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Sonic Arrow: Investigating Aiming in Virtual Reality with Blind People

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Resumo

Esta tese de mestrado, tem como nome "Sonic Arrow" e incide sobre um projeto de investigação com o objetivo de explorar novas abordagens ao mecanismo de tiro em mundos virtuais, mais precisamente em Realidade Virtual (RV), com acessibilidade para pessoas com deficiências visuais. Por haver uma forte correlação entre a visão e a utilização de realidade virtual, as pessoas cegas encontram-se na sua maioria impedidas de experienciar variados sistemas virtuais desenvolvidos neste domínio. Estudos ao longo dos anos têm surgido, com o objetivo de estudar este problema, bem como as respetivas soluções, no entanto a quantidade destes estudos, ainda se apresenta reduzida, e o problema prevalece.

Sonic Arrow, surge então como um projeto com o objetivo de contribuir para o estudo deste problema. Surge ainda também com o objetivo de incidir numa mecânica tão utilizada, mas pouco explorada no ramo da acessibilidade, a mecânica de apontar, encontrada por exemplo no mundo dos vídeojogos no tiro/disparo de armas virtuais, mas também noutros casos tão simples como a navegação de menus virtuais, onde a precisão para apontar para as opções que pretendemos interagir é exigida. Devido à dificuldade encontrada em indicar a localização espacial de um determinado objeto ou inimigo, leva a que na sua generalidade, sistemas que contenham esta mecânica, cujo objetivo passe por apontar sobre determinados alvos, se encontrem também pouco acessíveis para quem possua baixos níveis de acuidade visual. Com frequência encontramos por exemplo jogos de tiro "mainstream", com nenhum grau de acessibilidade para pessoas cegas. Por isso, consideramos crucial a pesquisa de soluções que consigam então resolver este problema.

Neste estudo, é acompanhado todo o processo de desenvolvimento do protótipo de Sonic Arrow, uma experiência auditiva de Realidade Virtual, que coloca utilizadores (um de cada vez) numa tarefa de tiro-ao-alvo, onde os mesmos, através da utilização da arma medieval, besta, terão que apontar e disparar sobre um determinado alvo, que irá aparecer aleatoriamente no ambiente virtual. Para executar esta tarefa, os utilizadores irão experimentar três formas distintas de alcançar este objetivo de acertar no alvo. A primeira forma, terá como objetivo simular o estado atual (pouco acessível) da maior parte dos sistemas de Realidade Virtual com tarefas de tiro-ao-alvo semelhantes. Nesta forma, os utilizadores, numa sala virtual ampla, terão a possibilidade de através do premir de um botão, despoletar um som vindo do alvo. Tendo Sonic Arrow som espacializado, o utilizador ganha assim uma noção geral de onde este alvo se encontra, através do sítio ao qual lhe parece vir o som. Efetuando movimentos horizontais com a cabeça, de um lado para o outro, da esquerda para a direita, esta noção fica ainda mais perceptível. Se o som estiver a vir da frente

do utilizador, quando este vira a cabeça para a direita, irá perceber que o som será mais intenso no ouvido esquerdo. Caso vire a cabeça para o lado direito, irá ouvir este som mais intenso do ouvido oposto. Relativamente à segunda forma que apresentamos, esta já apresenta uma ajuda auditiva. Esta forma irá ser exatamente igual à primeira, mas com uma diferença crucial. Irá existir uma ajuda auditiva, em que quando o utilizador, se encontrar com a besta, a apontar próximo o suficiente do alvo, o utilizador irá ouvir uma série de "beeps" que irão tocar a uma certa frequência, repetidamente. Acontece que quanto mais perto o utilizador se encontrar de estar a apontar a arma para o lugar certo (o alvo), estes beeps aumentaram respetivamente a sua frequência. O utilizador tem assim a confirmação de estar a apontar de forma correta para o alvo, quando os beeps estiverem na sua frequência mais acelerada, sendo então apenas necessário disparar a arma. Por último, existirá uma terceira forma, que em semelhança à segunda, também aparecerá neste estudo com o objetivo de testar uma outra solução para este problema de acessibilidade, no entanto, esta será uma forma um pouco diferente das restantes. Nesta forma, em vez do utilizador se encontrar na sua própria perspetiva, este vai-se encontrar na perspetiva do alvo. O corpo virtual do utilizador irá manter-se longe do alvo, e o objetivo de disparar sobre o mesmo, mantém-se. A diferença é que nesta forma, em vez de ser o alvo a emitir um som, indicando ao utilizador onde se encontra, será uma zona (calculada pelo sistema), que corresponderá ao sítio na parede onde a arma está a ser apontada. O utilizador, já na perspetiva do alvo, irá ouvir este som, emitido pela região que está a apontar, onde a lógica irá ser, se ouvir este som do ouvido esquerdo, o utilizador terá de apontar a arma mais para a esquerda, se ouvir mais da direita, terá de fazer o movimento oposto. Quando o som estiver centrado, significa que o utilizador estará a apontar para a região central do alvo. Após disparar, o utilizador irá também ouvir a flecha a embater algures ou na parede ou no alvo, respetivamente à proximidade com que disparou sobre o mesmo, pois mesmo após o disparo, o utilizador irá encontrar-se na perspetiva do mesmo.

Este protótipo, foi desenvolvido por uma equipa de 5 investigadores, com reuniões frequentes. Inicialmente num regime de reuniões semanais, que mais próximo da finalização do protótipo, passaram a reuniões para discutir os avanços significativos no desenvolvimento do mesmo. Foram também nestas reuniões que desenvolvimentos preliminares, bem como o "bug testing" do projeto teve lugar.

Relativamente às sessões de utilizadores, o projeto contou com um total de 15 participantes cegos. O objetivo inicial seria esse mesmo, evitando sessões com utilizadores normovisuais com um venda, de modo a evitar resultados que se verificassem tendenciosos. Cada sessão teve a duração de aproximadamente uma hora e meia, e contou com um questionário preliminar, relativamente a informações gerais sobre os participantes. Posteriormente ao questionário, prosseguimos com o teste do protótipo desenvolvido, onde cada participante testou todas as três formas desenvolvidas, anteriormente explicadas. Os dados relativamente aos disparos efetuados em cada técnica foram recolhidos, a fins de avançar com a análise dos mesmos, bem como do protótipo realizado. Por último, elaboramos um questionário relativamente à experiência que cada participante teve, ao experimentar o protótipo, com o objetivo de recolher algum feedback mais subjetivo.

Os dados recolhidos, bem como as análises e conclusões correspondentes são apresentados nesta tese, bem como um enquadramento do projeto no domínio da realidade virtual, acessível para pessoas cegas. Possíveis caminhos a tomar para tanto melhorar este projeto como também para trabalhos futuros que advenham deste, são apresentados nos últimos capítulos.

Palavras-chave: realidade virtual, pessoas cegas, acessibilidade

Abstract

This master thesis will explore a novel approach, accessible for blind and visually impaired people on aiming and shooting at a specific target, in a Virtual Reality (VR) world. The study will be conducted under the name of "Sonic Arrow" and will present a different approach to the massively used mechanic of aiming and shooting in the virtual worlds, that we encounter for example in some titles in the gaming world. Having some complications in passing the spatial information of a certain object without using sight, leads to the existence of a lack of accessibility for blind and visually impaired people in the implementation of these aiming mechanics. This ends up creating the impossibility of experiencing these virtual reality environments for users with visual impairments, excluding a considerably high number of people in the world. In this study, in order to develop and test a solution for this accessibility-lacking problem, we came up with Sonic Arrow, as a purely audio-focused solution tested with 15 blind participants, assigned with the task of aiming a crossbow, ultimately shooting an arrow towards a target to test whether or not, it is possible and how good it is possible, for someone to aim and shoot a weapon at a target that cannot be seen. We test and compare data results, from three main approaches, one representing the current state of aiming and shooting within VR, and two different solutions that will help users with their task.

Keywords: virtual reality, blind and visually impaired people, accessibility

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Chapter 1

Introduction

Virtual Reality (VR) is a highly growing tech field, with an impact on multiple fields of society such as Education and Training, Industry and Business, Socializing, and Entertainment. With this spread on these multiple fields, it is assumable that a high number of people end up being impacted by this phenomenon. Oftentimes associated with powerful graphical experiences (and a lot of times developed with that exact purpose) it is registered that "most newer VR environments are visual experiences" [21]. Adding to this fact, it is seen that throughout the years, VR hardware is getting more and more convenient for end consumers, with VR headsets such as the Oculus Quest 2, or the HTC Vive, being not only more financially accessible but also plug-and-play and user-friendly [68].

With a broad audience impacted by VR, a lot of different user needs and demands are also observed. Within this spectrum of users, people with impairments, in this thesis case blindness and visual impairments, are not an exception. The problem is, for these users, VR remains a particularly challenging field to enjoy. Often times we see VR development, from the hardware to its interactions, being shaped by the developer's needs and perspective, leading to many people not being able to fully experience these systems since they are a lot of the times developed as visual experiences [21].

1.1 Motivation

With the rapid development in VR, there are a lot of mechanics, and interactions, that end up lacking accessibility features. More specifically and towards the scope of this thesis, there are a lot of mainstream VR projects that end up being hard to experience, or even impossible, for people with visual impairments. "Too often, the accessibility of technology to people with disabilities is an afterthought" [53]. One mechanic in particular, which after a search was done on the background for this project, ended up being difficult to find, with a strong accessibility component, was the mechanic of aiming. This mechanic is commonly encountered in multiple technological systems. From systems that require the user to align a camera to a certain target, to blind photography, made throughout the years, the search on audio instructions and sonification studies emerge

[30, 70, 11, 28].

It has been also studied that VR can have a lot of real-life benefits, including for people with impairments by proportioning the training of specific skills and improving their life quality. There are studies that test the systems to improve skills like Echolocation, for example, [2] a skill encountered in some mammals like bats, that humans can also develop, and some VR projects have registered some good results helping this development. There are also studies that test simulations on real-life environments replicated in the virtual worlds, in order to proportionate Orientation and Mobility (O&M) training without the actual need for blind people to be in the physical space they want to explore, avoiding real-world dangerous situations and impracticalities, ultimately improving their independence [61, 23, 35, 11, 45, 37, 39]. So, there is a lot of good potential for people with visual impairments in some VR projects, and at the same time, these life conditions are also being ignored within the majority world of VR development. "Too often, the accessibility of technology to people with disabilities is an afterthought" [53]. With that said, there should exist interest in exploring this VR accessibility and expanding it to all users, because of its corresponding big potential for improving people's lives.

After having aiming in mind, more research was done and, it was also noticeable, the low number of VR shooting systems, such as games, accessible for blind people. Humans gather spatial information mostly using their vision [17], and this statement remains true in virtual environments. Because of that, the action of shooting a weapon the majority of times, is co-related to the assumption that the person who is shooting has sight, another statement that is transposed to the virtual worlds as well. It is considerably easier to pass the spatial information to a user, making her/him understand where a certain target location is, by using the vision channel, and that is why vision is used as the primary stimuli in the vast majority of first-person shooters (FPS) games [76].

Essentially, this master's thesis work is aimed towards combining VR and its potential benefits and its corresponding lack of accessibility for blind and visually impaired people, with the aiming mechanism, in the form of first-person shooting systems that also seems far from being fully explored, regarding its accessibility features towards visually impaired people, making this into a challenging project.

1.2 Goal

The main goal for this master's thesis project is to develop "Sonic Arrow" an accessibility-focused project within VR environments that explores multiple approaches for the aiming mechanic. More specifically, our goal is to understand what approaches end up resulting better, for a domain considered to be lacking in accessibility features to blind and visually impaired people, that is aiming and shooting a weapon toward a specific target in VR. This lack of accessibility exists due to the challenge that is aiming toward something we cannot see. So to provide it, we develop and test three different techniques to support blind people in aiming tasks in VR: 1) Spatialized Audio, where the target emits a specific sound to convey its location; 2) Target Confirmation, which adds

secondary beep sounds to indicate proximity to the target – closer to the target means higher frequency of beep sounds; and 3) Aim-Target Perspective, where the auditory feedback conveys the spatial relationship between the user's aim and the target. All three are explained more deeply in further sections of the document. The goal of the study is to test the different approaches developed, as well as the approach that we currently have in the mainstream systems that lack accessibility. In the development process, we will also focus the majority of the attention on spatialized audio cues, having Sonic Arrow an almost nonexistent visual interface.

