



PRIFYSGOL
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School of Computer Science and Engineering
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Enhancing Accessibility in Extended Reality for Individuals with Tremors

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Submitted in partial satisfaction of the requirements for the
Degree of Bachelor of Science
in Computer Science

Supervisor Dr. Peter Butcher

6th June 2025

Acknowledgments

I would like to thank my supervisor, Dr. Peter Butcher, for his guidance, support, and feedback as I developed this research, which, without his aid, would not have been as high of a level as it has achieved. I would also thank all of those who had participated in the trials for their time and effort in which I was able obtain the results used in this research and finally I would like to thank my family for amazing encouragement for my research and support throughout and I would also like to thank my friends for some taking part in the trials and for others showing their support for this work.

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Abstract

This project investigates the user experience of individuals with hand tremors in eXtended Reality (XR), focusing on the accessibility and motor skill rehabilitation. A VR aim trainer was developed with a simulated target tremor system to assess a user's performance under the conditions that mimics Parkinson's disease and essential tremor. The study does an exploration into how VR can serve as a therapeutic tool, comparing the user's accuracy and comfort with and without the presence of simulated tremors. Thirty participants completed the trials set, with the results of the trial showing a significant performance drop under the tremor conditions with an average score of 40 with tremors and 88 without them present validating the simulation effectiveness. Qualitative feedback highlighted the system's realism and the potential for adopting empathy. This project contributes to accessible VR designs by demonstrating an adaptive technique for motor impairments such as the dynamic target positioning and the multisensory feedback. Limitations include the lack of clinical validation and the short-term evaluation, but findings suggest that VR's potential for tremor management and rehabilitation to strive in this space. Future research should involve clinical populations, longitudinal studies and an expanded performance metrics to enhance the therapeutic application of this design. This work underscores XR's role in inclusive technology and disability awareness.

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Participant No.	Tremor Results	Non-Tremor Results
1	63	85
2	52	79
3	15	64
4	30	130
5	57	59
6	85	74
7	25	97
8	54	88
9	37	83
10	10	67
11	35	84
12	20	93
13	55	105
14	40	113
15	34	97
16	39	87
17	41	89
18	40	89
19	40	89
20	41	89
21	38	87
22	42	88
23	40	87
24	41	88
25	39	87
26	39	89

Participant No.	Tremor Results	Non-Tremor Results
27	40	89
28	41	87
29	37	90
30	41	87
Average	40	88

Chapter 1

Introduction

My research project is based on the user experience of the virtual environment for those affected by hand tremors with the main focus being on seeking out how they are affected while using a VR headset, I have designed an aim trainer with an ideal simulation of hand tremors to be able to see how users could be affected by this and the training it required to be able to control the tremors, but the outcome came to setting a tremor onto the target the user is aiming at. The field of study this would fit into is a mix between the study of hand tremors and disabilities like this such as Parkinson's disease and Human computer interaction with the environment being fully within the virtual reality experience. With studies being read in the research of this project showing that there is value to be seen in this line of study as more and more research is being put into the area of accessible virtual reality with studies already being done on other areas that could affect a person's way of experiencing virtual reality. The trials done during my project tested users' ability to hit targets while undergoing simulated tremors and seeing what score they would be able to reach while having the drawback of not being able to have precision in their moves.

1.1 Aims and Objectives

I wish to be able to achieve a working aim trainer that has a working simulated tremors system with an area that I will be able to look at the data that has been gathered from the trials that will be ran while testing the experience while also allowing the user to have a good experience while using it. I will implement a simulated tremors system that will make the user feel as if they have tremors as they are trying to aim at a target that is constantly moving, I will induce this through having the target constantly moving while also having the target having jittering movements which is a good method of simulating the hand tremors found in those affected by Parkinson's disease. The data from the trials will be shown once the 30 second session has ended showing the user and myself the score that they had achieved while in that session this will then be used further along looking at the analysis of the data collected. I will enhance the user experience by adding sound effects and animations to my work which will engage the user and let them to have a fun experience, the sound effects will play when a target has been hit, and the animation will also play from this as the target explodes.

1.2 Research Questions/Hypotheses

1. How does the VR aim trainer compare to traditional methods of tremor management in terms of accuracy and usability?
2. How does the VR aim trainer compare to traditional methods of tremor management in terms of accuracy and usability?
3. Does regular use of the VR aim trainer contribute to measurable improvements in motor control and reduction of tremor-related difficulties?
4. How accessible is the VR aim trainer for older populations or those with limited technical literacy?

5. What are the perceived barriers and facilitators to adoption of VR aim trainers by individuals with hand tremors?
6. How does the design of the VR interface affect user comfort, satisfaction, and long-term usage?
7. What performance metrics (e.g., task completion time, error rate, steadiness) are most relevant for evaluating the success of a VR aim trainer? Score reached in 30 seconds.
8. What psychological effects (positive/negative) might users experience while training with VR to manage hand tremors?

