	2	2
4	669.9576	9	FALSE	14.98297	43.81257	0.9608589	0.9731386	0.9864733	5.655576	FALSE	2	2
4	726.3708	10	FALSE	56.41315	43.48511	0.9965365	0.9965922	0.9999225	4.692740	FALSE	1	1
4	814.1545	11	FALSE	87.78375	42.61118	0.9961406	0.9961954	0.9999386	7.852740	FALSE	1	1
4	830.2209	12	FALSE	16.06641	42.48460	0.8889731	0.9061381	0.9776549	1.705248	FALSE	1	1
4	876.3030	13	FALSE	46.08203	42.12888	0.9930340	0.9930093	0.9999982	4.368236	FALSE	1	1
4	993.7147	14	FALSE	117.4117	41.23191	0.9993004	0.9999478	0.9993523	5.874080	TRUE	0	0
5	7.766998	1	FALSE	7.766998	64.23114	0.9916722	0.9999491	0.9917219	3.182093	FALSE	1	1
5	29.10182	2	FALSE	21.33483	66.33060	0.9717233	0.9825515	0.9874678	2.548012	FALSE	1	1
5	110.2240	3	FALSE	81.12215	55.51989	0.4054340	0.7051411	0.2995656	3.007097	FALSE	1	0
5	136.7586	4	FALSE	26.53463	53.81151	0.9738024	0.9797524	0.9926929	8.420585	FALSE	1	1
5	161.3269	5	FALSE	24.56831	51.92974	0.9856011	0.9964501	0.9890524	3.161714	FALSE	1	1
5	209.5798	6	FALSE	48.25284	47.93152	0.9862428	0.9998670	0.9863673	4.185812	FALSE	0	0
5	234.9648	7	FALSE	25.38501	45.94092	0.9711456	0.9749977	0.9945123	2.113603	FALSE	1	1
5	275.2509	8	TRUE	40.28618	43.17939	0.9753573	0.9811505	0.9939748	2.589234	FALSE	2	2
5	298.2025	9	TRUE	22.95160	41.56445	0.9142009	0.9142778	0.9998726	1.279460	FALSE	2	2
5	331.5721	10	TRUE	33.36960	39.49023	0.9986837	0.9998873	0.9987960	3.683498	TRUE	2	2
5	351.6059	11	TRUE	20.03372	39.44374	0.9765676	0.9781015	0.9983901	4.668144	FALSE	2	2
5	376.3909	12	TRUE	24.78506	38.20015	0.9841700	0.9903607	0.9936864	2.957272	FALSE	2	2
5	383.7078	13	TRUE	7.316895	37.97367	0.9630013	0.9636935	0.9992491	3.418272	FALSE	2	2
5	413.5762	14	TRUE	29.86835	36.54581	0.9874375	0.9982400	0.9891398	1.531355	TRUE	2	2
6	47.13756	1	TRUE	47.13756	111.9903	0.9703776	0.9723407	0.9974892	3.198217	FALSE	1	1
6	79.55695	2	TRUE	32.41940	99.47392	0.9764173	0.9959285	0.9802271	2.038828	FALSE	2	2
6	100.8917	3	TRUE	21.33470	94.03233	0.9642082	0.9990597	0.9649163	1.179185	TRUE	2	2
6	117.4090	4	TRUE	16.51732	89.92753	0.9325696	0.9522625	0.9744776	1.695956	FALSE	2	2
6	137.3435	5	TRUE	19.93456	86.52263	0.9931672	0.9985200	0.9945686	1.359707	TRUE	2	2

Nr.	Time	Round	Head Track.	Round Time	Avg. Mov.	Precision	Precision X	Precision Y	Dist.	Hit	Fl. Player	Fl. Target
6	184.4475	6	TRUE	47.10393	76.36494	0.9783904	0.9924890	0.9856201	1.930380	FALSE	2	2
6	203.0153	7	TRUE	18.56786	74.11767	0.9998035	0.9998386	0.9999634	3.488502	TRUE	2	2
6	244.2180	8	FALSE	41.20265	68.42368	0.9930571	0.9999762	0.9930803	3.109290	FALSE	2	2
6	253.4187	9	FALSE	9.200699	67.84294	0.9835277	0.9907790	0.9926115	2.316035	FALSE	2	2
6	263.0194	10	FALSE	9.600769	67.35211	0.9979766	0.9998968	0.9980789	2.060266	TRUE	2	2
6	282.8541	11	FALSE	19.83463	64.82854	0.9839865	0.9984310	0.9854883	1.081204	TRUE	1	1
6	293.1212	12	FALSE	10.26715	64.78885	0.9887050	0.9998344	0.9888632	4.985482	FALSE	1	1
6	344.0741	13	FALSE	50.95288	60.49522	0.9879701	0.9883256	0.9995440	4.522267	FALSE	0	0
6	353.3576	14	FALSE	9.283539	60.04572	0.9927980	0.9935809	0.9991682	5.458152	FALSE	0	0
7	25.53568	1	TRUE	25.53568	22.53183	0.8219985	0.9778470	0.8366470	1.047344	FALSE	1	1
7	84.20747	2	TRUE	58.67179	17.83767	0.9935932	0.9933956	0.9995510	2.116572	TRUE	0	0
7	108.6594	3	TRUE	24.45195	19.60340	0.8819190	0.9925867	0.8861436	0.9777088	FALSE	1	1
7	164.7473	4	TRUE	56.08787	16.84095	0.9856261	0.9885525	0.9966289	2.419558	FALSE	1	1
7	231.7363	5	TRUE	66.98906	17.95817	0.9821409	0.9999919	0.9821485	3.251479	FALSE	1	1
7	260.8388	6	TRUE	29.10243	17.87408	0.9233612	0.9380053	0.9832810	0.8805954	TRUE	1	1
7	297.7602	7	TRUE	36.92142	18.59673	0.9984442	0.9985566	0.9998709	2.546409	TRUE	1	1
7	333.0796	8	FALSE	35.31943	17.58201	0.9844315	0.9974095	0.9869186	4.612291	FALSE	2	2
7	393.0000	9	FALSE	59.92035	16.74594	0.9881102	0.9944267	0.9935607	3.318660	FALSE	2	2
7	436.5194	10	FALSE	43.51944	15.71043	0.9676656	0.9992597	0.9683484	0.6490627	TRUE	2	2
7	454.6375	11	FALSE	18.11807	15.45565	0.8132963	0.8907399	0.8954895	0.7677221	FALSE	2	2
7	491.5390	12	FALSE	36.90152	15.25155	0.9736920	0.9790178	0.9943043	1.553111	TRUE	2	2
7	509.0565	13	FALSE	17.51752	15.03175	0.9830753	0.9862721	0.9966173	1.506472	TRUE	2	2
7	597.0236	14	FALSE	87.96710	13.60276	0.1937933	0.08299974	0.1335818	1.149963	FALSE	2	2
8	39.22022	1	TRUE	39.22022	10.86784	0.9767308	0.9974295	0.9791040	2.292048	FALSE	2	2
8	79.82388	2	TRUE	40.60366	11.23769	0.9966983	0.9991077	0.9975846	3.909522	TRUE	2	2
8	105.7260	3	TRUE	25.90208	11.07916	0.9991342	0.9995419	0.9995914	2.185412	TRUE	2	2
8	123.7941	4	TRUE	18.06818	10.51602	0.9729607	0.9770206	0.9957117	3.020409	FALSE	2	2
8	144.6961	5	TRUE	20.90195	9.841458	0.9973975	0.9997803	0.9976158	2.722667	TRUE	2	2
8	175.1156	6	TRUE	30.41951	9.037651	0.9960935	0.9985956	0.9974892	2.715560	TRUE	2	2
8	201.5681	7	TRUE	26.45247	8.419629	0.9832639	0.9986640	0.9845577	1.982272	FALSE	2	2
8	242.0718	8	FALSE	40.50377	8.558629	0.9976802	0.9980503	0.9996173	4.044889	TRUE	2	2
8	266.7570	9	FALSE	24.68518	8.176405	0.9973161	0.9977566	0.9995475	5.971265	FALSE	2	2