Developing the project with off-the-shelf and financially accessible hardware such as the Oculus Quest 2, also contributes to a more different and not so straightforward goal. Developing systems that only require off-the-shelf products to be used, contributes to a wider audience that can be targeted, and the secondary goal we want to achieve.

1.3 Contributions

The main contributions of this study reside in the development and testing of three different techniques that support the VR task of aiming. A deep analysis of each technique is presented, based on user sessions done. Performance data, like shots done by the participants, followed by subjective feedback and general thoughts given by them are also here presented. We plan on contributing with this project, into a better understatement of the problem, as well as presenting some potential solutions for the visual impairment accessibility domain.

1.4 Document Structure

The document, after this introduction, proceeds with the background section, where we contextualize a little bit more the main concepts mentioned throughout the rest of the document. A general description of visual impairments, alongside some explanation of important terms and mechanisms used within user accessibility, such as spatialized audio and virtual reality and environments.

After, we present the related work segment, where an overview of the most similar projects found to this one, is given. Projects such as Sofia Cavaco's study with a user study done with blind children, with the task of aiming the smartphone toward specific elements in a virtual world.

Related work is followed by the Implementation section, where we present the design for this study, and highlight some doubts and topics that went through the development process, explaining why we took the route we took.

After, we present the user study itself alongside how was decided to proceed with the user testing of the prototype developed in the previous section. Decisions made while designing user testing, are also presented here.

We present the results in a new section. Data such as the shots made by the participants as well as how many points on average, users got. This is essentially the section where all the data collected is displayed, without a few or any subjective comments made by our team. Apart from data collected from the prototype, in shot characteristics format, we also present here the subjective feedback collected from the participants.

We present then a new topic where we discuss the previous one and take some statements based on the information collected. We decided to present this information on a different topic, purely to separate the data collected that is "certain", from statements based on the data collected that have a degree of "uncertainty" due to a hypothetical misinterpretation from us.

We end the study document with a conclusion, highlighting what we learned from this study, future work, and some thoughts from this project.

Chapter 2

Background

This section provides the definition and explanation of some key terms and expressions, of the research field on accessible Virtual Reality to blind and visually impaired people.

2.1 Blind/Visual Impairments

”Vision impairment occurs when an eye condition affects the visual system and its vision functions.” [57] Essentially is a life condition correlated to the low levels of visual acuity, that happens within a spectrum, as it is divided into groups with different levels of intensity. [57] When this intensity gets high enough, is considered blindness. Currently in the world, according to the World Health Organization (WHO), there are at least 2.2 billion people with blindness or a visual impairment [57], which corresponds to approximately 28% of the world’s population, so it is a condition present in a considerable amount of people’s life.

2.2 Haptic and Audio Feedback

Like it was mentioned before, humans acquire spatial information mostly using their sight [17], so, when a person with a certain life impairment, gets this sensorial stimulus negatively affected, the occurrence of challenging scenarios is inevitable. To adapt systems, and more importantly, make them accessible to blind and visually impaired people, there’s a necessity of using compensatory sensorial channels, such as tactile and audio (as the most commonly used ones). That is what is called haptic and audio feedback, a viable way to inform the user about certain environments and their characteristics, as well as the output of the user’s actions/interactions with the environment substituting sight. Webster’s dictionary defines Haptic feedback, as the feedback related to the sense of touch [47]. This definition integrates vibrotactile haptics and force mechanical feedback which were the most commonly used types of haptic feedback in the background research done on this master’s thesis. Audio feedback, as the name suggests, is the feedback given to the user using the auditory channel. From the background research done, it was found pretty common that the so-called 3D Spatial audio, which consists of surround sound audio that with the help of

computational algorithms has the potential to proportionate immersive user experiences. Haptic and Audio feedback are here, in this thesis, mentioned in a dedicated section, because are the most known and used types of sensory substitution (to vision) feedback. [41]

2.3 Spatialized Audio

Spatialized Audio is an Audio system used in Virtual Reality Worlds to promote immersiveness. Essentially it is a system that takes into consideration the location where the sound is originally produced in the virtual world, and in the case of Virtual Reality, the location of the user's head, to reproduce the feeling of acoustic rooms [54]. It is often correlated with surround sound, as it uses sound system devices with multiple output angles (360° sometimes), to replicate the angles where the audio should come from. Ways to achieve spatialized audio are by the usage of Head-related transfer functions, algorithms that hold the mathematical formulas in order to calculate this sound propagation effects in the Virtual Worlds [44].

2.4 Virtual Reality

Virtual reality (VR) is a term credited to Janor Lanier, and it refers to the capability of simulating realistic environments but virtually [78]. It uses the human capabilities of abstraction, to set up an immersive environment and also holds a lot of capabilities. There are entertainment purposes, for example, exergames, a term referring to “Exercise games”, being VR games that are focused on the exercise aspect and body energy expenditures, making the gaming experience similar to real-life sports [51] (in terms of real-life physical exercise). An example of an Exergame is VI Bowling [51], a Virtual Reality bowling game, adapted to blind and visually impaired people. With a non-visual interface, the developers substituted the visual sensorial information with audio and haptic (vibrotactile) feedback.

Besides entertainment, there are also positive contributions of VR in spatial information gathering. To explore new real-life places, blind and visually impaired people, often encounter the need for external guidance from another person, for the first time they explore those certain places. Sometimes, a guidance person is not even an option, so some people's first approaches to new places are made by themselves alone, exposed to all real-life dangers with some potentially harmful situations. So, it has a lot of interest, a system where these real-life places, can be simulated virtually, so the blind person, can download them and explore them without the real-life dangers, and with no need for another person. With this scenario, a stronger independence factor is added since this makes the person able to spend as much time needed on that area (not depending on the availability of the person guiding). Multiple kinds of research were done on exploring areas, from outdoor to indoor zones [61], as well as using some less human walking mechanisms such as keyboards [11, 45], to closer to real-life methods, such as using a virtual white cane, with force feedback (with also haptic and audio feedback) as the work done on “Virtual Reality Without Vision” [61]. Apart from the entertainment factor and the spatial navigation already mentioned, VR also holds a

very positive aspect, in training skills from the person's own skill set. For example, Echolocation, a skill studied in some mammals such as bats or some other aquatic animals, is also used by a percentage of blind people. It is studied that 20 to 30% of the blind or visually impaired people use it, and some studies on replicating this Echolocation skill on simulated environments, as well as constructing a training setup for people to develop it, have been conducted, such as the study made with Echo-House [2].

2.5 Virtual Environments

Virtual environments (VE) are, as the name says, environments simulated virtually, that can be used as the setup for users to explore and/or interact. There are multiple sizes that these VEs can have, and there's an article read prior to this study [36] that proposes a taxonomy for these environments based on their size. The small scale is the type of environment where everything is "hand" reachable, and the user doesn't need to move (maintaining its absolute position) to navigate and interact on these VEs. The medium scale is the room size type of environment, where usually the user uses a respective room size trackable area to navigate the virtual environment. And Large scale being, as the name suggests, the big areas where users no longer have a trackable room size area, because that would not be practical, and the user uses a controller to navigate in this environment. In every scale, common hardware and common usage scenarios are mentioned which gives an informative overview of these 3 different scales.

2.6 Real-life Archery For Blind People

Archery constitutes a Paralympic sport with some aspects we can take into consideration, so that is the reason for being highlighted in this study.

According to WorldArchery.sport [3], Para Archery has been in the Paralympic Games since 1960 and has remained in it since then. It is an "extremely accessible sport for people with impairments" [3], and Blind people are not excluded from this statement.

Being a vision-based sport, to turn into an accessible to blind and visually impaired people sport, some physical aids are added. One of them is the foot locators. These are physical supports, located on the ground, that help the person who's going to shoot, where to put his/her feet, to make sure it is in the right position of shooting. Besides the foot locators, tactile sights placed in a tripod are also used, as another physical aid, to help the person shooting to make sure the bow is aligned with the center of the target. After shooting an arrow, using both of the mentioned aids, in para archery, it's common to see a visual assistant, that will tell the blind person, the points achieved with the shot that was made (Being the regions closer to the center of the target the most valuable ones just like in non-accessible archery).

Chapter 3

Related Work

3.1 VR for Blind People

As mentioned before, VR appears in many life domains, from the entertainment world in video game formats to education and social interaction purposes. Due to the strong relationship between VR and visual feedback, we encounter multiple systems, that lack accessible features for blind and visually impaired people. Consequently, more and more studies have emerged, to understand this problem, as well as test different approaches that can result in different solutions. In digital gaming, for example, there are studies not only to understand the barriers faced and the strategies to overcome some challenges faced by expert blind people [22], but also to provide users with tools to understand and move in the environment [55, 63, 2].

There is also in some other contexts, research studies that test solutions developed to gain knowledge about a virtual environment, often to transfer it to the real world [13, 27, 40, 19]. We even see more immersive, and real-life-like ways to explore the virtual environments appearing, opposing to the keyboards, joysticks, or smartphones, used in the studies mentioned. Hardware pieces, such as HMDs and hand-tracking systems (e.g., Meta Quest, Sony PlayStation VR) are currently helping VR by bringing more new and realistic interactions, within the domain, and are checking to have a good potential due to this ability to replicate more natural human gestures to the virtual worlds.

For instance, to support navigation researchers have leveraged blind people's Orientation and Mobility (O&M) skills and navigation aids, proposing techniques that augment a white cane [62, 77, 42, 38] or that enable users to walk freely in the real world [67, 29]. Additionally, we encounter other solutions designed for blind and visually impaired people for specific contexts, such as support for VR social interactions and environment awareness [32], or sports [26, 71, 74]. In particular, Guerreiro et. al, [26] proposed a design space to augment visual objects with an auditory representation to support designers in developing accessible VR experiences, which we leveraged during the ideation of the aiming techniques explored in this work.

Virtual worlds in immersive VR are not yet fully accessible to blind people. Past work has focused on various challenges (e.g. navigation and social cues) and contexts (e.g. O&M), slowly contributing to our shared knowledge of creating accessible experiences. Aiming has been identified as one

prevalent and open challenge.

3.2 Aiming for Blind People

If we focus on the scope of the thesis, specifically on the action of firing a weapon toward a target, the action of aiming may seem for only entertainment purposes. The reality is, that the action of aiming goes a little bit deeper than that. We find this mechanic in even real-life interactions using technology, such as mobile apps for object identification [1, 25] that require users to align the phone camera with that certain object. Within a similar scope, there are also applications for text reading content [14, 75], or even applications to receive remote assistance [5, 9] where the same principle applies. Alongside these contexts, research on blind photography resulted in approaches to support blind people aiming at a particular target or landscape, usually making use of audio instructions or sonification [30, 70, 1, 28]. Still, accurately aiming at a specific target, especially at a distance, remains an open challenge.

Besides these more real-life scenarios, we also check these challenges to occur in the virtual worlds. For example, we often encounter mainstream video games that include complex environments with respective complex interactions, not designed necessarily for blind players. Even experienced blind players, struggle with these titles with aiming at targets, controlling the camera, and aligning it [22, 4, 55]. There are also studies on strategies that these players end up using in order to surpass this lack of accessibility. But another problem relies on these strategies affecting user engagement, such as aim assistance, sharing the controller with friends, relying on audiences, or even auto-aim [22, 55].