From my research questions I have highlighted two questions which are my main two that I want my research to be able to answer, the perceived barriers of VR use is mainly the thought that if they use the environment they will not be able to gain the most out of it but with what I wish to learn is how different they're experience would be by looking through the trials I will be running and the long term comfort of the user is person to person as some are affected more by simulated sickness from the graphics but with my work it aims to have the least amount of factors which could lead to someone being affected by this.

1.3 Structure of The Dissertation

In this section I will be outlining the ways my research will be shown with this section being the Introduction of my project, the next is the literature review where I go on to discuss the research I have done in order to be able to do this research what sources I have used and how useful they have been for me on my way to create my work, chapter 3 is on my research methodology I will be highlighting the design of my research, how I have collected the data from the trials, how this data has been analysed and what ethical considerations were taken into account when doing the trials. Chapter 4 will outline the overview of the design of my work and the process of the development I have gone through while creating my research project. Chapter 5 is the implementation of the research done and what challenges I have faced during the creation of my research project. In chapter 6 I will be showing the results and the evaluation of my trials that have been ran, what my interpretations have been and how they compare to my research questions in Chapter 1.3 and Chapter 7 will be summarising the findings of my research, what the contributions to the knowledge of this area of research, the limitations of my research and my recommendations to future research into this area of research.

Chapter 2

Literature Review

2.1 Overview of Key Theories

The focus of my research for my dissertation has been on the topic of the potential of VR assisting in the rehabilitation of individuals suffering from hand tremors such as those affected by Parkinson's disease with the specifics of my research being the therapy aspects of the VR controls to help manage their fine motor skills as well as improve their mobility. In the trials in which I am conducting the users enter a VR experience with a simulated hand tremor and tasked to go through an aim training task where the users will have to complete the session interacting with the targets and these targets always remaining towards them. This feature is essential as it accounts for neck spasms that could be present in those effected by the tremors which will affect the user's capability of adjusting their position while running through the task. Through ensuring that the target is facing the user the system allows the participant to only be focusing on their hand controlling ability without being held back by the other potential limitations that may be affecting them.

The targets within the VR simulation have been designed to test the user's ability to accurately hit them in the centre as a test of the user's hand control and their precision of movements as the target is designed to give different points depending on where the user hits. This aim training can be paralleled to real world movements which could improve the user's ability to use keyboards, interact with devices or even have more control of their hand in their everyday lives. The goal of this research is to refine the users fine motor skills that can help the users to perform their own daily tasks that can be present in both the real world and the virtual environment. My research does not only just focus on those affected by Parkinson's disease but also how VR can be a vital application to improve the accessibility of the VR experience for anyone affected by tremors.

The area that is being researched is done through looking into areas such as accessibility in VR, Parkinson's research, how to use React Sandbox, Research on aim control with using real weapons and the target methods, and research done through giving participants in trials simulated tremors. This research into these areas have thoroughly enlightened me into how important the research into accessible VR is and how this is a rapidly growing thought in the minds of the others with my research into the use of hand tremors this will be a stepping stone into developments into figuring out how we can improve the experience of virtual reality with the world no matter the setback.

Within this literature review I have included all the papers that I have read that have value to this dissertation this ranges from papers and resources being incredibly relevant to my research to some being useful in giving ideas that advanced the way in which I progressed in working on the trials that I will have run. The resources I have used will have been gathered through my own research using resources such as google scholar finding me the research papers, google for articles on trials ran in the past and GitHub which a seminar on accessibility in VR was ran.

2.2 Previous Research

In my research I have come across papers and sources that have fundamentally aided me in my progress from starting my research till writing the dissertation. I will include the research papers in chronological order that had the most influence in this paper and what aspects of their papers I have found value in. Voluntarily Simulated Tremor in Normal Subjects, published January 18th, 2002, this study aimed to analyse the neurophysiological characteristics of simulated tremors in healthy subjects compared to pathological tremors in patients with Parkinson's disease and Essential Tremor, but it was the Parkinson's disease compared to the healthy subjects I was most interested by. The findings from this study resulted in the healthy subjects having simulated tremors were almost identical to the patents with Parkinson's disease in terms of frequency of tremors. The amplitude of tremors was higher in those with simulated tremors compared to the Parkinson's patients [1]. The takeaway from this study was that although the frequency of tremors may be the same the fact that those affected by Parkinson's disease had less amplitude of the tremors indicates that there can influence helping to control the amplitude of those tremors.

Virtual Reality and Parkinson's, published 1st May 2014. This website article talks about how we are starting to introduce VR technology for therapy for Parkinson's disease. The article shows a spot on how VR can become a valuable source of therapy and the potential for future uses of VR treatments for people who are affected by Parkinson's. The research into how the treatment utilising VR as it has been seen to increase limb mobility, their sense of balance, quality of life, day to day living and increased emotional and psychological states. The case study that Physiopedia has conducted showing a 66-year-old woman who was diagnosed with Parkinson's disease with the study aiming to delve into the effectiveness of how VR can affect the skills in their day-to-day life with the results being positive for their motor skills, cognition and their mental health.