Nr.	Time	Round	Head Track.	Round Time	Avg. Mov.	Precision	Precision X	Precision Y	Dist.	Hit	Fl. Player	Fl. Target
8	297.9759	10	FALSE	31.21887	7.863106	0.9954953	0.9997010	0.9957891	3.941472	FALSE	1	1
8	360.2967	11	FALSE	62.32083	8.025335	0.9959201	0.9979612	0.9979467	4.610163	FALSE	0	0
8	387.7007	12	FALSE	27.40399	8.173247	0.9995404	0.9999945	0.9995458	4.250883	TRUE	0	0
8	413.9183	13	FALSE	26.21759	8.202065	0.9796555	0.9907683	0.9884560	2.632160	FALSE	0	0
8	468.2408	14	FALSE	54.32245	7.732892	0.9829090	0.9998341	0.9830687	2.468747	FALSE	1	1
9	42.58627	1	TRUE	42.58627	121588.4	0.9948461	0.9993758	0.9954484	3.852096	FALSE	1	1
9	84.62315	2	TRUE	42.03687	106686.8	0.9731838	0.9758536	0.9969214	3.649357	FALSE	2	2
9	133.6773	3	TRUE	49.05418	93338.37	0.9987398	0.9997323	0.9989977	7.175890	FALSE	2	2
9	198.0332	4	TRUE	64.35587	80177.48	0.9806970	0.9890418	0.9914265	3.729837	FALSE	1	1
9	251.5376	5	TRUE	53.50436	71764.20	0.9363460	0.9525928	0.9815984	2.602301	FALSE	2	2
9	291.0558	6	TRUE	39.51823	66602.83	0.9999223	0.9999994	0.9999228	1.539089	TRUE	2	2
9	337.0247	7	TRUE	45.96893	61461.60	0.5458377	0.5429884	0.9834223	0.7513205	FALSE	2	2
9	373.9103	8	FALSE	36.88562	57877.43	0.9074602	0.9365998	0.9659135	0.979117	FALSE	2	2
9	422.0796	9	FALSE	48.16928	53780.50	0.9979367	0.9989451	0.9989860	4.377449	TRUE	2	2
9	468.7833	10	FALSE	46.70370	50326.38	0.9965513	0.9998206	0.9967267	4.415544	FALSE	2	2
9	533.9859	11	FALSE	65.20258	46185.13	0.9951198	0.9997337	0.9953803	2.302444	TRUE	2	2
9	751.1390	12	FALSE	217.1531	36250.98	0.9990231	0.9992671	0.9997500	2.807886	TRUE	2	2
9	789.1892	13	FALSE	38.05017	34933.95	0.9713695	0.9710613	0.9999217	4.693030	FALSE	2	2
9	823.7566	14	FALSE	34.56738	33818.28	0.9932622	0.9997888	0.9934641	4.221655	FALSE	2	2
10	6.817272	1	FALSE	6.817272	14.67494	0.9732716	0.9813464	0.9899980	3.485464	FALSE	1	1
10	23.00207	2	FALSE	16.18480	15.14495	0.9883912	0.9985877	0.9897710	3.527359	FALSE	1	1
10	73.35652	3	FALSE	50.35445	31.96854	0.9940259	0.9989275	0.9949894	2.518922	TRUE	0	0
10	80.94038	4	FALSE	7.583855	32.25343	0.9784110	0.9999869	0.9784220	2.603240	FALSE	0	0
10	93.14131	5	FALSE	12.20094	32.33562	0.9876497	0.9968820	0.9905651	4.459582	FALSE	1	1
10	163.6805	6	FALSE	70.53922	29.18734	0.9550706	0.9936242	0.9575221	1.674771	FALSE	1	1
10	192.5165	7	FALSE	28.83600	28.75110	0.9846931	0.9937539	0.9906092	3.424540	FALSE	1	1
10	243.1539	8	TRUE	50.63741	25.97537	0.9834579	0.9998136	0.9836339	4.167699	FALSE	1	1
10	257.7885	9	TRUE	14.63452	25.66026	0.9916058	0.9959218	0.9956478	3.928671	FALSE	1	1
10	303.4911	10	TRUE	45.70264	24.51525	0.9901706	0.9953074	0.9947577	3.453996	FALSE	2	2
10	319.8754	11	TRUE	16.38431	25.06682	0.9900504	0.9915377	0.9984856	3.855528	FALSE	2	2
10	362.0115	12	TRUE	42.13608	23.89708	0.04809153	0.02906847	0.02029255	0.5795788	FALSE	2	2
10	384.5299	13	TRUE	22.51846	23.60591	0.9658548	0.9995693	0.9662564	2.639180	FALSE	2	2

Nr.	Time	Round	Head Track.	Round Time	Avg. Mov.	Precision	Precision X	Precision Y	Dist.	Hit	Fl. Player	Fl. Target
10	449.4404	14	TRUE	64.91046	21.88495	0.9436566	0.9481966	0.9949129	3.984293	FALSE	2	2
11	47.27095	1	TRUE	47.27095	3112.959	0.9440517	0.9592608	0.9796579	5.035588	FALSE	2	2
11	65.45584	2	TRUE	18.18489	2864.810	0.9864690	0.9995109	0.9869196	3.488769	FALSE	2	2
11	68.47276	3	TRUE	3.016922	2827.687	0.2869139	0.2846808	0.005928606	2.579694	FALSE	2	2
11	85.57398	4	TRUE	17.10122	2634.009	0.3085411	0.3466310	0.0008193851	0.6359625	FALSE	2	2
11	136.0112	5	TRUE	50.43726	2190.642	0.9597989	0.9613104	0.9983611	3.619153	FALSE	1	1
11	206.0498	6	TRUE	70.03859	1776.172	0.9299229	0.9291447	0.9997631	2.967166	FALSE	2	2
11	214.3004	7	TRUE	8.250519	1737.509	0.5765426	0.6238264	0.7476770	1.434418	FALSE	2	2
11	226.6012	8	FALSE	12.30087	1682.790	0.9730991	0.9729986	0.9999561	4.232600	FALSE	2	2
11	241.6857	9	FALSE	15.08444	1620.095	0.6802913	0.6800638	0.9821193	2.070061	FALSE	2	2
11	254.7534	10	FALSE	13.06770	1570.070	0.9988500	0.9998559	0.9989915	2.079104	TRUE	2	2
11	266.6204	11	FALSE	11.86702	1526.875	0.9178413	0.9260389	0.9891249	3.692957	FALSE	2	2
11	327.6572	12	FALSE	61.03680	1337.333	0.9599803	0.99984550	0.9601198	1.930561	FALSE	1	1
11	362.6432	13	FALSE	34.98599	1248.787	0.9439760	0.9903142	0.9515592	3.501294	FALSE	2	2
11	368.2269	14	FALSE	5.583710	1235.830	0.9296167	0.9294691	0.9984590	3.366288	FALSE	2	2
12	12.55115	1	TRUE	12.55115	97.94705	0.9982810	0.9998692	0.9984097	3.876278	TRUE	0	0
12	24.03554	2	TRUE	11.48439	92.57076	0.9990754	0.9990676	0.9999950	1.771269	TRUE	0	0
12	37.95348	3	TRUE	13.91794	86.84729	0.9859173	0.9999936	0.9859232	2.193833	FALSE	1	1
12	50.80466	4	TRUE	12.85118	82.36871	0.9378523	0.9362866	0.9954971	3.320969	FALSE	1	1
12	66.15606	5	TRUE	15.35139	79.47914	0.9735847	0.9988136	0.9746705	1.606263	FALSE	2	2
12	89.67454	6	TRUE	23.51848	76.66015	0.9591303	0.9608365	0.9971648	4.468454	FALSE	2	2
12	101.1755	7	TRUE	11.50095	74.44790	0.9765088	0.9766520	0.9996194	3.454052	FALSE	2	2
12	176.4640	8	FALSE	75.28854	62.28476	0.9496832	0.9904298	0.9584576	1.069025	TRUE	2	2
12	195.5819	9	FALSE	19.11792	60.89574	0.9236290	0.9724082	0.9482596	2.413210	FALSE	2	2
12	254.4521	10	FALSE	58.87015	57.47293	0.9761174	0.9773974	0.9985587	2.718405	FALSE	2	2
12	269.2197	11	FALSE	14.76758	57.73262	0.9995549	0.9999568	0.9995979	3.584293	TRUE	2	2
12	296.5380	12	FALSE	27.31833	54.80190	0.9932177	0.9998523	0.9933630	3.880587	FALSE	1	1
12	316.2069	13	FALSE	19.66891	53.46173	0.9927135	0.9927056	0.9999959	2.856062	TRUE	1	1
12	336.0916	14	FALSE	19.88467	52.12245	0.9854169	0.9905547	0.9947537	3.350405	FALSE	1	1
13	11.86787	1	TRUE	11.86787	8.559518	0.9888943	0.9998209	0.9890640	3.420884	FALSE	2	2
13	60.93894	2	TRUE	49.07107	7.332755	0.9993871	0.9996879	0.9996798	4.017553	TRUE	2	2
13	72.60651	3	TRUE	11.66758	7.181756	0.9990843	0.9991153	0.9999621	3.530348	TRUE	2	2