Some challenges related to aiming are reduced when considering VR and using an HMD. In particular, an egocentric perspective (the virtual avatar is commonly the player) alongside the direct control of the camera with head movements enable a more natural interaction. This is complemented by using the controllers and hands themselves (rather than a keyboard or joystick) to aim at a specific target or area of interest. Still, there is very little work on aiming in VR for blind people. One exception is the work by Chung et al. [12], which explored omnidirectional guidance feedback, enabling users to focus on locating the target's vertical position, followed by a horizontal search, or vice-versa. It uses beep sounds that increase their frequency when approaching the target. In a study with blindfolded sighted participants, the two-step conditions outperformed a default one with simultaneous horizontal and vertical feedback. An alternative solution relied on the person's head movements to control the trajectory of an arrow to hit a specific target that emitted sound [18]. Their work focused on head-trunk coordination, where a second solution would also consider the relation between head and trunk to rotate the arrow.

Overall, prior work showcases the challenges of aiming tasks for blind people in VR but also calls for effective solutions that support blind people in contexts where aiming is required.

3.2.1 Projects with Accessible Aiming

The paper found with the most similarities to this master thesis scope in the aiming skills improvement was Sofia Cavaco's paper [10], showing a study conducted in 2015, to test and analyze a game developed, based on 3D spatialized audio, aimed to blind/visually impaired children and teenagers. The game's objective was to successfully capture the different creatures that there were in two stages and lastly, follow a robot, making it into the three stages of the game. To interact with the game, the players would use a smartphone, which would be the main controller of this system. Utilizing its gyroscope, the smartphone would track users' rotation and spatial orientation so the users could successfully do the objective tasks. The "following the robot" task runs out of the scope of this thesis since with it (thesis), the objective goes to test aiming skills in a static user position instead of walking in real life with a "following objective", but this challenge was not tested in the paper mentioned anyway.

From the two tasks tested, "Cockroach Hunt and Space Bees" the objective was for the users to capture creatures, using the main device (smartphone), with a mechanism that required pointing it in the exact direction the creatures were, similar to taking a picture. To indicate to the users the creature's location, they would make specific sounds, in a spatialized audio environment, so it was possible to mentally calculate the position of the creatures to capture. After the user tests, it is stated that the study registered some "very good results" as some students registered a high amount of creatures captured. Another interesting result was the improvement in students' location estimation and/or confidence in these estimations. This was registered by the fact that "missed attempts decreased from the first day to subsequent days" since this was a study conducted in more than one day. Adding to more interesting results it was also seen by the tester team that in the beginning students remained static only moving their arms to successfully point the smartphone to the right place where the creatures were. But by the end, this lack of movement from the students (only moving the arms), which was pointed out to be most likely a lack of security since they usually needed help to move around places like school, started to disappear. And on the final part of the user tests, it was registered that students tended to move around the body more freely as well as in some cases, do little steps, factor correlated to a degree of immersiveness and again showing how important it is the already mentioned spatialized audio in this process.

On a different note, speaking about a different project but maintaining the scope of the section within aiming skills in virtual worlds, we also have another project worth mentioning, Game Hub 2 [56]. In cooperation with the Gamification Lab of Leuphana University Lüneburg and the School of Computer and Mathematical Sciences of Auckland University of Technology, they developed this mobile app with multiple games accessible to sighted and blind people as the games are focused on the audio aspect. From the game list, one of them is in fact an archery game. It is not VR and not even 3-dimensional, but it is a 2D game where the user presses the screen with a finger, and a crosshair [72] moves around the virtual environment emitting a sound while the user remains hearing this crosshair from the target's position. This game utilizes spatialized audio, so the user is able to understand if the crosshair is located far away or if it is on top of the target. If that is the

case, the user proceeds to release the finger making the cross-hair's weapon to shoot, ultimately making the user understand if the target was hit or not.

3.3 Importance of Spatialized Audio

The study of Canetroller [61] developed in 2020, is from a team conducting research on a VR white cane with multi-modal feedback through haptic and audio for blind participants. With a 6x6 m room, sensors, and a very special white cane designed for VR and the exploration of VE's, the objective of this study, was to test how accurate this white cane on a VR standpoint and how well user could get environmental information with the already mentioned "White Cane". This cane was built with horizontal and vertical brakes (force feedback), to simulate hazard or objective target's shape and a support harness to help spread the weight of the cane through the user's body, alongside some vibrotactile feedback. Auditory feedback was also incorporated and was meant to replicate the user's cane movement hitting other objects. Sound effects were pre-recorded to a more realistic audio experience and were played when the user inside the VR system would hit the various hazards or objective targets. Even though, this study itself goes a little bit out of scope from this master's thesis (especially considering the hardware used), is the last comment on the article that we take as an important tip. From this study's feedback, users had very good comments on their audio feedback system. "Audio Provides Spatial Information and Realism" is a quote from the article, as well as, "It also provided information on participants' orientation, distances, and occlusions", evidencing the benefits of good audio spatialized 3D audio, contributing not only for better element perceptions but also contributing for a more immersive experience, which consists as an important objective in the field.

3.3.1 Alternative way for VE exploration

In VR, the most common way for the user to explore the virtual environments relies on a first-person perspective. That also ends up being the main point of VR and their controllers embedded with sensors, granting hand gesture replication. But on the accessibility area, and especially for systems that want to grant accessibility to the visually impaired, we need to have richer environments to be able to have vision substitution components. In this case, we tried to find different ways for spatial exploration and found the usage of different perspectives. The usage of different perspectives (other than the user's first-person perspective) is not new. We have some examples in games such as First-Person Shooter (FPS) Tom Clancy's Rainbow Six Siege [65] with a drone mechanic. In the game, players can release a controllable drone to navigate through the map to obtain more information about the game's status/adversaries. So besides the usual first person/player position perspective, we do have the perspective of this drone, in order to get a better understanding of the environment as well as different information you would normally have if there was just the player character perspective, to successfully take down the enemy team as the main objective. Using the example of another game, we do have Assassin's Creed Valhalla [16] a third-person Role Playing Game (RPG) game, that takes place in the IX century, between the Viking Invasions

of Great Britain. One of the mechanics of the game is letting the player release a controllable bird (Raven) that guarantees the ability to see the map from above since it can fly. The main objective of this mechanic remains to give the player a better understanding of the surroundings, the bird can also bring quests and resources or/and scan nearby areas of interest.

Having both of the games mentioned, different concepts behind it, we do see a pattern still. We see in both of the cases a multiple perspective usage with at least one characteristic in common, the better understanding of the surroundings, surpassing the first/third person's limitations regardless of the surrounding perspective. Different games, from different genres, having similar mechanisms like the multiple perspective usage, show a wider potential usage of this mechanism in other types of games/systems, and expanding this potential usage to Sonic Arrow can be the way to go.

3.3.2 Summary

Searching for the related work section, there was a clear difficulty in finding studies that focused on Aiming as a mechanism, within Virtual Reality accessible to blind people. As mentioned in [3.2.1](#) there was a similar project by Sofia Cavaco, however, using a smartphone. There are some notes that we can take, as there are some aspects in common with studies conducted in VR, such as the usage of spatialized audio to express some spatial notions of certain objects, but these are still two different topics. Having Sofia's project be conducted with a smartphone, and being the closest project we found with ours in terms of scope, highlights the space that there is still to explore this interaction within VR.

Chapter 4

Implementation

Developing a project within Virtual Reality, accessible for blind and visually-impaired people was a challenge on its own. Wanting to do an aim/shooting mechanism with the same accessibility capacity was another challenge, given the lack of similar projects on the field. We knew that a couple of aspects were going to be taken into consideration. For feedback stimulus, it felt that the better option was to go for a robust and complex audio experience since audio is already the most used stimulus by visually impaired people, for spatial orientation. Complementing this stimulus, the usage of haptics was also planned to be used, to make sure we did not overuse the audio aspect of it. Having too many elements triggering audio feedback could cause unnecessary audio overload that could lead to potential confusion. This was a thought we had throughout the whole development of the prototype.

4.1 Hardware and Software Used

Hardware speaking, we decided to use something that would be fairly financial accessible to a broad audience. Based on the hardware usage within the projects of the other articles found in the background and related work section, we decided to use the Meta Quest 2 (two hand controllers and a head-mounted display) as the main tool for this project. It is to be mentioned that the head-mounted display was used in this study to purely grant us the capability to track the user's head movement. Both of the hand controllers were to grant us the capability to track user's both hand gestures. The development of the prototype itself was made on a laptop capable of running VR, with an NVIDIA GeForce GTX 1060 graphics card.

Software speaking, we used the Unity Engine, given its powerful tools, as well as a wide usage not only in the Virtual Reality research field, as it was found in our background research, but also in other fields such as for example the video game industry. Familiarity from the team with the engine also weighed in this decision. Inside Unity, to make sure the project was compatible with the Meta Quest 2, as well as to more easily develop this VR experience we used the Unity XR Interaction Toolkit. The Oculus Integration Package was also used in the development of Sonic Arrow. For version control, we used Git, to make sure the project was always available and secure. For team-related documents, to keep everyone updated, it was used the Google Drive.

4.2 Aiming and shooting with a Crossbow

This project started initially as a bow and arrow virtual experience. But quickly onto the development, we noticed that to shoot a bow, some extra movement is required. To shoot it, the person needs to pull a string and release it. Adding to this, the person shooting would also need to align perfectly the hand holding the bow, with the other hand pulling a string to make it shoot straight forward. Not aligning both hands and making the one holding the string slightly more to the left (for example), would make the arrow shot go respectively more to the left. This movement complexity would most likely get in the way of the project's main objective, which is simply to locate a target and shoot at it. Adding to this problem, in archery, the hand that pulls the string goes during this movement behind the head. The Meta Quest 2 requires the user to keep both hands in the front part of the body, due to its hand tracking sensors not capturing what is in the back. So to eliminate not only this problem but also what we considered an over-complex mechanism that would require extra movement, the virtual bow idea was abandoned and substituted for a virtual crossbow. With a crossbow, we would have a weapon very close to a gun, where aiming would only depend on the hand holding it and its direction, making it a straightforward movement. The reason for not simply changing to a gun and sticking with a crossbow relies on the fact that we ended up proffering arrows and the sounds they make, over gun bullets. This preference will be better explained in the next sections. As a foundation for this project, we found a tutorial of a bow and arrow project done on YouTube by the channel Sunny Valley Studio [64] that we followed, making it the starting point of Sonic Arrow, in the Unity Engine. We then proceeded with developing the weapon change to the crossbow.

4.3 Shooting Environment

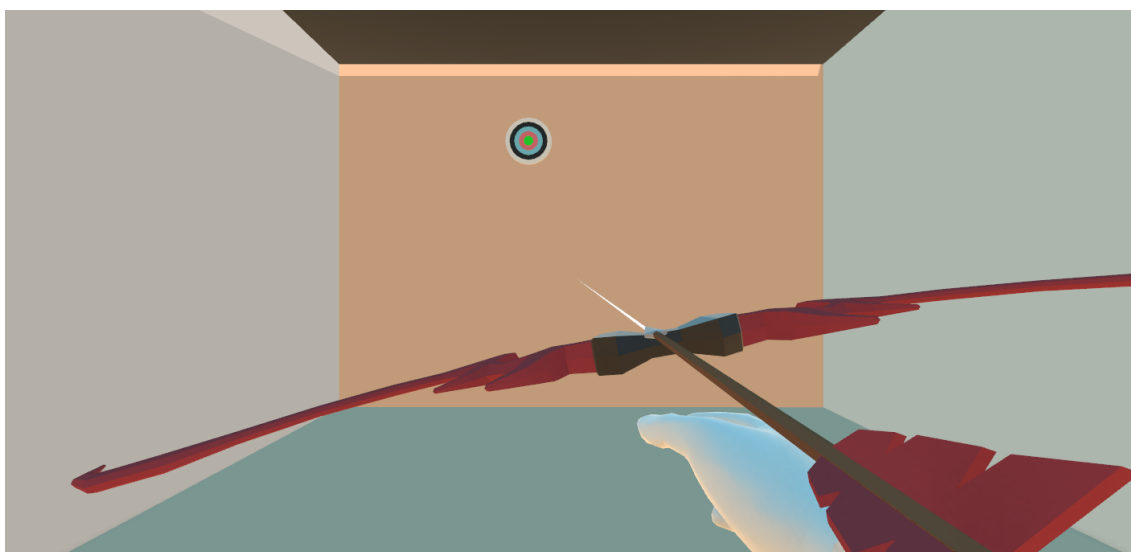


Figure 4.1: Virtual Environment of Sonic Arrow

The creation of the environment for Sonic Arrow came with some other aspects to take into consideration. For practical reasons, we decided to create a virtual environment where the person would be inside a big empty room (25 x 11 x 7 meters), surrounded by four walls, a floor, and a ceiling. The reason why we went with the big room environment option, was so there were some spatial constraints in the virtual world. With these walls present, in case of a missing shot, the arrow does not move indefinitely towards the sky for example, since there is a ceiling. The same logic is applied to every other direction that does not contain the target. Having the four walls surrounding the person that enters Sonic Arrow, to simplify a little bit, we made it so the target would randomly appear anywhere within the wall in front of the user, and would always stay in that wall even if it changes location. The wall decided to be the "target wall" is still considerably big, so there is still space to give a good variety of different places the target could be. It is to be noted that the user in this environment will always be in the same stationary region of the map, unable to walk, and consequently leaving that place, approximately 20 meters from the target (diameter = 1m). The target, similar to the archery target, is in a circle shape and has 5 sub-circle regions. Each region corresponds to points between 5 and 1 depending on the region we hit and decreases in size the closer we go to the center of the target. The smaller and the closest the region from the center, the more points the user gets by hitting it.