Physiopedia also noted a meta-analysis and a review which had involved over 1,000 applicants, which had examined the effectiveness of VR in therapy with the results being the same as their own case study with the 66-year-old woman. Overall, the study conducted by Physiopedia taps into the integration of VR technology in the therapy programs with promising perspectives on how well this can be achieved enhancing patients' motor skills, quality of life and their balance [2]. This study done by Physiopedia has been a valuable source of encouragement for my dissertation as they have done similar studies on what I want to develop and with them having positive results it gave me inspiration on making a system to simulate tremors to see how those who suffer from Parkinson's are truly affected by it.

Tremor Assessment During Virtual Reality Brain Tumour Resection, published May/June 2020. In this study there were two important notes to state the physiological tremors which for Parkinson's disease include involuntary muscle oscillations which are mostly found in the patients' hands, which can heavily affect fine motor skills being performed. This study utilises a VR tremor assessment tool called NeuroVR formally NeuroTouch which provided the study with an environment with feedback which measures the tremors during the tasks, with the study being performed seeking to use a tumour resection simulator to view how hand tremors among those performing in the study vary. And the levels of variation between skilled participants and new ones. This study had two groups with 23 being skilled and 92 being new and they were tasked to do a simulation of a surgery with the data of their hands (x,y,z) coordinates being recorded as well as their hand rotations. The skilled group showed little tremors being measured as well as their hand rotations were also limited with their skills being shown as they proved more stable force during movements showing their better tremor management [4]. The tremor assessment shows the use of VR recording as the details of participants' hand tremors showing a benchmark for stability which can be adapted into aim trainers such as what my study aims to simulate for ones suffering from Parkinson's.

Algorithmic Virtual Reality Reduces Parkinsonian Tremor, published on February 7th, 2023, explores the use of virtual reality (VR) to reduce tremors in individuals with Parkinson's disease (PD). The study aimed to create a tremor-free VR experience and assess whether stabilizing digital tremors could lead to real-life tremor reduction. The participants completed a Postural Tremor Test, holding their hands in an elevated position for two one-minute intervals—one with a tremor-stabilizing algorithm active and one without. Motion tracking recorded hand movements to evaluate tremor levels. The results showed a 76 percent reduction in digital hand tremors and, notably, a 35 percent reduction in real-life tremors in 78 percent of participants. These findings suggest that visual feedback from stabilized virtual hands may influence the neurological pathways responsible for tremors. This study demonstrates the potential of VR as a non-invasive therapeutic tool for PD and highlights the importance of real-time motion tracking and stabilization algorithms [3]. It directly informs my dissertation, which focuses on developing a VR aim trainer to help individuals with hand tremors improve fine motor skills. By incorporating similar stabilization techniques and biofeedback, the aim trainer could not only assess tremor severity but also contribute to motor skill rehabilitation. The study reinforces the role of computer science in advancing healthcare technologies through algorithm development and interactive VR systems.

Enhancing Mobile Interactions for Individuals with Tremors Via Optical See-Through Augmented Reality, published September 13th, 2024. This study aimed to test the challenge individuals affected by hand tremors with the touch-based interfaces used by mobile devices as this is seen as a difficult spot for hand tremors as it is more likely to lead to incorrect inputs and time taken to execute tasks are longer. Tremors affect a wide population, and the increase of tremors only become more likely with the development of age. The goals of this study aimed to develop an AR system with a stabilised filter that aims to aid those to use their devices more effectively. This will assess this effectiveness, compare user performances, experiences between the traditional and new systems and evaluating the usability of these redesigned interfaces. The system includes AR glasses, hand tracking systems, and a computer which renders the interface of the mobile device in the AR environment. There are a De-Shake filter makes a weighted moving average which stabilises the hand movements working as a harmony frequency to the tremors this filter prioritises the responsiveness to the intentional movements which surpassing the tremor movements. The redesign of the mobile devices interface shows an enlarged elements while reducing unnecessary sections and having a high contrast to accommodate the tremors as a focal point to the user while focusing on minimising the accidental touches and improving the navigational skills of the user. The key finding of the study show that the de-shake filters have drastically reduced the time taken to complete tasks for the users with simulated hand tremors, the users had reported that the experience they were having was more stable and increased their accuracy in their navigation with their feedback being that they have experienced the redesigned system being better than traditional mobile devices for the participants with simulated tremors and those who are not had a similar experience to this although they did not care for the redesign made for the system [6]. This study compared with my own work shows that the usability of methods to work around someone tremors make their experiences better compared to having to adapt to the traditional designs made for the ease of navigation for those without tremors.