Nr.	Time	Round	Head Track.	Round Time	Avg. Mov.	Precision	Precision X	Precision Y	Dist.	Hit	Fl. Player	Fl. Target
13	107.6093	4	TRUE	35.00275	6.662286	0.9821592	0.9937066	0.9882764	3.918413	FALSE	1	1
13	132.4777	5	TRUE	24.86848	6.592621	0.9951659	0.9987497	0.9963987	2.835439	TRUE	2	2
13	165.5974	6	TRUE	33.11967	6.310324	0.9860363	0.9998705	0.9861616	1.852752	TRUE	2	2
13	187.7994	7	TRUE	22.20201	6.076749	0.9972254	0.9973065	0.9999083	3.962904	TRUE	2	2
13	222.7530	8	FALSE	34.95357	5.953540	0.9867260	0.9972467	0.9894075	4.783237	FALSE	2	2
13	240.1214	9	FALSE	17.36841	5.811944	0.9892584	0.9989603	0.9902626	2.922069	FALSE	2	2
13	251.6057	10	FALSE	11.48434	5.782311	0.9974222	0.9999596	0.9974619	4.404770	TRUE	2	2
13	260.1732	11	FALSE	8.567444	5.803205	0.9887867	0.9959224	0.9928051	1.523554	TRUE	2	2
13	280.0087	12	FALSE	19.83548	5.643925	0.9902837	0.9992225	0.9910426	3.184253	FALSE	2	2
13	322.6295	13	FALSE	42.62082	15.64214	0.9936659	0.9966025	0.9970431	5.707606	FALSE	1	1
13	329.2968	14	FALSE	6.667328	15.61978	0.9835117	0.9908879	0.9924705	4.557356	FALSE	1	1
14	30.18608	1	FALSE	30.18608	27.21485	0.9967919	0.9969202	0.9997344	2.035916	TRUE	1	1
14	69.25623	2	FALSE	39.07015	20.38046	0.9319955	0.9636707	0.9634198	4.599139	FALSE	1	1
14	86.25757	3	FALSE	17.00134	18.38631	0.9622935	0.9720654	0.9894898	2.154923	FALSE	1	1
14	115.4100	4	FALSE	29.15240	15.75631	0.9833143	0.9907471	0.9922673	2.175697	FALSE	1	1
14	170.4470	5	FALSE	55.03706	12.51109	0.9967439	0.9988667	0.9978709	5.872127	FALSE	1	1
14	194.4652	6	FALSE	24.01816	11.52037	0.9709536	0.9857130	0.9843081	2.032467	FALSE	1	1
14	218.3501	7	FALSE	23.88487	10.66644	0.9966140	0.9979805	0.9985726	2.640182	TRUE	1	1
14	259.6200	8	TRUE	41.26994	9.490694	0.9294167	0.9516960	0.9747345	2.018523	FALSE	1	1
14	281.5881	9	TRUE	21.96808	8.965757	0.8091209	0.8124599	0.9941392	3.203739	FALSE	1	1
14	290.2725	10	TRUE	8.684448	8.775160	0.9664054	0.9738193	0.9915949	2.065017	FALSE	1	1
14	320.2748	11	TRUE	30.00226	8.182932	0.9738895	0.9763279	0.9952641	1.919724	FALSE	1	1
14	421.7654	12	TRUE	101.4906	8.013798	0.9629046	0.9789008	0.9832922	2.213258	FALSE	0	0
14	441.7349	13	TRUE	19.96951	7.743431	0.9983783	0.9997656	0.9986085	2.184061	TRUE	0	0
14	462.1867	14	TRUE	20.45187	7.471128	0.9462244	0.9527469	0.9916993	3.964108	FALSE	0	0
15	37.05340	1	TRUE	37.05340	35.16741	0.9823847	0.9994241	0.9829341	1.421746	TRUE	2	2
15	59.02202	2	TRUE	21.96862	35.09314	0.8786787	0.8787144	0.9990514	4.069170	FALSE	2	2
15	78.04038	3	TRUE	19.01836	32.95457	0.9887332	0.9915382	0.9970553	2.678682	FALSE	2	2
15	97.42513	4	TRUE	19.38475	36.62531	0.9978781	0.9995674	0.9983076	2.181871	TRUE	2	2
15	146.0788	5	TRUE	48.65365	36.32851	0.9355713	0.9420468	0.9924042	2.768791	FALSE	1	1
15	219.7179	6	TRUE	73.63910	32.51618	0.9880433	0.9939295	0.9939892	3.176479	FALSE	2	2
15	232.5687	7	TRUE	12.85081	32.17411	0.9319040	0.9355389	0.9958116	2.822877	FALSE	2	2

Nr.	Time	Round	Head Track.	Round Time	Avg. Mov.	Precision	Precision X	Precision Y	Dist.	Hit	Fl. Player	Fl. Target
15	260.7702	8	FALSE	28.20154	31.44243	0.9943054	0.9948946	0.9994045	2.107067	TRUE	2	2
15	280.9214	9	FALSE	20.15118	30.73993	0.9872013	0.9887515	0.9984132	3.193503	FALSE	2	2
15	306.2392	10	FALSE	25.31778	33.84356	0.9983387	0.9999850	0.9983536	2.800276	TRUE	2	2
15	316.9064	11	FALSE	10.66718	33.82182	0.9902741	0.9999264	0.9903461	3.004509	FALSE	2	2
15	419.2116	12	FALSE	102.3053	31.75575	0.9938411	0.9997910	0.9940472	1.999814	TRUE	2	2
15	440.1802	13	FALSE	20.96857	30.73737	0.9671564	0.9819428	0.9845865	1.549430	FALSE	2	2
15	468.2980	14	FALSE	28.11777	31.20759	0.9594833	0.9594760	0.9999720	2.287492	FALSE	1	1
16	51.58782	1	FALSE	51.58782	30.46904	0.9687763	0.9685236	0.9997098	5.700792	FALSE	2	2
16	66.28882	2	FALSE	14.70100	29.91457	0.8955541	0.9125410	0.9628646	6.260671	FALSE	2	2
16	97.12411	3	FALSE	30.83530	30.12911	0.9397054	0.9621758	0.9756253	2.408921	FALSE	2	2
16	174.1123	4	FALSE	76.98816	30.57008	0.9826646	0.9838433	0.9985087	3.715642	FALSE	2	2
16	198.5303	5	FALSE	24.41808	30.15675	0.9620754	0.9943677	0.9668070	3.085910	FALSE	2	2
16	277.2525	6	FALSE	78.72215	33.82472	0.9993245	0.9999557	0.9993677	1.601420	TRUE	1	1
16	323.0219	7	FALSE	45.76944	34.35909	0.8848276	0.9425790	0.9329908	2.620270	FALSE	1	1
16	357.8896	8	TRUE	34.86771	35.18328	0.9874794	0.9986705	0.9887726	4.125973	FALSE	0	0
16	383.9748	9	TRUE	26.08514	34.32634	0.9982880	0.9998360	0.9984506	3.367282	TRUE	0	0
16	403.1754	10	TRUE	19.20065	33.94955	0.9959354	0.9992018	0.9967282	2.718364	TRUE	0	0
16	417.9430	11	TRUE	14.76755	33.95376	0.9900720	0.9924213	0.9974933	3.561852	FALSE	0	0
16	456.5451	12	TRUE	38.60211	35.38588	0.9753612	0.9833456	0.9917397	5.767017	FALSE	0	0
16	486.7133	13	TRUE	30.16815	34.85559	0.9926940	0.9933305	0.9993427	4.507677	FALSE	0	0
16	524.0305	14	TRUE	37.31720	35.54775	0.9578364	0.9961072	0.9612917	2.445708	FALSE	1	1
17	42.53712	1	FALSE	42.53712	46.06918	0.9857624	0.9910995	0.9944640	4.206063	FALSE	2	2
17	46.08749	2	FALSE	3.550369	46.74373	0.5250617	0.5334544	0.7878776	3.136811	FALSE	2	2
17	65.65588	3	FALSE	19.56839	42.93150	0.9491761	0.9997514	0.9493968	1.570327	FALSE	1	1
17	132.3615	4	FALSE	66.70561	38.24609	0.9887799	0.9982566	0.9904883	2.451721	FALSE	0	0
17	150.7960	5	FALSE	18.43449	40.22250	0.9683584	0.9953798	0.9725320	1.989810	FALSE	0	0
17	193.4149	6	FALSE	42.61891	39.30095	0.9916322	0.9989165	0.9926843	4.558041	FALSE	1	1
17	220.0667	7	FALSE	26.65182	36.90233	0.9926350	0.9999359	0.9926979	4.098585	FALSE	1	1
17	253.4523	8	TRUE	33.38557	34.58664	0.9976093	0.9976635	0.9999011	3.906876	TRUE	2	2
17	262.1195	9	TRUE	8.667175	35.17733	0.9996680	0.9999927	0.9996752	3.523145	TRUE	2	2
17	317.8739	10	TRUE	55.75443	31.20822	0.9985378	0.9995152	0.9990203	2.326854	TRUE	2	2
17	393.2450	11	TRUE	75.37109	29.00027	0.9670415	0.9714429	0.9948603	4.169229	FALSE	2	2