To grant some complexity, and to proportionate a more immersive experience, a background noise of air conditioning was added, to avoid the so-called "dead silence", and successfully emulate the feeling of being in a room.

4.4 Audio Feedback

To make the user understand even better the outcome of its actions, in this case, where the arrow shot hit, we implement Sonic Arrow with a virtual assistant capable of letting the user know if the shot hit a wall, the ceiling, the floor or in case of a successful shot, how much points did the user gets. This virtual assistant is implemented using a text-to-speech tool in the website Micmonster [50]. Besides where the shot hit, the assistant also tells the user each time the target changes its location.

For all the audio effects such as arrows hitting either the target or the wall, we used the Freesound website [20] and its audio pool. We prioritized, the most realistic and pleasant sounds to enrich the Sonic Arrow experience and add an extra layer of immersiveness.

4.5 Haptic Feedback

In terms of Haptic Feedback, we applied mostly vibration within the Meta Quest 2 hand controllers. When the shot would hit somewhere the left controller would vibrate to give that indication. In addition, the crossbow would also take some time to reload, making the user not able to do a new shot instantly after shooting once. After reloading the right-hand controller would also

vibrate indicating it.

4.6 Techniques and Objectives

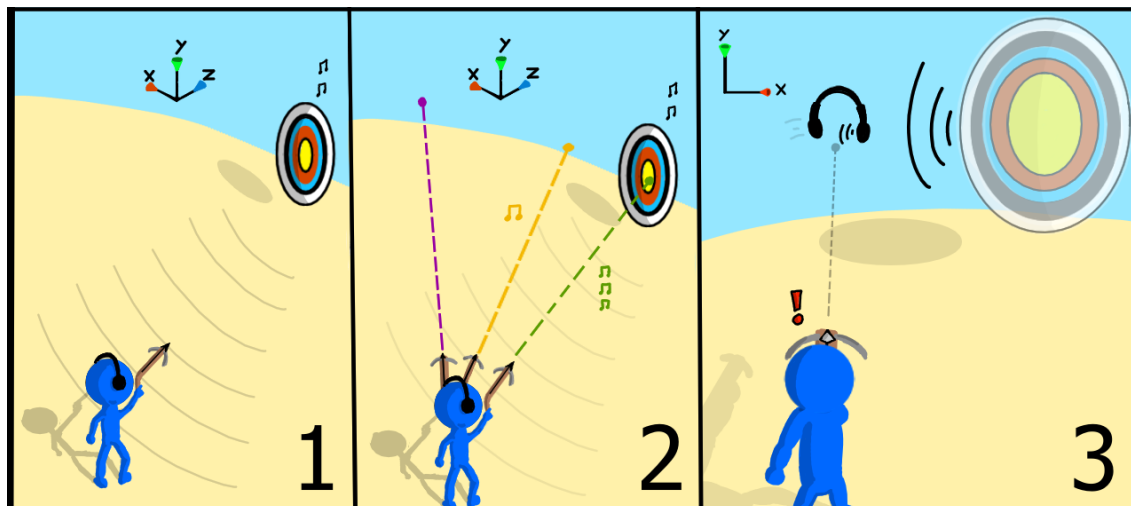


Figure 4.2: We designed and implemented three techniques to support blind people in aiming tasks in VR: 1) Spatialized Audio, where the target emits a specific sound to convey its location; 2) Target Confirmation, which adds secondary beep sounds to indicate proximity to the target – closer to the target means higher frequency of beep sounds; and 3) Aim-Target Perspective, where the auditory feedback conveys the spatial relationship between the user’s aim and the target.

The main task of Sonic Arrow, as mentioned before, is for the person to successfully shoot the crossbow and hit a certain target that is located far away. As it was mentioned before, similar to archery, this target has five regions, each one with points associated. The closer the region is to the center of the target, the more points a shot has.

Since Sonic Arrow’s objective as a project is to proportionate the capability of aiming and shooting using ways purely focused on audio and haptics, we developed three different ways, which we call techniques, to help the people with this objective. Each technique is going to help differently, the user in Sonic Arrow, to successfully shoot at the target.

Ideally, at the end of the study, we want to understand which technique was the most effective and helpful, to understand what feedback type works better, and which is more clear for blind and visually impaired people.

4.6.1 Spatialized audio

The Spatialized Audio technique is considered a baseline for this study. It is the most simple technique in the way that it is the least helpful one. In this technique, we correlate the user’s location as well as its head rotation, with the far-away target and its location. To successfully know where this target is, the person will trigger (with a press of a button) a sound, that is going to come from

where the target is. Since Sonic Arrow uses spatialized audio, the person will be able to understand from which direction the target sound is coming, giving it a clue on where this one is located. Understanding if the sound is heard more in the left or right ear, as well as rotating the head in the Y axis (figure 4.3), helps in having this perception.

After thinking that this would be the way to make the person understand in which direction the target is, we faced a new challenge. In virtual reality there is a problem, that remains of passing the right vertical height of something. In this case for example, if the person shooting the crossbow, successfully located the target by getting in which direction, the sound heard from the left ear and the sound heard from the right ear were on the same level, if the target would be let's say, 1 meter from the ground or 7 meters from the ground, it would not be distinguishable. So for that reason, we knew that a vertical sound aid feature was required.

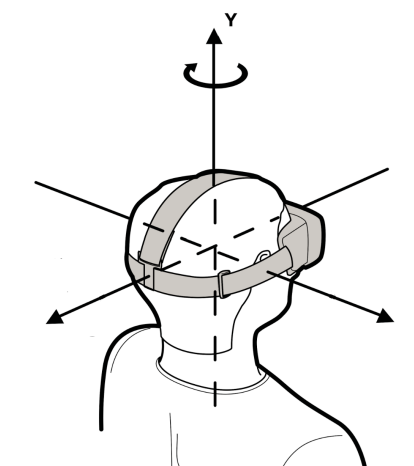


Figure 4.3: Rotating the head in the Y axis reference.

Verticality Problem Approach

To approach this verticality challenge, we decided to correlate two elements, the sound that the target makes impacted by how high or low a person was aiming the crossbow. For the solution to this problem, we selected the audio pitch as a variable, and we made it so, that if the person was aiming too low, compared to where the target is located, the sound that the target would reproduce would have a lower pitch, compared to if the person was aiming the crossbow too high. Then the sound would have a higher pitch. In this solution, the person would know when the crossbow was being aimed at the right height (compared to the target's distance to the floor) by searching for a specific height where the target would make its original sound without any pitch distortion. To help a little bit, and make the person using Sonic Arrow, know what sound is the original sound reproduced by the target, and consequentially, make the person know, which sound is being sought, we allocated another button, that if triggered, the person would hear this target's original sound.

Shooting the Crossbow

After knowing where the target is, horizontally and vertically, the person should shoot the crossbow. To do so, it is a matter of simply pressing the trigger button on the Quest 2 hand controller, in the hand that is holding the weapon. This weapon makes mainly two distinct sounds. When the user proceeds to do a shot, the crossbow, emits a string release sound, confirming that the weapon was indeed triggered. When it reloads, it also emits the sound of a string getting pushed, to confirm the weapon is being reloaded.

Note that after the user shoots the arrow, once this one hits either a surface wall or the target, the

left controller vibrates, confirming the arrow already hit something.

This prototype was developed in a way to replicate the shooting of a real-life crossbow, so the arrow trajectory is purely dependent on where the dominant user's hand is pointing.

4.6.2 Target Confirmation

The Target Confirmation technique is the same as the Spatialized Audio technique but it adds another specific audio cue. In this technique, if the user aims close enough to the target, there is an intermittent "beep" sound that can be heard, that gets faster and faster, the closer the crossbow is aimed at the target. When the person aiming the crossbow, achieves the fastest beep sound frequency, it is a sign that the crossbow is being aimed at the center of the target so it is ready to shoot successfully hitting it.

4.6.3 Aim-Target Perspective

The Aim-Target Perspective is where we consider purely the target's location as well as the aim of the crossbow. To understand this technique, it is important to note that the system is constantly tracking where the crossbow is being aimed in order to calculate where the arrow if shot is gonna hit. This tracking is done by a straight line that starts at the tip of the crossbow and goes until it reaches either a wall or the target.

For this technique, we used that exact place calculated from where the crossbow is being aimed and made it possible to emit a sound on command as we did to the target in the previous techniques. On top of that, we relocated the user's hearing perspective from its avatar body to where the target is. What this means, is that, while aiming the user would be able to trigger a sound, coming from the place that he/she was aiming, and since the hearing would be located at the target's perspective, the sound would be perceptible (if the crossbow was being aimed close enough to the target). Hearing the sound from the left ear, makes the person need to aim more to the left, and hearing from the right ear makes the person need to aim more for the right, making this technique's logic, to always follow the sound. When a shot occurs, the arrow still comes from the crossbow, in the user's avatar hand, located far away from the target, but if it hits close enough to this one, the person will be able to hear this arrow hitting the target's wall surface and understand where the shot exactly hit. Essentially, we want to grant the user a different perspective, other than its first-person perspective, to analyze if this aspect, contributes to a better understanding of the main problem (where the target is located).

Verticality Problem is solved without the Pitch aid

Within this technique, the verticality aspect was not a concern, unlike the other two techniques. We thought of doing a similar approach, changing the audio pitch depending on how high or low compared to the target the user was aiming, but since we have access to the target perspective in this technique, the sound will go further or closer to us, depending on how high or low we would aim. The closer we aim, the more intense the sound will be, against the low-intensity sound heard

if we aim too high or low towards the target. Having the intensity of the sound, to tell the users, how close they were to the target both horizontally and vertically, the change of pitch aid, was removed from this technique.

4.7 Controls

The Meta Quest 2 controllers have in total 12 programmable buttons (6 buttons each) as shown in [4.4](#). For Sonic Arrow a considerably low amount of buttons is used for this project. One aspect highlighted within team meetings was to keep the prototype straight to the point and avoid overcomplicating the user's tasks, with accessory and irrelevant tasks. This kept us from only using a total of 3 out of 12 buttons available for these controllers. Sonic Arrow requests the trigger of the pinch button (from the dominant hand controller) to shoot the crossbow. The other two buttons used are "A" and "X" from the right and left hands respectively. If the user is right-handed, the "A" is responsible for triggering the main sound of either the target or the aim (depending on which technique we are in). The sound triggered by this button is a sound that is going to change depending on where the user is aiming. It triggers the main sound in the Aim-Target Perspective and it affects the target sound pitch in the other techniques. The "X" button triggers the sound the user wants to achieve when aiming at the correct spot. This button is only used in both Spatialized Sound and Target Confirmation, as it triggers the continuous sound of the target, in the correct pitch, helping the user to understand which pitch to "search". If the user is Left-handed, these buttons are switched.