Feasibility of a Non-Anticipatory, Random-Action Target System to Improve Shooting Performance: A Brief Field Trial, published on November 11th, 2024, focuses on evaluating a randomized target system to enhance shooting performance. While this study does not directly relate to hand tremors, it has influenced the design of the trials in my research. In the study, six experienced shooters engaged with a Random-Action Target System, where targets varied in location, size, and exposure time. As the trials progressed, shooters improved in both accuracy and reaction time, suggesting a learning curve that supports skill development through repeated exposure [5]. This aspect aligns with the therapeutic goals of my research, which focuses on improving fine motor control in individuals with hand tremors. For my VR aim trainer, I have adapted elements from this study but with modifications suited to tremor research. Specifically, my trials will use static targets that remain visible until hit, with only the location changing. This setup emphasizes precision and allows participants to focus on fine motor control without the added pressure of time constraints, making it more suitable for users managing tremors.

Chapter 3

Research Methodology

3.1 Research Design

The approach my research as lead into as my project is experimental and has a mix-methods approach to it I wished to gain both quantitative and qualitative data through sources like the target scores from the quantitative side and the feedback from the people doing the trial with their user experience and their comfort levels throughout the testing. The reason as to why I have gone with basing my research into XR as I wish to develop more into the accessible XR and this I have felt is a progressive stepping stone into furthering that research, going forward with this from the XR studies I have researched I find that studying the fine motor skills and how users interact within the XR space will lead me into having the most impact from my project. A simulated tremor system was implemented; the artificial tremors are induced through both a circling target movement and a target jittering simulation which aim to simulate those tremors found in Parkinson's patients based on studies done. The amplified pointer movement enhances the distance hand controls are made this is done through making any hand movement made make a bigger distance crossed rather than without such as a slight hand movement down will create the distance shown being greater. The hand jittering simulation is made through just having the pointers constantly rotating in a small circle to create a constant base tremor, with both in place this creates a natural looking hand tremor simulation.

The structure of the trial is as follows, the user is introduced to a floating target with 6 rings with a main red one followed by black and white rings with one final invisible ring finishing this as a guidance and tested to hit the target as close to the middle within a 30 second session where performance metrics such as the score will be logged, the independent variable within my trial will be the presences or absence of the simulated tremors as I wish to understand the base of how the user will react when having the testing simulation vs their natural skill level. The dependent variables are the target session scores and the user feedback from each session.

3.2 Data Collection Methods

The participants for my study were collected with a range of ages and demographics, I wanted to gain how people of differing ages would react to the different feels of the trial as well as usage of VR to see how a regular user of VR would react being compared to those without a regular use of these machines. The quantitative data that I am aiming to collect is the score from the VR trials with the precision of target scoring, the duration of the session being 30 seconds and the task completion metrics with that being the number of targets successfully hit within the given session and the percentage of the score from the targets hit completion rate being $\text{targets hit} / \text{total targets presented} \times 100$. The qualitative data is gathered through the observational notes and post session feedback gathered through the trial experience with questions being asked such as how comfortable the VR experience for you was and do you feel like the tremor simulations you were put under feel realistic? This data gathered is vital as I wish to gather how the users feel while undergoing the testing as this is more insightful to what I wish to achieve rather than the quantitative data as I want to have the user experience from this be the best experience it can be while being realistic. The tools used in these trials will be a meta quest 2, react sandbox which was used for the development of the project and Microsoft edge beta for the camera clips of the testing in first person.

The environment of the trial will be in the Dean Street Room 312 there will be a control over noise, closing the door to the lab room to reduce any external noise, light if the room become too bright, we will close the blinds and too dark turn on the lights for the lab while being controlled in the space of the lab. The users are ran through a quick questionnaire beforehand just for a base of how they are and if they are comfortable with going under the trial, then they will be tasked either with the controls set or without the tremors in as I wish to keep it random testing then they will have a break answer questions on how it feels then run through the other version finally running through the final questions that are needing to be asked then that will be that user done.



Figure 3.1: VR Scene Showing The Users First Person View

3.3 Data Analysis Techniques

This section will outline the techniques I have used in the data analysis of this project gathered from the VR aim training trials which will be focused on the impact of the simulated target tremors that are placed in and the user performance and experience while doing the trials. This includes both the quantitative and qualitative data from performance metrics and feedback gathered from the completed trials. The quantitative data was analysed through the user score and the interaction effectiveness under the simulated conditions with the key metrics being, the score achieved within the 30 seconds and the task completion rate. These metrics are recorded through the finishing part of each trial a video of the trial is recorded and the score on the trial is shown as an overlay, the task completion rate will then be calculated after and put into the spreadsheet of the participants. This analysis will be able to help identify how the artificial tremors have affected the user's performance and how they compared against other trial participants.

In addition to the quantitative data gathered the qualitative data must also be analysed the participants are asked to provide subject feedback through open ended questions and a post-trial interview with the data that I am gathering focusing on how difficult the user felt it was, was there any physical or cognitive fatigue while experiencing the trial, was there any discomfort gained from the simulator i.e., nausea or dizziness, if the tremors made for the trial was perceived as being realistic and the accessibility of the interface of the trial. Responses to the questions are using a thematic analysis approach where the recurring statements and common patterns or if contradicting opinions are stated are identified and grouped into their themes. This has helped provide an insight into how the user satisfaction has been set, the usability challenges are for adaption and the potential barriers for further progress in this field are set.