Nr.	Time	Round	Head Track.	Round Time	Avg. Mov.	Precision	Precision X	Precision Y	Dist.	Hit	Fl. Player	Fl. Target
17	414.4962	12	TRUE	21.25125	28.39585	0.9506347	0.9985237	0.9518673	3.400827	FALSE	2	2
17	433.7983	13	TRUE	19.30206	28.18735	0.9657500	0.9701611	0.9947861	2.305862	FALSE	2	2
17	463.4666	14	TRUE	29.66824	27.27642	0.9956570	0.9991238	0.9965250	2.307651	TRUE	2	2
18	20.81853	1	TRUE	20.81853	8144.632	0.9953001	0.9962670	0.9987833	1.008546	TRUE	1	1
18	111.0593	2	TRUE	90.24081	4838.659	0.9933125	0.9926812	0.9999033	2.399098	TRUE	1	1
18	134.0780	3	TRUE	23.01862	4373.493	0.9306429	0.9796996	0.9474006	1.452911	FALSE	1	1
18	301.6746	4	TRUE	167.5966	2729.729	0.9155974	0.9965718	0.9179613	3.314518	FALSE	1	1
18	350.0128	5	TRUE	48.33826	2442.300	0.9357047	0.9623102	0.9678060	1.930941	FALSE	1	1
18	398.4494	6	TRUE	48.43655	2210.440	0.9693410	0.9980011	0.9711754	2.587266	FALSE	1	1
18	423.1175	7	TRUE	24.66812	2108.454	0.9819463	0.9956096	0.9861774	1.664062	TRUE	1	1
18	506.9719	8	FALSE	83.85437	1821.807	0.9756471	0.9956473	0.9797881	1.337764	TRUE	0	0
18	538.6198	9	FALSE	31.64789	1733.323	0.9989388	0.9995219	0.9994090	3.135739	TRUE	0	0
18	568.6508	10	FALSE	30.03107	1657.385	0.8980309	0.9497235	0.9406722	1.476589	FALSE	0	0
18	610.5314	11	FALSE	41.88055	1561.222	0.9942378	0.9999853	0.9942520	0.7793807	TRUE	1	1
18	638.2964	12	FALSE	27.76508	1503.251	0.9761564	0.9829274	0.9898285	2.353970	FALSE	1	1
18	689.0928	13	FALSE	50.79633	1408.857	0.8924444	0.9215218	0.9597582	2.969539	FALSE	2	2
18	728.6389	14	FALSE	39.54608	1342.854	0.9315035	0.9505150	0.9773006	1.280056	FALSE	2	2
19	22.90204	1	TRUE	22.90204	17.60337	0.9971586	0.9999619	0.9971961	3.969163	TRUE	2	2
19	47.35425	2	TRUE	24.45221	15.80631	0.9870384	0.9980156	0.9889774	2.716597	FALSE	2	2
19	62.92228	3	TRUE	15.56803	14.97966	0.9965094	0.9999889	0.9965203	4.312722	FALSE	2	2
19	81.90726	4	TRUE	18.98499	13.96744	0.9937804	0.9954671	0.9982808	2.880415	TRUE	2	2
19	104.4091	5	TRUE	22.50182	12.79633	0.9730462	0.9780154	0.9943627	3.555187	FALSE	2	2
19	117.9435	6	TRUE	13.53443	12.31531	0.9973637	0.9973682	0.9999955	4.722138	TRUE	2	2
19	135.1783	7	TRUE	17.23473	11.81916	0.9897633	0.9992207	0.9905232	3.260493	FALSE	2	2
19	149.3625	8	FALSE	14.18430	11.35364	0.9698479	0.9973859	0.9723170	2.913176	FALSE	2	2
19	175.0980	9	FALSE	25.73546	10.90840	0.9873751	0.9999863	0.9873883	2.047529	TRUE	2	2
19	228.3190	10	FALSE	53.22101	14.46129	0.9933774	0.9982637	0.9950964	6.249013	FALSE	1	1
19	262.8387	11	FALSE	34.51973	14.04792	0.9983363	0.9999055	0.9984300	4.552282	TRUE	1	1
19	288.9576	12	FALSE	26.11890	13.73993	0.9926708	0.9985694	0.9940833	4.783235	FALSE	1	1
19	348.0924	13	FALSE	59.13474	13.65787	0.9889299	0.9907836	0.9981021	4.429761	FALSE	2	2
19	404.6942	14	FALSE	56.60178	12.89039	0.9956055	0.9985228	0.9970738	6.069720	FALSE	1	1
20	3.316744	1	FALSE	3.316744	61.80243	0.9896396	0.9961670	0.9933759	5.511329	FALSE	1	1

Nr.	Time	Round	Head Track.	Round Time	Avg. Mov.	Precision	Precision X	Precision Y	Dist.	Hit	Fl. Player	Fl. Target
20	25.60206	2	FALSE	22.28532	58.08700	0.9844790	0.9848400	0.9993281	2.601248	FALSE	1	1
20	65.32228	3	FALSE	39.72022	53.07877	0.9924531	0.9997590	0.9926755	1.681555	TRUE	2	2
20	84.27370	4	FALSE	18.95142	57.26067	0.9887629	0.9985445	0.9901627	4.824743	FALSE	2	2
20	95.57459	5	FALSE	11.30090	55.83334	0.9104234	0.9586050	0.9432356	2.761190	FALSE	2	2
20	103.4418	6	FALSE	7.867249	55.00027	0.9949909	0.9982573	0.9966542	6.224829	FALSE	2	2
20	128.3273	7	FALSE	24.88551	52.32968	0.9476722	0.9963827	0.9506027	3.337142	FALSE	2	2
20	179.5487	8	TRUE	51.22131	47.53198	0.8694428	0.9956150	0.8726457	5.789662	FALSE	1	2
20	213.2679	9	TRUE	33.71921	45.08442	0.9997640	0.9997844	0.9999708	2.439260	TRUE	2	2
20	227.2522	10	TRUE	13.98433	44.12711	0.9918150	0.9998113	0.9919978	4.317672	FALSE	2	2
20	243.2036	11	TRUE	15.95135	43.06664	0.9938809	0.9943166	0.9994961	1.854379	TRUE	2	2
20	258.7216	12	TRUE	15.51810	42.00941	0.9951361	0.9986111	0.9965061	4.886228	FALSE	2	2
20	310.7251	13	TRUE	52.00348	38.97584	0.6778322	0.8643875	0.7417486	4.036692	FALSE	0	1
20	319.0927	14	TRUE	8.367523	38.72884	0.9932722	0.9999493	0.9933208	5.261559	FALSE	0	0

B Quantitative Data Open Experiment

1. Subject Number
2. Total Elapsed Time
3. Round Number
4. Spatialisation of Audio with Head Tracking
5. Time to Complete Round
6. Average Head Movement
7. Total Precision (0.0-1.0)
8. Precision on Horisontal (X) Axis (0.0-1.0)
9. Precision on Vertical (Y) Axis (0.0-1.0)
10. Distance to Target
11. Hit Target
12. Floor of Player at Time of Firing
13. Floor of Target at Time of Firing

Table B.1: Quantitative Data Open Experiment

Quantitative Data Open Experiment												
Nr.	**Time**	**Round**	**Head Track.**	**Round Time**	**Avg. Mov.**	**Precision**	**Precision X**	**Precision Y**	**Dist.**	**Hit**	**Fl. Player**	**Fl. Target**
21	54.23727	1	FALSE	54.23727	27.87003	0.9933705	0.9970688	0.9962789	3.005395	TRUE	2	2
21	86.03938	2	FALSE	31.80211	24.79019	0.9953732	0.9981192	0.9972281	3.236408	TRUE	2	2
21	102.0403	3	FALSE	16.00090	23.45061	0.9967966	0.9971606	0.9995984	2.559842	TRUE	2	2
21	169.3108	4	FALSE	67.27055	19.33728	0.9903736	0.9934908	0.9967936	3.40532	FALSE	2	2
21	210.8136	5	FALSE	41.50278	17.49129	0.9954421	0.9968238	0.9985839	4.38556	FALSE	1	1
21	238.8314	6	FALSE	28.01784	16.39770	0.9947052	0.9992685	0.9954298	4.118162	FALSE	1	1
21	286.9861	7	FALSE	48.15468	14.95850	0.9836445	0.9960403	0.9874331	3.57428	FALSE	2	2
21	338.3420	8	TRUE	51.35590	42.31875	0.9650806	0.9727827	0.9916590	3.309867	FALSE	2	2
21	409.4316	9	TRUE	71.08960	53.97736	0.9951706	0.9990783	0.9960831	2.332623	TRUE	1	1
21	459.0679	10	TRUE	49.63626	84.97041	0.9223931	0.9294078	0.9917996	3.322401	FALSE	1	1
21	573.9122	11	TRUE	114.8443	110.4199	0.9989090	0.9996256	0.9992796	2.563047	TRUE	0	0