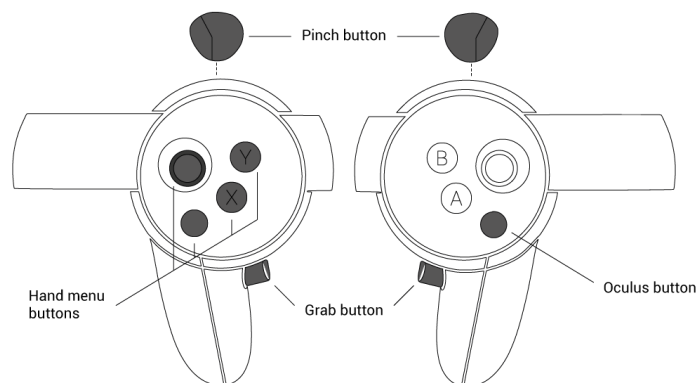


Figure 4.4: Meta Quest 2 controllers and respective buttons

4.8 Limitations

Speaking about the limitations of this prototype, we have to consider a few. First of all, the prototype is designed for a certain shooting distance (20 meters) from the wall where the target is located. This distance remains the same throughout the whole experience.

Another limitation remains on the target only being able to be in the same wall of the Virtual Environment. From all four walls surrounding the user, only one (in front of the user) is designated the "target wall", from where the target can eventually move, but never leave. Having only one "target wall" felt complex enough given the scope of the project, and adding more target walls would add unnecessary complexity, that could mislead the final interpretation of the results.

Lastly, it is to note that for every shot done by the user, the system would say a little sentence such as "You hit a wall", indicating some basic information, to make sure we grant the user some awareness. To prevent a continuous press of the button to shoot resulting in multiple arrows shot per second, in order to hit at least once the target, we programmed the prototype so the user could only shoot after the system was done giving the shot verbal feedback.

Chapter 5

User Study

For user study, our goal is to test all three different techniques developed for this system, to investigate how they support blind people in aiming tasks in VR. More specifically, we want to analyze the participant's aiming and shooting performance, as well as their feedback to understand technique preferences. We also want to develop a task where the target would remain stationary and a different task, where the target would be moving, for not only making the comparison between the two but also for stretching the potential analysis for this project.

5.1 Apparatus

For this project, we used a laptop with a capable system of running the VR prototype developed for the study. Connected to the laptop, we used a wired USB connection to the Meta Quest 2. We decided to use the wired connection due to wanting to change the virtual environment parameters on the spot as well as being able to access the visual feedback of that world, to guide the participants if needed. The cable usage felt like the most practical way to go for that reason. During the study, the participants would also wear headphones to proportionate a better and clearer audio experience. All the data collected by the system was stored locally. All the user sessions were always conducted by two to three researchers.

5.2 Participants

We recruited 15 blind participants through a local training institution for people with visual impairments. Seven participants were blind and eight had light perception but were unable to understand the elements of the virtual environment. Their ages were between 27 and 64 ($M=42.73$, $SD=11.40$). Twelve participants rated themselves as experienced with technology in general (at least 5 on a scale of 1 to 7), but most (9) were not experienced (3 or lower on a 1-7 scale) with virtual environments. Only two participants (one of them prior to becoming blind) have experienced VR in contexts outside of research studies (with most participating in one or two previous studies).

5.3 Procedure

This study was conducted under user sessions, each one with approximately 90 minutes done individually with each participant. Each study would start with an introduction, a study trial, where the participant would test the prototype developed and a final semi-structured interview.

5.3.1 Introduction

We started the user sessions with an overview of the project, explaining to the participant the main idea for an aim-and-shoot system, using a crossbow through multiple ways of doing so (three techniques). After giving this overview, we would make a demographic questionnaire. For the demographic questionnaire, we focused on the questions that other similar projects usually have, generic questions searching for information such as age, gender, and educational level. More focused on this study, we also asked if there were any mobility or physical conditions, as this study was thought to be tested, with the participants standing up, even though the prototype can be used while sitting down. The decision to make participants stand up while testing the prototype, was simply to avoid the body movement constraints we face when we sit down. To use this prototype, participants would be asked to remain in the same spot, but occasionally, rotating the body was something that some participants would prefer to do, instead of rotating the head from side to side. Rotating the body while sitting down, is more challenging, so for that reason, standing up was the stance thought for this study, to encourage the participants to choose what they felt most comfortable with. We also ended up having questions about registering the level of blindness from the participants, as well as how long they had that condition. By the end, we made sure we asked if the person was right-handed or left-handed, as the prototype handles both preferences.

5.3.2 Prototype Testing

After the demographic questionnaire, and before asking for the participant's consent, in order to inform the participant, an overview of the project as well as an overview of how the session would proceed was presented.

For the session's prototype testing part, we decided to show each participant all three techniques developed in sequence in a counterbalanced order to avoid carryover effects. For each technique, we structured three different phases, starting with a Learning Phase.

Learning Phase

Firstly to expose the participant to a new technique, we present the Learning Phase. This is our get-to-know phase and is the part where we would present the controls for the current technique, and explain how this one would work so that the participant would know how to successfully aim and shoot at the target. In this phase, the participant is already using the head-mounted display, as well as both controllers and the headset so it would be already trying the controls for the system as they were explained. The Learning Phase is approximately 5 minutes (for each technique) and

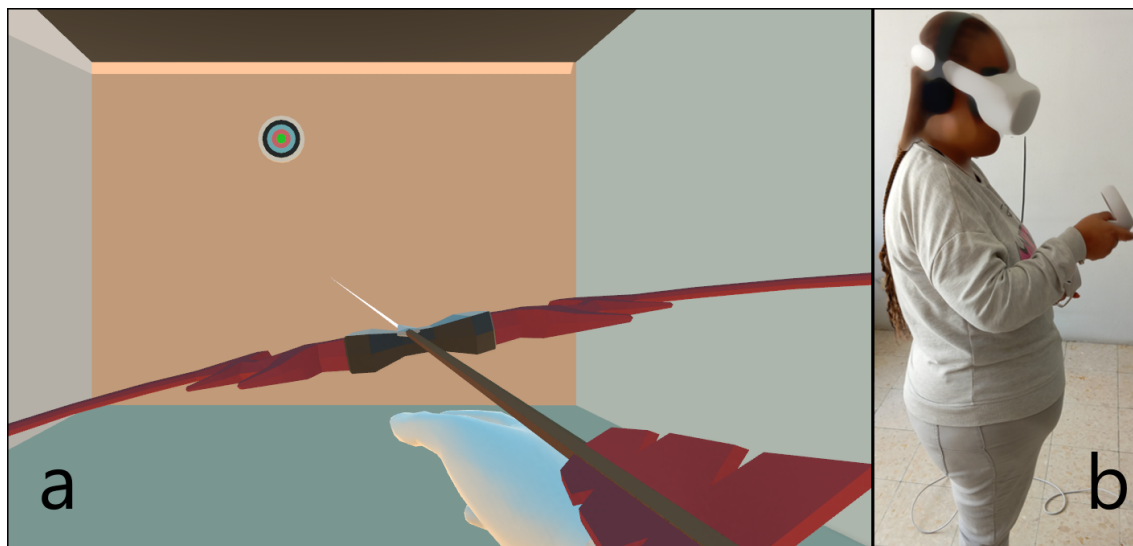


Figure 5.1: a) The virtual environment developed for the aiming and shooting experience, with a target far away, inserted in a big room. b) Participant aiming at the target.

ends as we understand the participant understood the explained technique. In some cases, our team would help the participant aim at the target correctly for explaining purposes.

Stationary Target

Following the Learning Phase, after explaining how the current technique works, the participant would enter the Stationary Target Phase. In this phase, our team would no longer be able to interfere or answer any participant's questions about the location of the target. The Stationary Target phase is designed to be the phase where the results gathered are the ones that matter for later performance analysis, so the participant must understand how the current technique works, and then proceed to aim and shoot the target independently.

In this phase, the target remains stationary, only changing its position on the wall on two occasions. The first one is if the participant successfully hits the target, then, since the target is discovered by the participant, the system changes its location. The second condition a target changes location is if the participant tries and misses 5 times the target. If a target in a certain position is not discovered within five attempts, the system changes its location as well.

This phase ends with one of the two conditions met. Either after the participant does fifteen shots in total, or after a five-minute timer, started at the beginning of the phase comes to an end.

Moving Target

After the Stationary Target Phase, we present the second phase, Moving Target. In common with the previous phase, in this one, the data collected is also considered for the next Analysis chapter, but there is one different aspect to take into consideration. In this phase, the target is not stationary. To add some complexity to the study, and to stretch the limit-testing for the prototype developed, we present a different phase with the same logistics as the previous one, but this time with a moving

target. Note that this movement is not described to the participant, and it is a horizontal side-to-side type of movement. We decided to not tell the participants the moving pattern to understand the system's capabilities and its respective potential. Also, not every participant experiences this Moving Target in every technique. Since we make the participants always do the stationary target first, and adding movement to it would reflect in a bigger challenge, we decided to advance to this moving target phase only if the participant managed to hit twice, the target in the previous one. We considered two successful shots as a green flag to advance to the Moving Target phase (instead of simply one successful shot) to increase the chances of only making it into this phase, participants who understood and were able to perform with the current technique and did not simply have a lucky single shot.

5.3.3 Semi-Structured Interview

After showing the prototype to the participant as well as after all the techniques were tried, we would move on to the final part of the session, a semi-structured interview. In this part, our goal was to understand the participant's experience with the developed prototype. We asked participants to rank out of preference all three techniques, adding a justification for each ranking spot they considered. Pros and cons were also asked about, as well as a question about the target still and the target moving difficulty. Out of the three techniques, we also interrogated each participant on the technique they thought was the most fun, and the most accessible (separately). All the other ideas and respective comments were registered by our team.

Chapter 6

Results

Our results for this study are supported by two main sources, the data collected by the prototype itself, which registers the participant's shots in a log system, resulting in a performance analysis. We also have a Subjective Feedback section, the result of all the information collected in the semi-structured interview part.

6.1 Performance Analysis

For the performance analysis, we section it into two parts, the first one related to the shots made toward stationary targets and the ones made toward moving targets. That separation felt natural to make, due to some aspects that are gonna be mentioned within those subsections. It is also to mention that we separate the performance measurements in two, the number of targets hit and the number of points made. The targets are far away from the user so hitting them is already a challenge. Nevertheless, we wanted to distinguish the participants who made, for example, 4 points with one successful shot, or 4 points by 4 successful shots (1 point per shot).

6.1.1 Stationary Targets

Of the 15 participants, two did not complete the trials with Spatialized Audio – P1 due to a technical problem, and P4 due to frustration in the learning period.

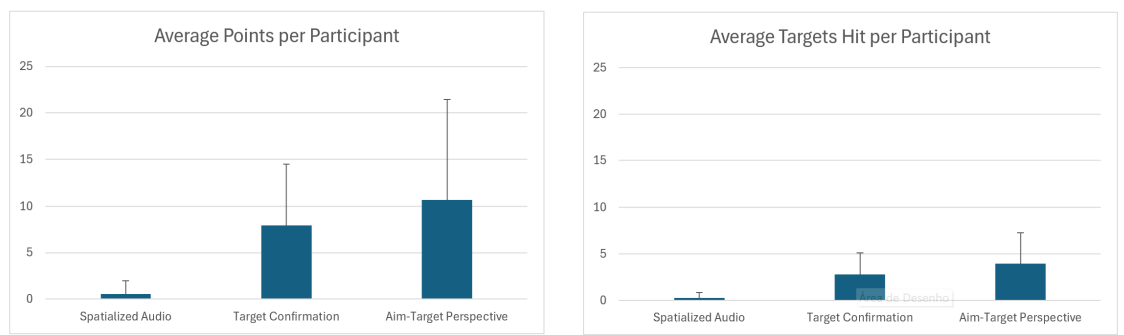


Figure 6.1: The average points and targets successfully hit per participant in each aiming technique with the stationary target

Comparing the number of targets hit, and looking at the results, there is a significant difference between the three techniques, especially with the Spatialized Audio technique ($M=0.23$; $SD=0.60$) and the other two, Target Confirmation ($M=2.80$; $SD=2.31$) and Aim-Target Perspective ($M=3.93$; $SD=3.33$), registering closer results (figure 6.1). These results also show that only one participant (P10) out of the 15 participants, managed to successfully advance to the Second Phase of the Spatialized Audio technique, with two successful shots done (2 points and 3 points respectively). It is to be noted that P10 was also the participant with the better performance across all techniques in both targets hit and points made with the stationary targets, having 22 successful shots (out of 41 shots in total) making a total of 70 points.