The integration of both quantitative and qualitative data collection analysis has allowed for the triangulation of findings where performance metrics are compared against the experiences make the analysis enhanced, for example someone who gained a low score and had a high level of discomfort may suggest that design aspects have negatively impacted the performance of their trial. This mixed methods approach has strengthened the validity of my findings and has provided a more holistic understanding of the user experience within the VR environment.

3.4 Ethical Considerations

This research involved human participants engaging within a Virtual Reality aim trainer which has been designed to simulate target tremors. As such ethical measure were taken to ensure that the safety of the participants, the informed consent of theirs is kept and the protection of data is set. The informed consent of the participants prior to the taking part of the study are proved with information of the research, what their role with this will be and the potential discomforts that may arise while the sessions running. Participants are required to give written consent before beginning the trial as well as they are informed that they may withdraw with this trial whenever they wish without any penalty. Given the nature of VR systems there measures taken place to minimise the physical or psychological discomfort the participants are told if they wish to they may take breaks if they are experiencing any discomfort, nausea, dizziness or visual strain with the simulated tremors being designed to carefully avoid inducing distress to the users and the experience of these tremors are kept only to the brief 30 second trial session to reduce fatigue or discomfort. There are no actual medical conditions simulated or diagnosed they system only simply mimicked the motor control instability for the testing purposes of this project.

All participant's data is anonymised at the point of collection. Identifying the information was not stored alongside the performance or the feedback data. The data is stored to a site where only I can access the data gathered in accordance with the data protection regulations GDPR all the information was kept confidential and was only used for the purposes of making this project come to life. The study has been reviewed and has been approved by the university's ethics committee prior to the beginning of the trials. The research has adhered to the institutional guidelines for the working with the human subjects and has followed the principles that has been outlined by the British Psychological Society's Code of Human Research Ethics.

Chapter 4

System/Project Design and Development

4.1 Overview of The Design

The overview of the design of this project is as follows, the purpose of this project is to make a VR aim trainer that can effectively replace natural tremors within those affected by hand tremors are present this is done through simulating target tremors through a constant rotating movement and an enhance movement addition to create this simulated tremor. It was created to develop a start into the accessibility of VR to the wider world including those with hand tremors aiming to make a session on how those feel and how the precision controls can be adapted into making the allowance for those who do suffer from them to navigate the VR world with more ease than started. The key features of my project are the targets that maintain spawning and movement abilities, the scoring system that keeps track of how well the participant is doing within the 30 second play session, the simulated tremor effect which is the main aspect of the project the timer on the session to control how long how each user is kept within the trial and the data collection being done more hard as I will be collecting it from each user myself and calculating their task completion rate myself for each participants sessions. The tools and technologies I have used in this project are React, React Sandbox, Three, Drei, Microsoft Edge Beta, Microsoft HoloLens, Meta Quest 2/3, and the language I have written the project is JavaScript with some HTML and CSS code being included.

The users will enter the VR state once clicked onto the enter XR button and are instructed to hit the targets either with or without the simulated tremors being applied there are both visual and audio feedback is provided with explosion effects and breaking sound effects being played once each target is hit. Each user's performance is logged as they are recorded, and the users score is kept for analysis. This design of the project has allowed me to be available to accurately evaluate the effects of tremors on the accuracy and usability of users in the sessions being ran.

4.2 System Architecture or Technical Specifications

The hardware components that my system requires are simply just a VR headset which has access to a web browser as the code is written using web technologies to access the project, the use of VR controllers are also available for aiming and shooting but it is not fully necessary for the completion of the tasks. The software used in this creation for the frontend and rendering I have used react with react three fiber for the framework, for the 3D rendering I have used Three.js through react-three/fiber and react-three/drei. The XR integration is done using react-three/xr which enables VR/AR functionality with WebXR support the camera is positioned to simulate the users eye height in VR with the average 1.6m ensuring accessibility as well as adapting to the real user heights too. The interaction system has controller tracking with real-time updates from the VR controllers being used in the WebXR the tremor simulation adds the random potential noise to the controllers every frame through the hand tremor, mimicking the hand instability from true hand tremors. The target interaction shows the user a target within their field of view once clicked there is a sound effect played and an explosion effect which will then create a transition into a new target being spawned the position is updated using the headsets coordinates to stay within the user's visible range.

The scoring and feedback are done through the 30 second timer running and the score incrementing depending on the certain ring hit during activation, the final score is then shown once the session ends showing the user that they have completed their session. During the runtime of the session, the controllers are continuously recording input with the natural or modified tremor effect placed upon it, the targets will update their position depending on the user's location and height where once hit the visual and audio feedback are triggered with the breaking sound and explosion effect playing with the score going up as well. All the logic is managed within Reacts state and effects, ensuring the smooth reactivity within the VR scene. This application is designed to be accessed through any web browser with WebXR support it does not require back-end design, and all gameplay's will occur on the client-side, the optimised performance is created through the minimal use of complex meshes and the efficient use of the rendering loop.