Nr.	Time	Round	Head Track.	Round Time	Avg. Mov.	Precision	Precision X	Precision Y	Dist.	Hit	Fl. Player	Fl. Target
21	618.3828	12	TRUE	44.47064	114.1021	0.9981339	0.9991367	0.9989882	1.500557	TRUE	0	0
21	652.3991	13	TRUE	34.01630	114.2221	0.9928079	0.9985172	0.9942597	4.116588	FALSE	1	1
21	765.4657	14	TRUE	113.0666	103.1130	0.8933569	0.9695553	0.9188609	1.840553	FALSE	1	1
22	48.82112	1	FALSE	48.82112	135.7179	0.9849350	0.9864933	0.9983982	5.131469	FALSE	1	1
22	112.7747	2	FALSE	63.95360	117.0122	0.9761906	0.9808426	0.9951109	1.652715	FALSE	1	1
22	149.8763	3	FALSE	37.10156	125.7863	0.9676476	0.9678542	0.9996883	6.344462	FALSE	1	1
22	194.6610	4	FALSE	44.78471	115.0078	0.9335961	0.9339292	0.9981528	1.391624	FALSE	2	2
22	281.1495	5	FALSE	86.48848	101.5445	0.9862019	0.9994299	0.9867445	2.41515	FALSE	2	2
22	340.7223	6	FALSE	59.57281	93.57079	0.9991949	0.9992493	0.9999270	4.897243	TRUE	1	1
22	374.7110	7	FALSE	33.98868	92.19520	0.9662870	0.9968731	0.9691266	2.297111	FALSE	1	1
22	429.3848	8	TRUE	54.67383	89.53959	0.9770288	0.9874761	0.9892282	3.612814	FALSE	1	1
22	467.5909	9	TRUE	38.20612	90.13663	0.9650065	0.9654985	0.9994483	1.328136	TRUE	2	2
22	520.9958	10	TRUE	53.40488	87.20779	0.9455352	0.9462416	0.9989572	5.917551	FALSE	1	1
22	537.5624	11	TRUE	16.56665	88.44791	0.9715241	0.9763200	0.9949284	5.220064	FALSE	1	1
22	599.6603	12	TRUE	62.09784	83.77487	0.5937891	0.7074380	0.7112638	0.7188802	FALSE	2	2
22	655.9106	13	TRUE	56.25031	82.14183	0.9932415	0.9935676	0.9996293	5.708662	FALSE	1	1
22	901.7603	14	TRUE	245.8497	69.93251	0.9317610	0.9339421	0.9973668	4.816659	FALSE	2	2
23	25.83563	1	FALSE	25.83563	14235.15	0.7707606	0.9673651	0.7893476	0.7337351	FALSE	1	1
23	29.30254	2	FALSE	3.466913	13938.12	0.1613050	0.1765603	0.08521095	11.92175	FALSE	1	0
23	41.20338	3	FALSE	11.90084	13008.63	0.9604775	0.9994282	0.9609811	2.321898	FALSE	1	1
23	99.28985	4	FALSE	58.08646	9813.659	0.9998659	0.9999957	0.9998701	2.074945	TRUE	2	2
23	113.7072	5	FALSE	14.41731	9517.872	0.9974105	0.9996601	0.9977480	2.663951	TRUE	2	2
23	134.3917	6	FALSE	20.68452	8793.339	0.9882419	0.9993394	0.9888870	2.60586	FALSE	2	2
23	155.6263	7	FALSE	21.23457	8155.065	0.9986950	0.9995005	0.9991930	2.581954	TRUE	2	2
23	178.6942	8	TRUE	23.06796	7575.283	0.9964936	0.9999405	0.9965518	1.560188	TRUE	2	2
23	195.1787	9	TRUE	16.48445	7203.561	0.9986821	0.9993207	0.9993538	3.097418	TRUE	2	2
23	216.8801	10	TRUE	21.70146	6779.027	0.9219090	0.9973345	0.9241585	0.9091718	TRUE	2	2
23	304.6384	11	TRUE	87.75824	5437.216	0.9959183	0.9963155	0.9995577	1.935328	TRUE	2	2
23	317.6227	12	TRUE	12.98438	5284.209	0.9976871	0.9999971	0.9976896	3.041092	TRUE	2	2
23	341.2087	13	TRUE	23.58597	5027.371	0.1801162	0.01545921	0.1699121	0.5969222	FALSE	2	2
23	392.8484	14	TRUE	51.63974	4539.549	0.9826035	0.9999922	0.9826109	3.933924	FALSE	1	1
24	21.63474	1	FALSE	21.63474	88.78310	0.9809894	0.9822084	0.9987346	4.760894	FALSE	2	2

Nr.	Time	Round	Head Track.	Round Time	Avg. Mov.	Precision	Precision X	Precision Y	Dist.	Hit	Fl. Player	Fl. Target
24	113.4895	2	FALSE	91.85474	64.65784	0.9878937	0.9973021	0.9904723	4.844113	FALSE	2	2
24	144.5579	3	FALSE	31.06838	58.95296	0.9881745	0.9979765	0.9901526	2.073804	TRUE	2	2
24	155.8751	4	FALSE	11.31720	57.27052	0.9670013	0.9671692	0.9998201	4.085196	FALSE	1	1
24	218.7446	5	FALSE	62.86954	49.28081	0.9500123	0.9995849	0.9503847	2.473263	FALSE	1	1
24	234.1786	6	FALSE	15.43398	51.04527	0.9631549	0.9997059	0.9634252	2.241048	FALSE	1	1
24	315.3383	7	FALSE	81.15968	47.47519	0.9968849	0.9994105	0.9974637	3.915544	TRUE	2	2
24	337.9892	8	TRUE	22.65091	46.43673	0.9912695	0.9912559	0.9999965	3.865583	FALSE	2	2
24	386.3272	9	TRUE	48.33804	44.92353	0.9876292	0.9886147	0.9989755	2.958384	FALSE	2	2
24	449.2511	10	TRUE	62.92389	44.24129	0.9884672	0.9998277	0.9886343	4.278553	FALSE	1	1
24	509.2746	11	TRUE	60.02347	46.30255	0.9554563	0.9878176	0.9668274	1.886121	FALSE	2	2
24	535.3420	12	TRUE	26.06747	44.75353	0.9904749	0.9999993	0.9904756	5.137145	FALSE	2	2
24	548.3749	13	TRUE	13.03284	44.00168	0.9988440	0.999775	0.9990685	4.167748	TRUE	2	2
24	565.7913	14	TRUE	17.41638	43.69739	0.9943674	0.998335	0.9960165	6.403255	FALSE	1	1
25	102.3240	1	FALSE	102.3240	157.0280	0.9614705	0.9738294	0.9868667	2.732424	FALSE	2	2
25	378.4961	2	FALSE	276.1721	73.00964	0.02438894	0.004193693	0.02048668	4.392169	FALSE	2	2
25	394.1147	3	FALSE	15.61856	71.68805	0.9995376	0.9995542	0.9999822	4.595248	TRUE	1	1
25	414.4166	4	FALSE	20.30194	69.81120	0.9970163	0.9972543	0.9997551	2.465358	TRUE	1	1
25	437.7688	5	FALSE	23.35220	67.40197	0.9982487	0.9999761	0.9982724	5.303339	TRUE	1	1
25	489.9257	6	FALSE	52.15686	63.02740	0.9470026	0.9485806	0.9982262	1.42002	FALSE	1	1
25	546.3110	7	FALSE	56.38535	58.59087	0.9990011	0.9995477	0.9994522	4.053525	TRUE	1	1
25	626.2111	8	TRUE	79.90002	55.71471	0.9929293	0.9983481	0.9945592	3.717792	FALSE	0	0
25	633.5114	9	TRUE	7.300293	55.46057	0.9775407	0.9898357	0.9872471	4.595654	FALSE	0	0
25	649.0952	10	TRUE	15.58380	55.50396	0.9889502	0.9977722	0.9911381	4.230177	FALSE	0	0
25	669.9619	11	TRUE	20.86676	54.32104	0.8861110	0.8907443	0.9916828	6.452411	FALSE	1	1
25	712.1283	12	TRUE	42.16638	52.00431	0.9965948	0.9977783	0.9988023	4.16384	TRUE	2	2
25	721.4948	13	TRUE	9.366516	52.15960	0.9861228	0.9970529	0.9890027	5.142726	FALSE	2	2
25	763.1598	14	TRUE	41.66498	50.08359	0.9998618	0.9998906	0.9999712	5.56356	TRUE	2	2

C Survey Responses Blind Experiment

Nr. Test Subject Number

Q1 FPS Experience **(0-4)**

- **0** 0 hours per week
- **1** A few times per month
- **2** 1-5 hours per week
- **3** 5-10 hours per week
- **4** 10+ hours per week

Q2 How well do you feel you could audibly localise the ghosts during the test?

1-5 , (Poorly - Easily)

Q3 How well do you feel you could audibly localise the ghosts on the vertical axis in particular?

1-5 , (Poorly - Easily)

Q4 How well do you feel you could audibly localise the ghosts on the horizontal axis in particular?

1-5 , (Poorly - Easily)

Q5 Was it difficult to discern when the ghosts were on the floor above you?

1-5 , (Not difficult at all - Very Difficult)

Q6 Was it difficult to discern when the ghosts were on the floor below you?

1-5 , (Not difficult at all - Very Difficult)

Table C.1: Quantitative Data Blind Experiment Survey

Survey Responses Blind Experiment						
Nr.	**Q1**	**Q2**	**Q3**	**Q4**	**Q5**	**Q6**
1	1	4	4	2	4	4
2	1	5	3	5	1	1
3	0	4	3	4	1	1
4	0	4	3	3	4	3
5	1	4	2	3	4	2
6	3	3	2	4	2	2
7	3	4	2	4	2	2
8	3	4	2	4	1	1
9	1	4	2	5	4	2
10	1	3	1	5	5	5

Survey Responses Blind Experiment						
Nr.	**Q1**	**Q2**	**Q3**	**Q4**	**Q5**	**Q6**
11	2	4	3	5	3	3
12	2	4	3	4	4	4
13	3	5	1	4	3	3
14	1	3	2	4	2	2
15	1	4	3	4	2	4
16	0	4	1	5	2	4
17	2	2	1	4	1	3
18	1	4	2	4	2	2
19	2	3	2	4	3	3
20	0	3	2	5	4	2

D Survey Responses Open Experiment

Nr. Test Subject Number

Q1 FPS Experience **(0-4)**

- **0** 0 hours per week
- **1** A few times per month
- **2** 1-5 hours per week
- **3** 5-10 hours per week
- **4** 10+ hours per week

Q2 What made it easier to localise the ghosts?