To understand which technique had the best performance results, we then excluded the Spatialized Audio due to this big negative performance discrepancy and focused more on the Target Confirmation as well as the Aim-Target Perspective. Comparing the two, within a similar amount of shots done (177 and 180 respectively), the Aim-Target Perspective was the one that managed to get a better performance out of the participants, with more successful shots done per participant ($M=3.93$) as well as more points made ($M=10.67$), while the Target Confirmation registered a lower number of successes ($M=2.8$) as well as points made ($M=7.93$), as shown in figure 6.1.

Aligned with these results, participants, having the worst performance within the Spatialized Audio, lead to shots that hit further from the target ($M=4.42m$) compared to the other two techniques, where Aim-Target Perspective ($M=2.40m$) and Target Confirmation ($M=2.00m$) had closer results. Having a more in-depth look at these results, and analyzing the offset of the shots, in the Spatialized Audio, the horizontal offset was bigger ($M=3.57m$) than the vertical one ($M=1.45m$). Examining the offset for the other two techniques we have Aim-Target Perspective ($h=0.77m$; $v=0.71m$) and Target Confirmation ($h=0.61$; $v=0.92$).

Another measurement registered within the user session was the time the participants would take to aim and shoot within all the techniques and both Aim-Target Perspective ($M=20.46s$; $SD=16.68$) and Target Confirmation ($M=21.75s$; $SD=23.07$) registered a similar amount of time. It was also registered that participants took less time to aim and shoot using the Spatialized Audio technique ($M=14.62s$; $SD=11.84$).

6.1.2 Moving Targets

As it was mentioned before, in the Spatialized Audio technique only one participant successfully made it to the moving target phase. Something that happened differently with the other two techniques as both Target Confirmation and Aim-Target Perspective, had 13 participants advancing to a second phase, with only 2 participants in each technique, being unable to do so. Analyzing more in-depth the data collected from the two most successful techniques, due to the lack of an obvious surface-level difference between them, we conclude that the results are even less discrepant this time with moving targets. Regarding the number of targets hit, Target Confirmation ($M=1.15$; $SD=1.21$) manages to get a slightly better performance than the Aim-Target Perspective ($M=0.77$; $SD=0.93$), inverting what happened within the stationary targets, where the Aim-Target Perspec-

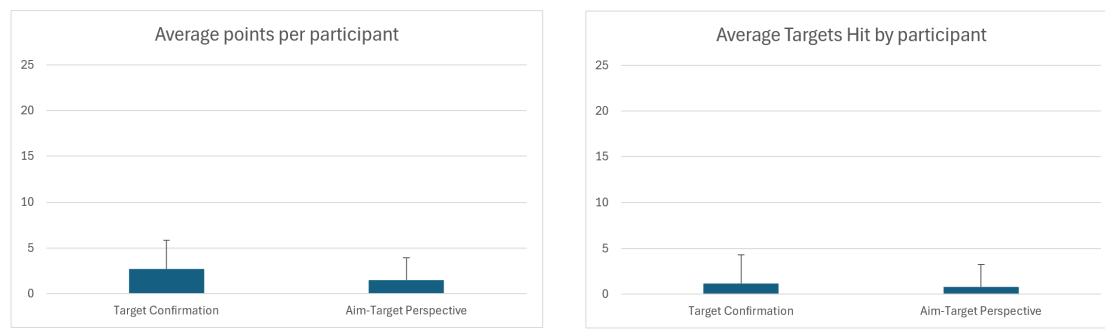


Figure 6.2: The average points and targets successfully hit per participant in each aiming technique with the moving target

tive had a better performance (figure 6.2). As for the number of points, the Target Confirmation ($M=2.69$; $SD=3.17$) also manages to outperform the Aim-Target Perspective ($M=1.46$; $SD=2.47$) even though, again, not significantly (figure 6.2).

Looking at the distance from the target to the shot positions on each technique we also register Aim-Target Perspective ($M=2.53m$) with a fairly smaller disadvantage compared to the Target Confirmation ($M=2.45m$). The comparison to the Spatialized Audio technique is not even considered due to having only one participant making it into this phase with that technique.

Since the target movement was only horizontal it was expectable for the horizontal offset to remain bigger than the vertical offset. This prediction was indeed by the results as both Target Confirmation (horizontal: $M=1.44$; vertical: $M=0.78$) and Aim-Target Perspective (horizontal: $M=1.51$; vertical: $M=1.25$) confirmed it. As for the time the participants took to aim and shoot, it was again similar between Target Confirmation ($M=22.61s$; $SD=23.75$) and Aim-Target Perspective ($M=20.29s$; $SD=20.60$). It is to note that this data goes actually against what we predicted because with moving targets we thought that the time to shoot would increase more abruptly comparing the Stationary Target phase with the Moving Target phase, however, this measurement stayed fairly closer in both phases.

6.2 Subjective Feedback

For the Subjective Feedback section, we look at the answers to our user questionnaires, as well as comments participants made during the user sessions. We present general overviews and also specific comments done by the participants, in order to advance to some conclusions.

6.2.1 Single Ease Questionnaire

A single ease question was made after the completion of each task, where the participants rated it from 1 to 7, the difficulty level of each specific task, with 1 being considered to be very hard and 7 very easy. There was a noticeable difference between all three techniques as within the first phase

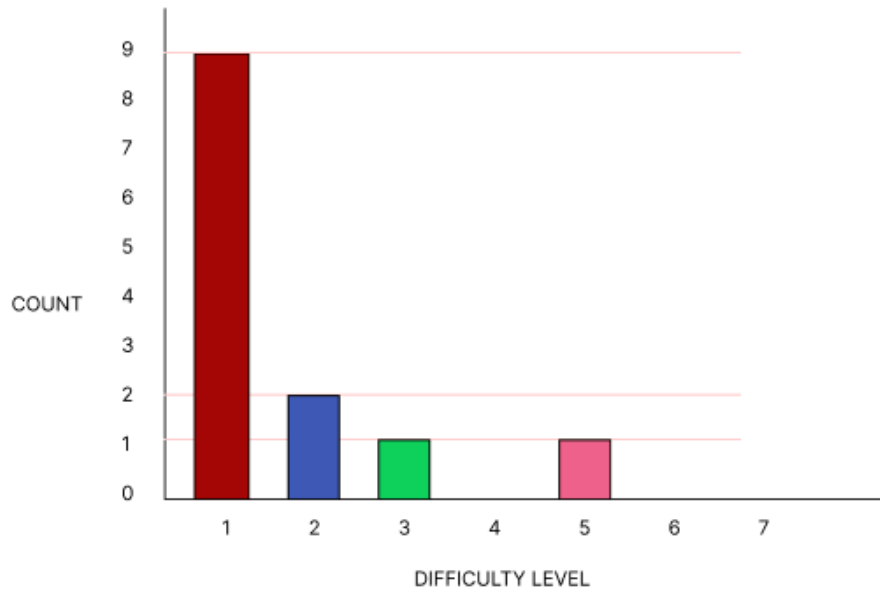


Figure 6.3: Spatialized Audio technique with stationary target: Single ease questionnaire results

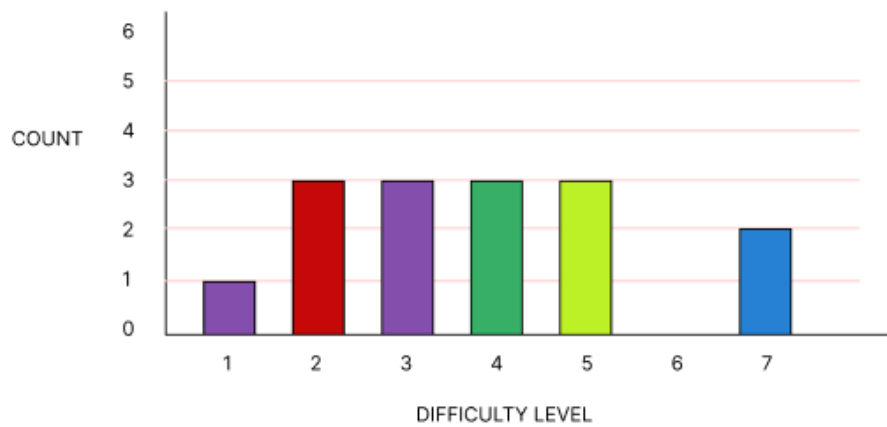


Figure 6.4: Target Confirmation technique with stationary target: Single ease questionnaire results

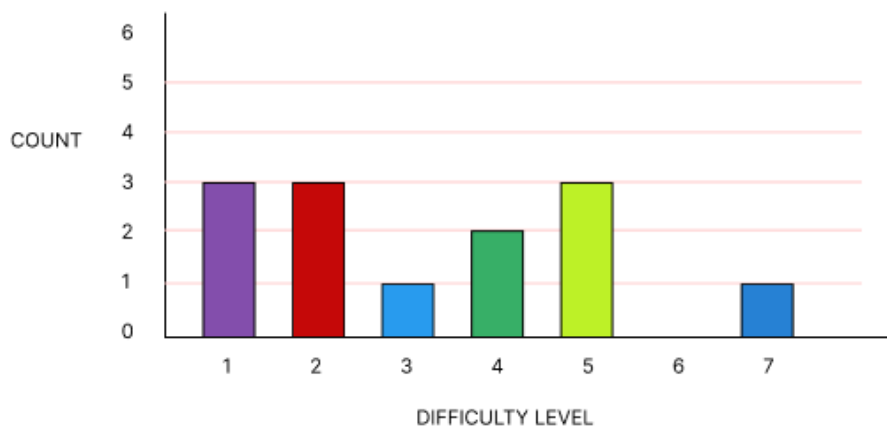


Figure 6.5: Target Confirmation technique with moving target: Single ease questionnaire results

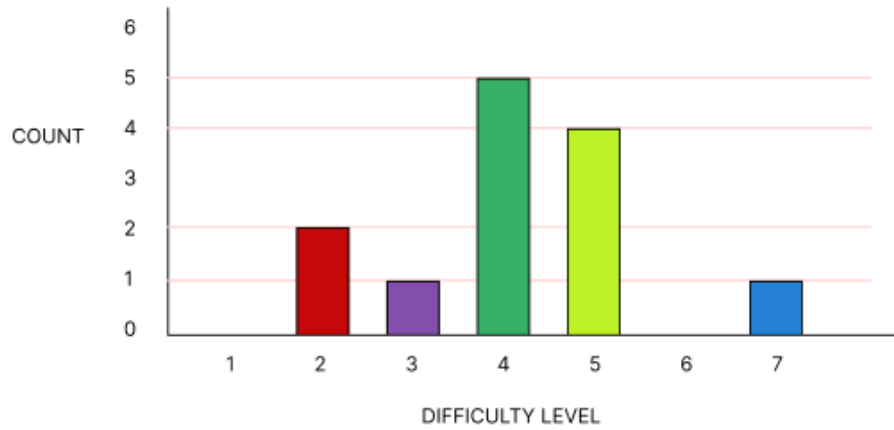


Figure 6.6: Aim-target perspective technique with stationary target: Single ease questionnaire results

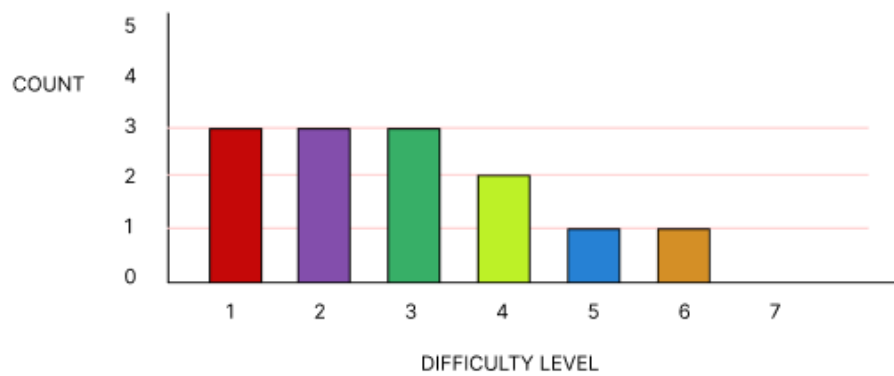


Figure 6.7: Aim-target perspective technique with moving target: Single ease questionnaire results

with the Stationary Targets, the Spatialized Audio Technique ($M=1.64$) (figure 6.3) was considered to be way harder than the other two techniques Target Confirmation ($M=4.33$) (figure 6.4) and the Aim-Target Perspective ($M=3.8$) (figure 6.6). Despite a small difference, Target Confirmation was considered to be the easiest technique within the Stationary Target Phase. On the moving target phase ratings it was registered for these two last techniques to be even closer in the difficulty rating, but with the Target Confirmation ($M=3.23$) (figure 6.5) to be considered a little easier than the Aim-Target Confirmation technique ($M=2.85$) (figure 6.7).