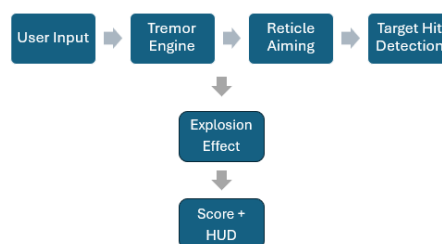


Figure 4.1: Architecture of The System

4.3 Development Process/Approach

The development of my project followed an iterative and more user-centred approach, combining both the technical prototyping with the design experimentation aspect. The project was developed using modern web based XR tools being react sandbox, react, three and drei with there being continuous testing and refinement based on the performance, accessibility and the users experience. This has set since the start from the orange spheres as targets through to the cartoon target with the sound and visual affects added onto it. For the tools and framework of this project, react was chosen for its components-based architecture and smooth state management which allowed for the interactive logic to integrate seamlessly with visual updates so I could view any updates that I made to my project in real time without having to stop and reload my work every time I updated it. react three/xr provided native support for VR devices using the WebXR API simplifying the controller and camera tracking. Three.js powered the low-level 3D transformations and rendered the logic for the project. @react-three/drei contributed helped the html for attaching the HUD while in the 3D space. Audio effects were implemented using the native HTML Audio API for its quick response without relying on external libraries, each of these technologies were chosen for their performance, and their ability to run in browsers without needing native builds.

The implementation of this project came up to 6 main stages. Stage 1 was the setup, in this stage I setup the canvas and the setup for the XR environment, positioning the camera at the average user's eye level at 1.6m to accommodate for most users as well as the adaptation for those shorter or taller also put into place. Stage 2 was the targeting logic, I originally had basic orange spheres to click onto but after this I designed a concentric ring target composed of planeGeometry layers, I also created the logic for the targets positioning based on the user's current field of view and their height to ensure accessibility for users with tremors or mobility constraints.

Stage 3 was the interaction and scoring, built in click-based target interactions using ray casting through a WebXR controllers' input, the implementation of the score tracking and in game timing logic via the react state. Stage 4 was the tremor simulation, I created the target tremor component which has added a subtle random motion to the VR controller positions the simulated difficulty of the aiming with the hand tremors was implemented to evaluate the user's performance under those simulated conditions. Stage 5 was the feedback and effects, I developed the explosion effect which visually rewards the player on completion of activating the targets, the added sound effects was added for the multisensory feedback from those activations making the experience better for the viewer the HUD was integrated using HTML for the VR score and timer display while the session is running. Stage 6 was the testing and iteration, each new feature was tested thoroughly within the Meta Quest headset using WebXR, adjustments were made to the ring sizes, sound timing and the position smoothing to improve the playability for the users affected by hand tremors.

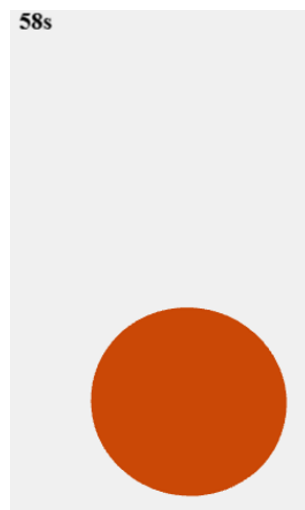


Figure 4.2: Original Version of Aim Training Simulation

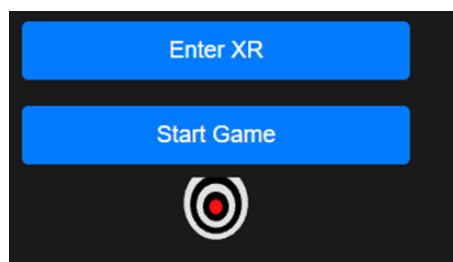


Figure 4.3: Final Version of Aim Training Simulation

There were some challenges when creating this project with two main challenges being the updating of dependencies and the creation of hand tremors. At the beginning of the project through making good amount of progress once the first version of the working model was created with the random targets, eye control, and explosion effects being in place with a working score system the dependencies within React Sandbox updated and led to the entire project no longer working resulting in two months of progress having gone to waste I had to quickly make the next version of the system up and working took a good amount of my time while keeping the current dependencies of the system in one solid lock as to not affect the work done after the fact. The other challenge I ran into was the creation of the hand tremors the creation of the tremors was difficult as I had to study videos of how hand tremors appear and what way they show through doing this I lead myself into not making one way of simulating the tremors but making two different ways of effecting the users hand controls join together as one to simulate a more effective way of creating the tremors to a more realistic degree. The development approach has the emphasis on usability, a real time feedback, the accessibility within VR, resulting in a lightweight but effective prototype for studying the users experience of individuals with hand tremors.