- **1-5** , (Without head tracking - With head tracking)

Q3 How easy was it to localise the ghosts on the vertical axis by using head tracking?

- **1-5** , (Very hard - Very easy)

Q4 How easy was it to localise the ghosts on the vertical axis without head tracking?

- **1-5** , (Very hard - Very easy)

Q5 How easy was it to localise the ghosts on the horizontal axis by using head tracking?

- **1-5** , (Very hard - Very easy)

Q6 How easy was it to localise the ghosts on the horizontal axis without head tracking?

- **1-5** , (Very hard - Very easy)

Q7 Did the use of head tracking help you discern when the ghosts were on different floors?

- **0** Yes
- **1** No
- **2** Do not know

Table D.1: Quantitative Data Open Experiment Survey

Survey Responses Open Experiment							
Nr.	**Q1**	**Q2**	**Q3**	**Q4**	**Q5**	**Q6**	**Q7**
1	4	4	2	2	4	3	1
2	0	4	2	2	4	3	1
3	2	4	3	1	2	5	1
4	4	5	3	2	5	3	0
5	2	3	4	4	2	2	2

E Interview Notes Blind Experiment

Table E.1: Qualitative Data Blind Experiment Interview Notes

Have you noticed any difference in your ability to audibly localise the ghosts during the test? If yes, what was it and how do you think it influenced your ability?	
0.1	Yes, it felt so.
0.2	Not really, it felt different, sometimes directly in front of me, sometimes otherwise. It felt like I was guessing every now and then.
0.3	I found it difficult at the beginning, I gradually developed a strategy through practice. I noticed that the sound became closer the closer I approached the ghost.
0.4	It was easier after a while.
0.5	I created a strategy on how to decide, because right or left was easier. There was a subtle difference whether sounds were in the same room/floor.
0.6	No, it was consistent throughout the whole experience.
0.7	In the beginning it wasn't very good but towards the end I learned and found a method of how I could locate sound sources.
0.8	Yes, it got easier as I learned how to listen. The hardest part was the middle, so learning to slowly turn helped.
0.9	I think what changed was when I realised what the sound sounds like when I'm standing in the ghost, it helped me localise it. When I looked up, I could understand where the sound was. I became smarter at locating it.
1.0	You could clearly hear when the ghost was further away, but vertically it was difficult to locate.
1.1	Yes, you listen more carefully.
1.2	Sometimes it sounded like the sounds were closer than they actually were, for example below you. It was more difficult at the beginning, then I learned about how and where the sounds sounded. Once you started to understand at match 8-10 then you understood how the sounds sounded, like if it was one floor above me.
1.3	It was hard to hear the sounds, the more I probed around the sounds the better I understood the position.
1.4	The ghosts moved around in the same room, then they were on different floors.
1.5	I felt towards the end that I learned how to think more and more. Then I didn't become accurate, but I got better at locating.
1.6	I felt that I gained more confidence in my ability during the test because you could see where the ghosts were when you shot. I became more confident.
1.7	Well, I think the first few ghosts were pretty hard but then I was pretty lucky because I aimed in the middle of the room. I thought that somewhere between the middle of the room would be enough to hit the ghost since I thought that it would have a humanoid body. I got better as I played, on the vertical axis too.
1.8	I think it was the same throughout, some felt more difficult because they were at different heights, it was still reasonably good, it was a bit more difficult and there was one place I got stuck on but it was otherwise good once you found some ghosts.
1.9	There was no difference. When it spawns it spawns in a certain space so I understood that I had to go through the house to see where the ghost was. I was not sure how I was supposed to play in order to be as well performing as possible, like was it about the accuracy of shooting or the time taken to find the ghosts.
2.0	I think I had a hard time localising them but then I understood that when it's louder the ghost is closer.

How well do you feel you could audibly localise the ghosts on the vertical axis and was there anything that helped or hindered you?	
0.1	Vertical was easy, harder to pinpoint above or below.
0.2	Sometimes it was unclear if the ghost was above or below me, used gut feeling.
0.3	I found it harder to localise that way, I didn't notice any big difference in the sound compared to if you had moved your head horizontally.
0.4	Most ghosts were higher up than I thought they were.
0.5	It was much harder, I felt it was easier to locate when I was right next to the ghost. Was hardest when there were ghosts in the same room.
0.6	As on the vertical, it was more difficult than horizontal, as it is easier to locate the position of the sound source using the exclusion method. Was more difficult to understand the exact position vertically.
0.7	The idea was just to get close enough and try to shoot it until it was impossible for me to not hit it.
0.8	I found it very difficult and I often took a chance on the vertical, I haven't been able to notice the difference, just aim straight ahead.
0.9	Vertical was difficult, there were small differences. It was to test the extremes to see how it sounds, with the extreme values try to localise.
1.0	Didn't find anything that helped me localise vertically, you noticed a difference when standing in the ghost, but without being able to crouch it was hard to locate the ghost.
1.1	Vertically was more difficult than horizontally
1.2	What was difficult was if it was a little close to the right or left, the smaller details, it was also difficult if it was a floor up or down.
1.3	It was quite difficult, the hardest part was finding the top and bottom. It was too general on the vertical axis to understand and I thought there was a crouch function to be able to use it.
1.4	Vertically, I felt it was more difficult to decide. Whether it was high or low was hard to tell.
1.5	It was harder on vertical compared to horizontal, with horizontal I can turn. Because I hear worse with my right ear, I used my left to listen.
1.6	I felt like it was hard to tell in the vertical, so that's where I often found myself failing. It was more difficult in the vertical axis compared to horizontal and it was probably generally not because of anything specific.
1.7	I think looking down at the floor helped me. If I would look at the ceiling then it would also help me understand where the ghost was. But on the vertical it was hard.
1.8	When I looked down or up, there wasn't much difference, it was harder to locate it vertically.
1.9	It was easy to localise the source in the horizontal axis, while the vertical was hard because there was nothing that could help me localise it vertically. Horizontally you could kind of dance around the ghost to understand the position. So I couldn't understand the exact position on the vertical axis.
2.0	That was very difficult but it was easier when the ghosts were under than above. It was hard.

How well do you feel you could discern when the ghost was on a different floor? Why?	
0.1	Not so good, didn't know if it was under or over. It was hard to tell.
0.2	I used an exclusion method to locate, had to walk around a bit to understand where the sound was.
0.3	Did not think it was as difficult, it got easier after learning the house.
0.4	It was difficult, had to back up to listen.
0.5	A lot was a bit of psychology about how it was broken down. Tried to think based on logic, like how high is the chance that the ghost was spawned one floor up. If you could crouch, be able to compare the sound on the vertical axis, it would have helped.
0.6	When the ghosts were on different floors, it was clear that the sound passed through walls. You notice that the sound changes.
0.7	I didn't think about it too much, I guess it wasn't too difficult.
0.8	It was much more muffled than when I was on the same floor, when I went down the stairs then I tried to listen.
0.9	It was quiet there for a while, which confused me, I felt that I had still walked towards the wall, but at some point it was difficult with the upper floor. It was hard. Tried shooting through walls.
1.0	It was quite clear, it had to do with the level that it became clearer also because you knew the house better and knew which floor the sound was playing from.
1.1	It was a bit difficult, if it was just over it was hard to understand.
1.2	I heard it wasn't on the same level but didn't know if it was below or above.
1.3	Not that good at all, was more about exploring. I mostly explored. So I do not know.
1.4	In my case, it was on the same level several times then I had problems getting to the bottom. I didn't have too many problems with it. The ghosts spawned multiple times on the same plane so it's hard to answer exactly.
1.5	I heard it was further away and then I tried walking towards it to understand better. There was a difference when I was on the middle level and going up or if the sound was further away.
1.6	It was easy to know if it was a floor above me because when you went up a floor it became clear that now you are getting closer. Then it was hard to tell if there was a floor below me, it was harder to tell if I should go up or down and I tried going up to see if I was going right, but I never tried going down to see where the sound source was.
1.7	I think it was pretty good because the sound is very weak when the ghost is far away. So I try to go to detect the sound to see where the ghost is.
1.8	If I heard it on a floor and walked around, I understood it better. When I realised it wasn't on the same floor because it was quieter, I just walked forward.
1.9	I did not have so much understanding of the exact position so I didn't rely as much on my hearing as on my vision. If I opened a room and could hear the difference in filter then it was easier to localise the ghost but when all doors were opened it stopped helping me that much.
2.0	The noise became more silent and the pulse was different. I experienced it to be more calm when it was on a different floor.