6.2.2 Final Interview

At the end of the session, as it was mentioned before, the participants were submitted to a semi-structured interview about their experience in the user session. There were some objectives for this interview, one of them being understanding for each participant the order of preference of the techniques experienced. Eight participants preferred the Aim-Target Perspective technique, followed by the Target Confirmation technique (preferred by seven). Due to its difficulty, and consequentially worst performance, the Spatialized Audio technique was never selected as the more preferred. For nine participants the technique where they scored the highest amount of points, was the one they preferred.

Spatialized Audio Technique

Regardless of the Spatialized Audio Technique, participants complemented the performances registered, mentioning the technique as "too difficult". P4, the participant who ended up not wanting to do this technique's Stationary Target phase, said during the tutorial phase that she "did not understand the technique", being that the reason for not wanting to advance with it. Participant P5 even stated:

"I think no one would use this technique." - P5, highlighting the poor appealing of it

On top of being by far the worst technique in terms of performance, and the one that participants found the most difficult, it was also a technique where only one participant (P11) found a good aspect. When asked about the pros and cons of the technique, P11 stated:

"It is a good technique for training." - P11, underlining the high difficulty of this technique, and the idea that, if someone is able to perform within it, it can perform in easier techniques.

Besides this good aspect found by this participant, we registered another participant (P3) who mentioned another good aspect of this technique, however, we do not count this as an "original" good aspect found, simply because it was a participant who preferred the Aim-Target Perspective technique to begin with, partially because she disliked the "beep" aid from Target Confirmation.

When asked about the pros and cons of this baseline technique, she mentioned that a "pro" would be the fact that this technique does not have the "beep" aid that disturbs the experience. Being mentioned as a "pro" we do not count it as a good aspect of the technique, because it does not compliment an existing characteristic, instead, just contemplates the non-existence of another aspect from another technique.

Overall, it is a technique where the words from P3, highlight the experience accurately, stating:

"I felt lost (...) without any help." - P3

Target Confirmation

As mentioned before, participants' preferences were split between the Aim-Target Perspective and the Target Confirmation techniques. So for the participants who preferred the Target Confirmation Technique, the additional audio feedback presented by the technique ended up being enjoyed:

"It is not monotonous, because there were also beeps, and the more elements appear the better, (...) the game becomes more interesting." - P15

In addition to the "beep" feedback, participants also mentioned the enjoyment of the actual confirmation aspect of this sound. One participant even compared the beep sound, with a familiar and previously real-life experience:

"P12: I used to be a fisherman, and hunt with a slingshot. The fish would go side to side while I was aiming at it.

Research Team: So you felt that the beep aid was like a crosshair?

P12: Yes." - P12, while asked about the advantages of the Target Confirmation technique

On the negative comments made towards this technique, we have participants that compared it to the Spatialized Audio one, since these two techniques are the same, being Target Confirmation only with one more crucial audio cue, the "beeps". Participant P11 mentioned that before aiming close to the target when we start to hear these "beeps", it is as difficult to execute this technique as it is to execute the Spatialized Audio technique. In alignment with this comment, P13 also mentions:

"I think I should hear the beeps all the time and not just when I am aiming close to the target." - P13

Regardless of this "beep" audio cue, there are more negative comments made. P9 mentioned being uncertain during the session, regardless of the right frequency of these "beeps" that corresponded that he was aiming successfully at the target. P10 also pointed out that this cue could cause some confusion among some people. In a more negative tone, P3 even mentioned this audio cue to disturb the experience.

Another note point we found important was made by the But overall, besides having negative comments made about it, the participants showed a visible and predictable higher enjoyment from this technique compared to the (in some way) similar technique of Spatialized Audio. Participants who directly transitioned from Spatialized Audio to the Target Confirmation even mentioned comments such as "There we go, with this, is easier", related to the addition of the beep audio aid heard. In fact, as it was mentioned before, this was the technique preferred by nearly half the participants. Some participants showed happiness towards the fact of being able to finally "hit the target".

Aim-Target Perspective

Participants who preferred the Aim-Target Perspective mentioned two main ideas. The technique was the right balance between challenging and fun, without being too easy, and the other point was that the technique was "making the target search more intuitive." (P10). P9 stated:

"This bi-directionality of the sound, for me at least, made it a little easier to understand the position of the target." - P9

On the engaging and fun aspect of this technique, there was even a participant (P5) who commented about the arrow hit sound, heard when the shot hits close enough from the target.

"The sound of the weapon here [in the Aim-Target Perspective] is more beautiful (...) this technique is cooler" - P5

Another point to register was that some participants enjoyed some simplicity attached to this technique being a good aspect, as P15 stated that he enjoyed the fact that he only needed one joystick to aim and shoot within it. P10 even highlighted the fact this technique only has one characteristic to pay attention to, which is following the sound, which is a positive aspect too. Still, regarding the Aim-Target Perspective, one participant (P2) also made what we considered to be an interesting comment about the irrelevancy of the head movement within this technique.

"From what I see, there are a lot of people, especially those who haven't seen since they were little, [that] do not focus on where the sound is coming from. In other words, you are talking to me and I am trying to look at you... there are many blind people who do not do this (...) And this [the Aim-Target Technique] is an advantage for those people." - P2

Facing this comment we took a look into the participants once more, and from the 15 participants, we registered 3 participants to be early-blind. We considered early-blind, participants that were blind since they were born or since very early ages (before 4 years old). In this case, all of the three early-blind participants indeed preferred the Aim-Target Perspective technique over the others.

Some critics made towards this technique, include P11 that considered the sound of it to "change too quickly" from one ear to the other. Sonic Arrow requires high precision, so this comment is

inserted within it, as small hand gestures can result in aiming from the left side of the target to the right side.

We also registered a disadvantage pointed out by P7 that considers the sound to be confusing at times. However, this aspect was not specifically pointed out by any other participant.

Overall, it was a technique that faces the Target Confirmation, as the potentially "better technique", where participants pointed out the "being able to find the target", the straightforwardness, and the simplicity of it.

6.2.3 Health Conditions Interfering

Of the 15 participants, two (P2 and P14) commented on having other health conditions that ended up affecting the experience. P2 mentioned having worse hearing from the left ear compared to the right one. This got in the way of the experience because Sonic Arrow depends directly on the audio-to-hearing relation. The participant mentioned that on the parts that involved centralizing the sound heard, in a specific head orientation, or the case of the Aim-Target Perspective to aim to a spot where this sound needed to be central (heard equally from both ears), the participant would simply try to predict where this central point was, based on the hearing loss he had.

P14 on the other way, mentioned having a health issue that made her not able to turn around the head too fast, otherwise, she could easily feel dizzy. This was a condition that also affected the experience, since in both Spatialized Audio and Target Confirmation are both techniques that require the user to move the head side-to-side to understand from which direction this sound comes. In the case of this participant, she did the entire session however with extra carefulness when it came to this turn of the head mechanic.

6.2.4 Hand Steadiness

It is to be noted that hand stability was also a factor that affected the participant's experience. This prototype, as already mentioned, required some precision, as the considerably long distance the user is from the target and its corresponding diameter, make this experience quite challenging, so to shoot the weapon, a steady hand is required. What was registered by the team, is that some participants either struggled to keep a steady hand on the aiming process or in the actual shooting mechanism, as some would press the trigger button too hard, making a slight tilting hand movement. P9 was a participant registered to not keep a steady hand movement, that on the final questionnaire mentioned: "to be honest, I did not found any techniques enjoyable" (P9).

On the other side, multiple participants were checked on moving the hand on the button press to trigger the weapon to shoot. This was not a measurement collected through the system in user sessions, but by our research team, by observations. It happened to some participants, aiming correctly at the target, after pressing the button, the hand movement derived from it, would move the weapon out of the target aim, leading to some confusion among the participants, thinking they were aiming correctly. This was something that in the tutorial phases for each technique,

Chapter 7

Discussion

In this section we will take a look once more at the results collected from the user sessions made, summarizing and interpreting the main points.

7.1 Target Confirmation and Aim-Target Perspective techniques outperformed Spatialized Audio

One of the main points that we can make out of the analysis of the results obtained, was the clear out-performance that both the Target Confirmation and Aim-Target Perspective technique had over the Spatialized Audio. This reality was not unexpected as for the development of the Spatialized Audio technique, we wanted it to be the baseline for the study, the most simple one. This technique's objective, was essentially to compare the aiming experience of a blind person in all shooting non-accessible mechanisms that there already are, where the person hears where the enemy (for example) comes from and nothing more, needing to be able to see it to shoot it. Given the non-particular focus on helping aids, as well as its simplicity, this technique was easily identified as the most difficult one, even before the user sessions, by the development team in bug testing. The results highlighted this fact.

7.1.1 Target Confirmation VS Aim-Target Perspective

Our main question was, before going into user sessions, which technique would be considered better between the Target Confirmation and the Aim-Target Perspective? After the user sessions, the answer became a little more difficult to give than expected. They both had similar performances overall as it was seen. Even paying attention to the details it was not as straightforward as we thought it would be. In stationary targets, the Aim-Target Perspective performed a little bit better than the Target Confirmation. In moving targets, it was reversed, as the Target Confirmation had a better score. The explanation for these results seems to reside in the fact that, on stationary targets, participants tried to aim at the target, at their own pace. With the non-moving target, it seemed that participants found it easier to center the sound in this Aim-Target Perspective technique. When the target was moving, the participants found themselves, aiming at the target and shooting at a pace defined by the system, as they needed to aim and shoot before the target would "run away".

It was also registered that none of the participants understood the target side-to-side movement. To every participant that hit multiple targets in the second phase, it was something that we asked and no participant correctly said the moving pattern. So on the moving target phase, it seemingly came down to a fast reaction phase, as participants would press shoot immediately after hearing some sort of confirmation on being aiming at the target correctly. Since the Target Confirmation technique represented exactly that, as soon as the beep aid was faster, the participants would shoot. Compared to the Aim-Target Perspective participants would hesitate a little bit more, as even if they were aiming, hearing the sound centered, they would not have the full confirmation of being aiming correctly. This led to a slightly better performance in Target Confirmation in this second phase.

7.2 The Increased Complexity of Moving Targets

Adding to the results highlighted in the previous section, it is worth mentioning the unanimous participant's opinions, about the expected and increased difficulty from the moving target tasks, compared to stationary target ones. What was less expected was having two different techniques, one being better within stationary targets (Aim-Target Perspective) and the other one being better within moving targets (Target Confirmation). It indicates that the Aim-Target might take a little bit more to successfully execute by the user, while the Target Confirmation takes advantage of the confirmation feedback giving more confidence on whether the user is aiming towards the target correctly or not.