Chapter 5

Implementation

5.1 Implementation Details

The implementation of the XR aim trainer that I have developed with the simulated target tremors needed a very careful integration of multiple technical components to create a project that was an accessible and scientifically valid testing environment. The system was built with three major components at its core with that being, the tremor simulations, the targeting interactions and the collection of the scoring from the training time. The tremor simulations that were created with a dual tremor system in mind for the target tremors component. Starting with a base tremor which was created with an organic circular movement that will mimic the resting tremors of those affected by Parkinson's disease this tremor is a smooth start to the tremors off. The second tremor that was added to go together with the organic hand tremor is an intentional tremor amplifier that has been added that will scale the targets jittering movements by 1.8x during the active use of the trial which is designed to replicate the overshooting characteristics of kinetic tremors caused while moving. The tremor intensity has been calibrated to ensure that the physiological accuracy is kept in line. The targeting interaction system that is in place for the trial has a cartoon ring target as a base design it is composed out of six mesh objects in Three.js with each of them containing a custom circleGeometry with the radius going from a minimum of 0.1m or the maximum 0.6m, there is a precise hit detection built onto each ring which ensures that the ring hit while the raycasting is over a specific ring ensures that only that one set score will be added instead of a base 1 point.

A Z-axis layering of each layer of the ring creates depth within the target with it originating from -0.05m at the base layer of the target to 0m for the red bullseye in the middle. The scoring system is using a recursive bounding algorithm which calculates every precise hit based on the distance from the centre of the target, with the bullseye resulting in five points, four for the inner black ring, three for the inner white ring, two for the outer white ring and one point for both the outer black ring and the transparent ring the bounding algorithm ensures that any hit to the target will result in the correct score as there is positioning included to decide where on the target the hit checked. There is the adaptive positioning system that I made that allows for any user to become a part of the trial as it adapts the simulation towards everyone, the target will adjust its height based solely on the viewers height from the ground and will decrease or increase in height when changed with the target going from 0.9m to 2.1m of the ground depending on the user.

5.2 Challenges Encountered

Through the development and the implementation of this project the XR aim trainer with target tremors has presented a variety of technical and design challenges which as required a massive amount of problem-solving and adaptation to be required to complete the project with the key challenges being, the dependency management within react sandbox, during the early months of the project I ran into a significant setback as the dependencies within react sandbox updated which broke multiple parts within the projects functionality which lead to an erasure of months of progress. The solution to this was to rebuild the project again from scratch with a locked dependency to ensure stability. This delay declared a necessity of reimplementing of the core features within the project like the target spawning and the scoring logic whilst maintaining the compatibility with WebXR. The targets interaction became a problem as the concentric ring target introduced a complexity with the hit detection, primitive iterations struggled with the accurate raycasting due to some overlapping geometries.

The solution to this problem was the recursive bounding algorithm was developed to calculate the score based upon the radial distances from the bullseye ensuring precise registration of hits across each of the rings. Accessibility and user comfort was also an issue I ran into; the simulated tremors introduced a risk of inducing motion sickness or frustration for inexperienced VR users. The solution to this was reducing the session time down to 30 seconds, and breaks were ensured to keep feelings induced to the trials to dwell down. The tremor intensities were tuned to remain challenging while also still being tolerable.

There was a major setback with the project with that being the failure to create a controller tremor, the initial design has attempted to create a simulated tremor through manipulating the VR controllers' positional data however no tremor effects appeared whatsoever during the various attempts, despite the multiple approaches that was taken code level issues appeared as multiple attempts to inject noise into the controllers position and rotation values through the useFrame hooks but this failed to produce a visible jitter as React Three Fiber runs at 60-90Hz but the tracking system of the Quest updates at around 1000Hz causing the jitters to be imperceptible, the eventual solution I had to come up with was developing the tremor system onto the target that the user is trying to hit, this target driven solution applied frame positional offsets to the targets mesh creating an illusion of unstable aiming while leaving the controllers tracking untouched. Whilst being less physiologically accurate than the controller-based tremors this solution still achieves the core goal which is impairing the precision. User testing confirmed that the effect was perceptible and functionally equivalent for creating a simulated experience of hand tremors within an aim trainer.

5.3 System/Project Outcomes

The implementation of the XR aim trainer has successfully achieved its core objectives in demonstrating the feasibility of the creation of a tool for studying how hand tremors affect the users of hand tremors with the key outcomes including a functional prototype, the dual tremor system that was created provided a realistic show of how Parkinson's presents itself also being validated through users feedback comparing the tremors to observed tremors seen in natural tremors. The targeting system contains an adaptive positioning to ensure that the accessibility across user heights (between 0.9 and 2.1m), while the scoring system algorithm ensures that there is a reliable precision checking for the rings scores (1-5 points per hit). The feedback mechanism shows both visual and auditory responses that enhance the user's engagement and provides immediate performance feedback. The data collection framework is set for both quantitative and qualitative data to be collected, quantitative metrics being collected are scores, task completion rates which carries over to show how accurate the participant was which was all logged for analysis, the qualitative insight from the questionnaires revealed each user's perceptions on the tremors realism, comfort levels, and the interface usability.