Do you have any thoughts on your experience of playing the prototype?	
0.1	Very cool, well done, if the doors could open towards the direction you walked it would have been better.
0.2	It was fun, was surprised that the targets were not as spread out as I thought.
0.3	No, I thought it was cool, but you have to sit and listen.
0.4	Very impressed, the environment matches the sound.
0.5	It was exciting.
0.6	It was fun and interesting. Having a good grasp of surround sound is crucial, visual cues are also important.
0.7	No not really.
0.8	It was a very exciting and interesting game idea, a bit difficult, I often missed, which is a hard feeling as I should've tried to aim more.
0.9	It was pretty fun but I've never tried this. I was surprised how good I became over time.
1.0	It was a different kind of sound when you got closer to the ghost. Had to turn around a bit to hear better.
1.1	Cool, different.
1.2	It was difficult but fun and it takes an hour or so to understand how the sounds work.
1.3	It was cool, I thought it would be scarier but I like single player immersive games. If the ghosts were dangerous it would make for a very different experience.
1.4	I thought it would have been good if the pitch was faster because it was harder to locate ghosts based on just sound differences. So if the pace changed the closer you got it would have been easier.
1.5	Just that I thought it was fun, possibly that I didn't know if the ghosts were placed from the start or if they were randomly spawned. It was satisfying when you managed to hit the ghosts.
1.6	It was a lot of fun, it was hilarious, the sounds were superbly made, everything was well designed, sufficiently clear, sufficiently diffused. It was good that the weapon needed to be reloaded and that you have one chance per ghost. Very nice graphics, the controls were nice but I got stuck somewhere on the stairs. I became so immersed because of everything, that you need to aim and think tactically.
1.7	It was pretty good and I would actually play it.
1.8	It was interesting, fun. I would try playing again.
1.9	It was funny when the eyes dropped upon shooting a ghost, so it kind of changed the mood of the game. I thought that maybe there would be a jumpscare.
2.0	It was a very good prototype. I think it was fun and interesting to listen and not just play like a normal game.

Do you feel like the head tracking helped you localise the ghosts? If yes, in what way?	
0.1	I don't know, I think it helped because I noticed that I leaned my head.
0.2	I don't know if I actually turned my head.
0.3	Nope, didn't notice a difference.
0.4	It felt like when I moved I could localise the sound better.
0.5	No, otherwise I'm not used to keeping my eyes off the screen while playing.
0.6	I didn't know it was a thing, so I actively looked around with the mouse.
0.7	I suppose it didn't.
0.8	No, I thought about it and tested a bit at the beginning and now I don't know if it worked then or not.
0.9	I thought about it for a moment, I think I move a bit when I play, but I think it can help as a tool.
1.0	No. I noticed it was something but didn't know if it was related to head tracking.
1.1	No.
1.2	I turned my head without thinking. So I did it without thinking.
1.3	No.
1.4	I never tried moving the head, it would have been cool if I could try it. It wasn't anything I really thought about.
1.5	It was nothing I reflected on, it was nothing I tested.
1.6	No, I don't notice. I move my body instead when something sounds, I move my body towards where the sound sounds and not my head.
1.7	Because I was not aware of it anyway, if I would utilise it then it would help me a lot and the mouse is limited. So it was helpful.
1.8	I don't know if I noticed it, at some point I started to move my head and maybe instinctively I felt that there was a difference.
1.9	It didn't because I didn't feel any difference.
2.0	I don't know if it was that or if it was the camera I turned.

How do you feel head tracking impacted your immersion?	
0.1	The sound followed logically which made the immersion good, don't know to what extent it was.
0.2	I don't know if I turned my head. I think it has helped.
0.3	No.
0.4	Yes, absolutely.
0.5	Not very much.
0.6	Not so much.
0.7	I haven't noticed it really
0.8	Not at all in this case.
0.9	I don't know, I felt very familiar with the game because of the sound design. I think it did a lot.
1.0	Not at all, as I didn't notice it that much.
1.1	Yes, I knew that head tracking had some function.
1.2	I tried to listen with both ears. It was a more realistic experience compared to CS because there you use instincts instead and the game would have been slower if there were any head movements.
1.3	I don't know, didn't notice.
1.4	No.
1.5	I can't answer that either, but I was drawn in by everything else in the game.
1.6	Not that I'm aware of.
1.7	I can't compare it because I wasn't aware, but now since I know I think that it did.
1.8	I definitely think it would make it more immersive, you would be able to move your head however you would want to hear better.
1.9	It didn't.
2.0	I don't know what was the camera and what wasn't.

Do you feel that head tracking impacted your performance? If yes, in what way?	
0.1	Yes, it helped.
0.2	It helped me find ghosts, using exclusively gut feeling method.
0.3	I felt I could locate the last ghosts better.
0.4	Yes, like I was inside the game.
0.5	Didn't feel it had any effect.
0.6	No. I don't think so.
0.7	No I don't think so.
0.8	No.
0.9	I don't know, I think it should affect. It is clear that one acts with all one's senses, the autonomous. I think so.
1.0	No.
1.1	Yes, I can look around with that, I moved my head a bit.
1.2	No, not that I know of.
1.3	No.
1.4	Cannot answer this question because I haven't experienced it.
1.5	Not that I know of.
1.6	No, because I barely use head movements.
1.7	I don't think it did.
1.8	No, I don't know.
1.9	It didn't help my performance.
2.0	Maybe, I shot more ghosts at the end so maybe.

Do you have any thoughts on the head tracking from playing?	
0.1	Immersion gets better, it's fun to be able to hear in the right direction.
0.2	Thought it was fun, felt like you were a little more immersed. The sound was dynamic and made me feel in the game.
0.3	You become aware of the sound.
0.4	Became much more involved in the game.
0.5	Think it's cool, would like to see if I moved my head and how much. I think that head tracking in connection with computer games is not as useful as the eyes must be on the screen compared to VR.
0.6	Can't say much because I haven't thought about it.
0.7	Cool idea, it could be implemented in a more obvious way so the user knows that it's there.
0.8	No, it would have been interesting to know that it was there to approach it in a different way. Very cool.
0.9	I don't know, I thought it was nice and great fun.
1.0	You need an adapted technology/game for head tracking to be useful, like a wider screen.
1.1	Yes, now that you mention it.
1.2	It was fun, not much to say.
1.3	I wish I knew about it beforehand.
1.4	Would have been cool to know how it affects one's ability to locate sound sources.
1.5	No not really.
1.6	No, not from the game, not game-wise.
1.7	Because I did not notice the influence of it I can't say that I have any thoughts about it.
1.8	No, sounds cool and interesting, I would think that other games have it too.
1.9	I did not notice it so I don't have any thoughts.
2.0	It was fun, but I don't even know if I had the head tracking on but I think it was the second half when I shot more ghosts.

F Interview Notes Open Experiment

Table F.1: Qualitative Data Open Experiment Interview Notes

What are your thoughts on using head tracking for localising audio sources from your experience of playing?	
2.1	It's very interesting and very much a habit, you are so used to using ears in the game, so the ability for it is already there. I think that with more experience or possibility to get used to head tracking it can actually help.
2.2	You become very immersed in the experience. I felt like the head tracking was on at the start even though it wasn't, that the image of the sound followed when I turned my head.
2.3	I thought it was interesting, you move your head and locate but on the computer the screen is static so when I turn my head it's not as useful as the visual image doesn't follow compared to VR which I play quite a bit. During the game test the vertical was easier with head tracking but for the horizontal it was not as good as it pans correct in the headphones when you walk around but the head tracking didn't help much [with horizontal].
2.4	It was significantly easier when head tracking was on. Or maybe it didn't get that much easier when you were going to shoot, but finding the ghost got easier. I used the head tracking by turning my head. The mouse does the same thing, during the first time I used the mouse but I think it's a matter of habit that you use the mouse to listen around. But you also want to check the screen at the same time. In a VR environment, you would have ignored it and moved your head more naturally. I think 80% of the time I used head tracking just because "it was there" and I wanted to test it, but towards the end I used it because it actually helped. It is probably an extreme matter of habit. Until you reached a certain limit, head tracking helped more, but when you got closer, it became more difficult to orient yourself with head tracking than it was with the mouse. It was much more difficult to find the differences vertically. It was easy to find the right room or the right floor, but the last bit was difficult. It was probably equally difficult to locate the ghosts in height with and without head tracking.
2.5	It was hard to tell the difference. Thought I would notice a bigger difference now than in the last test. I tried moving my head to locate the sound sources but it felt much more natural to do it with the computer mouse than to do it with the head. Could be because I do it in games. I didn't do anything different to face the sound sources, I used the mouse to turn around and hear where it was coming from so, yeah, well, I thought I'd notice more of a difference. It might be that I'm required to sit a while longer in the game to get that sense of immersion for me to experience the spatialisation more. That you hear a sound coming towards you and that you duck for it. Maybe you should sit longer so that you "forget about yourself".