7.3 The Extra Aid of Pitch in Verticality

As it was mentioned before, Virtual Reality development for blind people faces a challenge in passing the verticality level of something using only sound. For instance, if a certain source is emitting a sound in a VR system with spatialized audio, a sighted user would have a clue in which direction this source is located. But to know how high or low this source is from the ground (and even the exact direction of the source), the vision plays an important part in giving this information right away. If we consider a blind user, the same clue of the direction a certain sound source is located, can also be passed purely by spatialized audio, as if the user is pointing the head to a direction where the sound comes centralized (same intensity level in each ear), the user knows the source is roughly located within the direction the head is pointing at. But once the sound is centralized, the challenge comes as recognizing the height from the ground of this source, remains fairly vague.

For the Sonic Arrow system, we ended up developing the pitch change as an aid for verticality level, implemented in Spatialized Audio and Target Confirmation as mentioned before. The objective was to develop a mechanism that would still maintain the user's control over the aiming experience, while still helping to understand if the crossbow was being aimed too high or too low compared to where the target was.

The results are considered to be positive. If we take a look into the data collected from the Spatialized Audio Technique (not only the most difficult technique but the one with a very high contrast of results compared to the other two) we can take a look into the offsets (both vertical and horizontal). Horizontal offset had, $M = 3.65$ meters, and Vertical offset managed to register $M = 1.49$ meters. As data indicate, the vertical offset was even less than half of the horizontal offset, which in this technique, horizontal direction was checked to be the greatest challenge, ultimately contributing more to the poor performance registered for this technique. Our approach seems to lower the difficulty blind people have in Virtual Reality to identify high and lower targets/sources, which we consider a positive aspect.

7.4 User Preferences are Highly User-Dependent

As was shown not only within the shot results obtained from each technique but also within the questionnaire answers given, user preferences ended up being highly dependent on the user's attributes and characteristics. For instance, seven and eight participants preferred Target Confirmation and Aim-Target Perspective, respectively. These preferences were highly linked with performance, likely due to the established link between competence and engagement in games [58].

There was also a preference checked from all early blind users to prefer the Aim-Target Perspective as all three early blind participants that were in this study indeed preferred this technique. This goes along with a statement made by one participant that early blind people, are not used to pointing their heads to a certain sound source. So by that statement, the participant pointed out that people who either were born blind or became blind very early on in life were most likely to prefer the Aim-Target Perspective technique over the other two since this is the only technique where the head position does not contribute to an advantage neither contributed to the experience at all.

Another aspect that seemed to influence participants' preference was familiarity. One participant compared the experience had in the Target Confirmation with his previous experience on using a real-life Sling Shot, saying it reminded him of the times he used to use one. This seemed to weigh when choosing the preferred technique, as the Target Confirmation ended up being the choice.

At the end of the day, different people will have different opinions, testing the exact same prototype. So for future work, the study with customizable features seems like the way to go, adapting to not only user preferences based on their life experience but even other life conditions such as hearing better from one ear compared to the other (stated by one participant).

7.5 Finding the Right Amount of Feedback

Within Sonic Arrow, our goal was also, to try to help the users achieve their main goal, of aiming and shooting successfully a target, by providing the techniques and the feedback enough for it to be possible. At the same time, we wanted the users to maintain control over the experience, and

avoid to over-help them. This felt like it was achieved, however mixed opinions were received from all the feedback sources, Sonic Arrow had. To some participants, the beep aid within the Target Confirmation was overwhelming in terms of distinguishing if the "beep" sound already meant the weapon was aiming at the target or not. On the other side of the spectrum, there were participants who expressed wanting the beep aid instead of being triggered only when the weapon was aimed close to the target, they wanted the beep aid to always be triggered.

Another aspect to mention was the duality of some comments received, on where P10 expressed his fears for a potential feedback overload, leading to confusion on the Target Confirmation where we have the beep aid, and (if it is triggered) the vertical pitch aid at the same time. However, it was registered the P15 comment: "The more elements appear the better", contributing to a more interesting experience.

It is obvious to us that finding the right amount of feedback ends up being a difficult task due to being very subjective, as it depends on the people's unique personality traits and skills. Yet, we express the importance of always keeping the control aspect always within the user.

Chapter 8

Conclusion

In this master thesis project, we implemented and evaluated three different VR aiming techniques for blind people. The study was conducted with 15 blind participants and reinforces the emphasis on the poor performance and lack of accessibility most current aiming VR mechanisms have represented in this study by the developed Spatialized Audio Technique. However, two other techniques, focused on accessibility features, are presented, Target Confirmation and Aim-Target Perspective as well as compared. The findings register a clear and expected out-performance by these two compared to the Spatialized Audio technique however finding the "better technique" out of the three was not as straightforward. The aim-Target Perspective technique had a better performance within stationary targets but Target Confirmation had a better performance when these targets were moving.

Besides the analysis of the data collected from a series of user sessions, we also break down the feedback received from the participants. We believe that the findings of this study, contribute to knowledge as well as help to improve aiming mechanisms for blind people within VR systems.

So to answer the initial question "If it is possible and how good it is possible, for someone to aim and shoot a weapon at a target that cannot be seen"? the data indicates that the answer is that it is possible, with what we consider, good results. However, the better solution for this question is the one that is left yet to be discovered, as results indicate this to be a more complex domain than initially thought.

8.1 Work Done and respective thoughts

The project was concluded successfully as we think the purposes for it were fulfilled. Our main point was to discover if it was possible and how good it would be to build an aim-and-shoot experience accessible for blind people, focused on audio forms of feedback within VR. The prototype was built and successfully tested, with everyone hitting the target successfully in multiple shots. If we do not count the Spatialized Audio technique, since this was the baseline for the study, we presented what we considered two valid solutions for the problem presented. Of course, after user sessions, some other questions occurred, but mainly regardless of what if we changed some parameters, or even combined some aspects that we already have but in different techniques. These

were all questions that felt normal, after finishing a research project, and these are the questions that we find important to highlight in Future Work Section.

8.2 Future Work

For the future work section, we will just highlight, future changes to the prototype, or even the user sessions, that like it was mentioned, were not explored within this study that could led to more advancements.

8.2.1 Changing the Sounds

All the aspects from Sonic Arrow were carefully tested as well as thought through before user sessions. This happened in the prototype testing phase that took place in the team meetings, where the sounds used, were changed to the sounds we thought were more pleasant and clear for the task attributed to the users. But like every prototype, that did not stop some of those aspects from being disliked by some of the participants. One of the aspects we registered some negative comments about was the sound used for the target noise. "Intrusive" and "bothersome", were some of the words used to describe this sound. For future work, changing the sound used on the target search for a more pleasant sound would be the path to go.

Another sound, that seemed to confuse some people during testing, was the AC background noise used, to avoid the "dead-silent" environment. Some participants during the sessions, even mentioned they were hearing the target noise without triggering this sound. Asked about the direction of this sound, we would come to the conclusion that these two sounds were being confused. For future studies, maybe either substituting the AC sound use or at least making it less present, seems like the solution for this.

8.2.2 Parameter Changes

For the more straightforward and "simple" changes that this study could take, we have the distance between the target and the user, which in this study remained approximately 20 meters, the diameter of the target (that in this study had 1 meter), or even the speed of the moving targets. These are all parameters that in future studies, can be changed, in order to obtain information that can answer other questions. Putting a bigger target, to make sure more shots are successful, to maintain lower levels of discouragement by the participants, or even putting the target further from the user, to make a more difficult task, testing even more the capabilities of this prototype. Perhaps making each shot scenario vary on these parameters, instead of putting them equal within shots, in order to replicate more realistic and unpredictable scenarios that users can find in mainstream video game titles for example. Changing the target movement, so instead of a horizontal side-to-side, we have a more complex movement. These are all possible changes, that can lead to different studies, and what we consider to potentially have interesting results.

8.2.3 Adding Different Features

Besides the parameter changes mentioned, we also have other changes and additions, that could enrich the studies using this prototype. Some participants mentioned the usage of haptic feedback, actually incorporated in the search for the target task. For example in the Target Confirmation technique, having one controller vibrate as much as the closer as the user is aiming at the target to complement the beep sound. Another feature that could be more explored, also mentioned by some participants was regardless of the pitch verticality aid. Some participants expressed an interest in a sound, that besides indicating the vertical level that the user should aim at, it would also be a sound that could indicate the horizontal level as well. The development of this feature would require a complex enough sound and the change of two parameters for example the pitch which is done already in Sonic Arrow, and the frequency of the sound to indicate the horizontal direction to aim. Besides being a feature that would require some more thinking, a different sound selected, and more iterations to achieve, it is a feature we see as interesting as well.

8.2.4 Learning Curve Analysis

For future sessions, making bigger sessions, as well as analyzing how much the experience within the prototype affects the user's performance, sounds very promising. The majority of the participants mentioned that with more experience, they felt they could achieve better results. Seeing the performance data over bigger user sessions might be not only revealing but could help with an interesting learning curve analysis.

8.2.5 Making a personalized experience

Like it was mentioned before, user preference and corresponding performance, had somewhat to do with personal attributes. For future work, regardless of this topic, granting the users, the ability to personalize their experience with some parameter changes for example, could be a successful idea. Even if a future study is taken with very specific parameters (like this study), having a previous training scenario where users can make the task easier to execute for themselves by changing some parameters, and progressively making it more difficult, can reveal itself to be a positive path.

Changing parameters can mean, making changing the target's size as well as how distant it is from the user. It can also mean changing the speed of the moving targets. Less obvious, and based on the participant's feedback received, we had one comment about the Target Confirmation technique, and how the "beep" aid, is only triggered when the user is aiming close enough from the target. It was mentioned by a participant that this beep aid would be better if it was always triggered no matter how far the user aiming. Perhaps changing this range from where the beep is

triggered might be needed for some people, especially if we have participants with less experience with this prototype.

8.2.6 Make it Less Monotone, or Adjust to It

One participant (P10) expressed the feeling of being "too static". He proceeded then to mention that more body movement could actually help not only to make a less monotone experience but even to make a less tiresome experience, comparing it with sometimes, it is less tiresome to walk, rather than to stay in the same spot for a long period of time. We find this comment a little bit hard to make prototype changes on, simply because we purely focused on fairly simple aiming and shooting mechanisms. In a more complex scenario, for example, a video game, other mechanisms can be combined to help within this aspect, such as a walking mechanism that would make the user move the arms more. Within our project's scope, we register this comment as an important note, however, we can not come up with a good solution for similar studies like this, besides adding other secondary mechanics like walking. On a similar side, another participant (P12) asked us if the prototype was "playable while sitting down", thinking about hypothetically using it at his home for long periods of time underlying that he would feel physically tired after some time of using it standing up. For future studies taking this into consideration and either developing a prototype that would check to be less tiresome or ultimately letting the user have the option to sit down, sounds like the path to take.

8.2.7 Prototype for Outside the Scope Purposes

Speaking a little bit outside the scope of what we actually explore and consider within this study, this prototype can also take place within software and hardware testing. Since Sonic Arrow deals with high precision, using for example two different audio plug-ins and comparing results from participants who tested both, can maybe help to understand which audio plug-in verifies to have the better quality, being the plug-in that leads to better performances. This scenario also applies if we test Sonic Arrow with perhaps two different headset models, wanting to know which one proportioned the best user experience.

8.3 Overall Experience

We consider this experience to turn out very positive. Not only did the data collected let us extract a lot of information, that contributed to what we consider valuable lessons considering the scope of the project, but also from the feedback and reactions received were positive too. Overall participants seemed to enjoy and remained enthusiastic during the sessions. A lot of participants also mentioned the importance of the creation of accessibility projects for blind and visually impaired people. We live in a world, where not being sighted, is living a challenging life on a daily basis. From our own homes to going outside, with all the other people, and all the other sorts of vehicles. It is here where technology comes to help decrease these challenges and help people with these

conditions. However, as stated before, there is still a considerable path to take in order to make technology fully accessible to everyone.

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