Was head movement something you found to be useful for the localisation of ghosts? Why?	
2.1	It was useful, I think it was mostly for micro adjustments, but it was generally harder to hear vertical differences. Sometimes I forgot that ghosts could spawn at different heights. It will be easy for me to compare it with CS:GO because there it can take longer if you use head tracking for head movements, but you can be more immersed in horror games, I feel.
2.2	There was a difference when it(head tracking) was on, I ended up much faster in the rooms the ghosts were in. I felt like I got more out of using head tracking when it was on. In any way, it was easier with head tracking at a precise level.
2.3	The vertical was helped by head tracking unlike the horizontal. It was a bit of a guess, I wasn't aiming straight at the ghosts but closer to the edges. It was better with head tracking to understand the approximate position vertically.
2.4	It can probably become a "perceived disadvantage" that you are above, and that it is experienced as a disadvantage. I probably experienced it as a disadvantage at first before I got used to it. On the new Play Station 5 gamepads with haptic feedback, the trigger has such that you feel when you tighten the bow in the game because it becomes a little slower. Before you get used to it, it feels strange, but once you get used to it, it's a no-brainer. Of course it's a matter of habit, I would use it a lot and it would be there naturally, but it also requires very good design. Both not to overuse it but also to actually design it in e.g. a horror game, where you actually design around it instead of just throwing it in. I think it's a matter of habit, that you're so used to it being that way. Headtracking is quite niche.
2.5	In this situation, it wasn't. It wasn't needed. I could use the mouse instead.

Is head tracking a feature you would like to passively have in the background even though you actively would not use it? Motivate	
2.1	Yes, in the right game, not CS:GO but Resident Evil maybe. I think it will be a matter of habit, for my part I felt that I can see the possibility of using it but it may take time to get used to. It can be used in many ways but I don't know how. One of the challenges is the size of the screen because then you can see less when you turn your head. It becomes a discreet ability to either look at the screen or focus on listening skills and finding it to work together is when you achieve the next level, I think. I think I would have liked it as usual, even when I spectate and look away I don't want it to be ruined.
2.2	Yes, I would absolutely like that, precisely because it is immersive, that it follows. When the sound image follows the eyes. Both because it is immersive and effective but more because of the immersiveness as head tracking increasing performance comes after a while whilst the increased immersion comes at once.
2.3	No I do not think so. We are so used to the old way, but people who are just starting to use it may find it more natural. Otherwise I see no purpose for it. But I can imagine that it could be useful for people with visual impairments.
2.4	It's easy for it to become a gimmick, that it is there but it serves no purpose, like it does nothing. I can imagine in story games like The Last of Us or God of War or some single player game, you would appreciate it more as it gives something to the immersiveness. If you play The Last of Us, you want to be in that world. In games such as CS:GO, you don't really have time to think about it.
2.5	Yes I think so. It would be a nice detail if the sound image accompanies and strengthens the immersion. It is very good in FPS because there you want to quickly hear where your enemy is coming from and if you turn your head it is a good complement that it matches with the movements you make in real life. It's not so good to look away from the screen in an FPS, but if you need to find something based on sound, it can be nice to be able to turn your head to locate it. It will feel much more real if the sound source sounds like it's coming from the direction it's coming from in the game if you turn your head instead so that the sound image follows your head. It's not really important for the gaming experience that the audio doesn't remain if you turn around to reach for something, but it would make it more immersive. Very cool to play, fun to test how well one can hear the sounds.

G Reflection Document Patrik Bergsten

How does your study correspond to the goals of the thesis course? Why? Focus on the goals that were achieved especially well and those that were not well achieved.

I have gained more knowledge about searching, finding and summarizing relevant scientific literature. I also now feel confident about my abilities to analyse and criticize said literature.

The proper use of a reference system was something I was lacking in initially when beginning my bachelors but through my studies in scientific writing courses, and in this thesis course I have developed greater confidence in this aspect of my writing.

The presentation of our work went especially well, public speaking is a skill that I have purposefully sought out to improve during my bachelors since I suffer somewhat from a phobia of public speaking. Preparation, being knowledgeable about the subject, and knowing the material helps immensely and made the presentation now go very well.

Reflecting upon ethical aspects of research and developmental work I found somewhat more difficult. The focus during the study was researching audio and spatialisation of audio in computer games so little thought went into other applications for the research initially. During the defence our opponent gave a suggestion for military applications that can be adjacent to our research. In hindsight, given the amount of military research we found while researching spatialised audio, and subsequently quoted, this should have been more obvious from the start.

How did the planning of your study work? What could you have done better?

Planning went relatively well. Work on the artefact took slightly longer than planned. We slightly overshot most milestone deadlines. On the other hand, us working through the deadlines until we were satisfied ourselves I believe meant that we did not have to make any major revisions to our work. We were well aware of our thesis shortcomings to meet the criteria and used an agile planning tool to keep track of our tasks, division of labor, and progress. What could have been done better would be to have several times gone through and revised shorter sections throughout the project, instead of a couple of times of going through and revising the whole thesis at once — that approach would probably have resulted in a more concise thesis and would have cut down on the amount of work.

How does the thesis work relate to your education? Which courses and areas have been most relevant for your thesis work?

The Scientific writing course VESK, and the Scientific Methodology and Communication within computer and systems sciences course, METOD, were greatly beneficial for learning the basics of scientific writing and methodology and data analysis for my work during this course. Since a game was made, all of the game development courses on the curriculum; SP1, SPD, MAPP, SPM, PROJ, PROD, and AIBU, have been greatly beneficial for making the artefact a good game. Since I was to a large extent responsible for the programming of many of the systems used in the artefact many of the programming and systems design courses; OOS, PROG1, PROG2, CPROG, ALDA, and AI have been very relevant for this thesis. Furthermore, the course on user experience and interaction design, MDI, and the Digital Media course, DMEDIA, that was to a large part focused on audio in computer games, came in use for my work on the artefact.

How valuable is the thesis for your future work and/or studies?

For my future work as a game developer and programmer the work for this thesis has helped my development in learning and applying unfamiliar algorithms and adding to my code library. I have learned a lot about audio in video games, different techniques for implementing it and best practises. I gained knowledgeable insights from researching how different games implement their audio and what requirements and limitations their game design puts on their audio implementation. The thesis itself I believe can show future employers my competence in audio, and in computer games.

How satisfied are you with your thesis work and its results? Why?

I am very satisfied with the artefact, even though making the game a fun experience was very much secondary to designing it to deliver the data we wanted. A majority of testers gave us compliments on the experience and its level of polish and many testers requested to play it again. We did utilise some game design principles to guide the testers behaviour to deliver the data we wanted, this apparently was enough to also make the experience an enjoyable challenge.

The thesis itself I am proud of, even though there is much to be improved, brevity first and foremost. I could have spent more time in revising the text to make it more concise and to the point.

H Reflection Document Mikita Kihan

How does your study correspond to the goals of the thesis course? Why? Focus on the goals that were achieved especially well and those that were not well achieved.

I think the study corresponds to the goals of the thesis course quite well as the investigation fulfilled most of if not all of the learning goals for a bachelor's thesis. This study has been independently completed, included relatively relevant scientific methods, reflection on ethical aspects of research, short summary of relevant scientific literature and their analysis, future research suggestions, good argumentation with adequate and professional language, proper utilisation of reference system, a short oral presentation and review of own work.

The goals that were achieved particularly well are argumentation, professional use of language, good use of relevant scientific literature, rich description of the methodology and application of method as well as reflection of the conducted study and its' limitations. Right from the start of writing the thesis I tried to use scientific literature as much as possible to make statements sound less like personal comments. Initially, it was not easy to find and reference studies that were relevant for our investigation and it was a part that had been developed over time. Hence, searching for and using right scientific literature was a process that did not go smoothly from the beginning and took time to be improved during multiple iterations.

Other goals that were not well achieved are perhaps a low number of referenced studies related to the investigated research question, choice of the data collection method, relatively small reflection about ethical aspects and a pretty high number of the study's limitations. Firstly, it was difficult to find earlier researches related to the studied topic which led to a low number of such literature being mentioned and referenced. Secondly, questionnaires did not contribute with much useful data to answering the research question which, thus, made it the least fertile data collection method. The next underachieved goal was reflection about the study's implications which was a generally difficult part to fill out as it was not particularly obvious what consequences this investigation could have. Lastly, our investigation showed to have a pretty high number of limitations which is of course good for the transparency but might be bad for the study's overall quality.

How did the planning of your study work? What could you have done better?

The planning of our study went relatively good as it was based on the recommendations set by the supervisor. However, many of our submissions, including finalisation of the artefact before the experiments, were delayed because of time management issues. Considering that both I and my thesis colleague Patrik alongside the thesis course also had other courses it is difficult to imagine what could have been done better. Apart from that we used an agile tool for planning our work for better efficiency and communication.

How does the thesis work relate to your education? Which courses and areas have been most relevant for your thesis work?

Courses that have been most relevant for my thesis work are courses for conducting a thesis work like VESK and METOD as well as courses that taught me game design, level design, audio design and programming like SP1, DMEDIA, SPM, SPD, MAPP and PROJ.

How valuable is the thesis for your future work and/or studies?

I think that the thesis is not very valuable for my future work as I am not planning on specialising in programming, game design or audio design. Nevertheless, I appreciate the experience and knowledge that I have gained from the thesis course as it has been instructive, interesting and generally useful for any possible research that I could do in the future.

How satisfied are you with your thesis work and its results? Why?

I am quite satisfied with my thesis work and its' results because I am happy with the amount of effort that we have put into the thesis and how it in the end turned out. The fact that we got null results did not bother or affect me in any way as my personal aim with this work was to gain experience and learn from conducting the thesis without hoping to achieve a certain result. In conclusion, I am happy with our work because I have learned a lot and I am proud of our effort.