The research contributions show the XR accessibility with this project highlighting the potential for how XR can be able to simulate disabilities for research and training which will lead to the bridging of gaps within traditional tremor management studies. The design guidelines from my project with its tremor calibrations will offer a base into a potential for further expansion for accessible XR developments. There are limitations from my work that could affect the future use of my research, the small sample size of participants in my trial with it being focused on able-bodied users with a simulated tremors while being useful could be increasingly more valuable if the trial were to be designed to test real Parkinson's patients as this would strengthen its validity.

The long term use of the program affects what the heart of the trial was originally as I wished for my design to show how tremors can be affected through repeated use of aim trainers with other research showing how this could be possible the end result of mine being a simulated tremor system only creates a starting point into how research into this could be done further down the line.

Chapter 6

Evaluation and Results

6.1 Data Analysis and Results

This chapter presents the collected results from the VR aim trainer trials that has been carried out with 30 participants being put under two conditions, one being tested with simulated target tremors and the other being one without any tremors added to the tool. The objective of this analysis was to evaluate how impactful the simulated tremors would affect the performance, usability and the user's perception. The data will be assessed with the success of the system in addressing the research questions.

Each participant of the trial was split into two trials lasting 30 seconds each. In some of the users trials the participant was shown the system with the tremor system being active, introducing the involuntary movements of the target replicated to the best degree I could produce the motor impairments that is produced from Parkinson's disease. In the other set the users were introduced to the system without the tremors included within the project allowing for a baseline for each of the participants performance to be stored. The primary performance used was the score achieved during this session with each target awarding points depending on the accuracy of the hit with a maximum score of five points for hitting the target in the bullseye.

The table of results shows the individual scores for each participant in both conditions of the system. The average score with tremors was 40 points and the average score without tremors being included was 88 points. This has demonstrated that there is a clear gap in the performance between the two modes. This difference suggests that the tremor simulation that was successfully introduced a meaningful challenge that will impact the ability to control the users' movements and in maintaining accuracy.

A visual representation of the scores that has been provided in Figure 6.1 and Figure 6.2, where both conditions have been plotted for each participant. The chart shows a consistent pattern for nearly all the participants, the scores within the non-tremor conditions were significantly higher which has added to the idea that nearly all the users have scored in the non-tremor trial was significantly higher compared to the tremor conditions. This shows that the tremor effect has a strong and constant influence across the sample group of 30. The spread of the scores in the tremor trials was also quite varied which ranges as low as 10 (participant 10) and goes up to 85 (participant 6), this shows that there are users were able to adapt to the tremor system more effectively than others.

There are participants such as Participant 4 who was able to score 130 points without the tremor but only scored 30 with the tremors induced. Others such as Participant 5 had a small drop in score going from 59 from without the tremors to 57 with the tremors suggesting that an existence of prior gaming experience or fine motor skills could have a role in the adaptability of the changing of environment. This raises an interesting question into how personal background or prior exposure to VR environments has the potential to influence the ability to cope with accessibility challenges.

The tremor simulation's impact was not limited to the score that the participants was able to get it has also influenced the participants behaviour and feedback. Many of the participants had reported frustration at how the simulation had reduced their control. However, they have also pointed out that the experience gained from this model feels authentic and has provided insight into what it may be like to live with a condition that affects one's motor control. This combination of a measurable score reduction and the strong subjective feedback has strengthened the credibility of the simulated system used in the study.

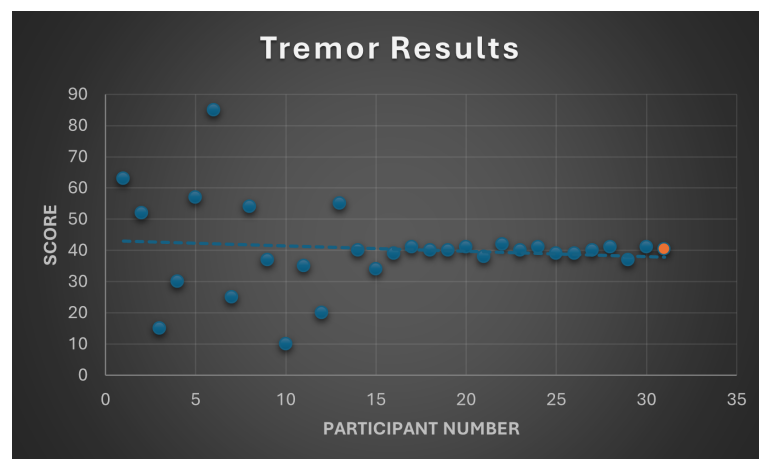


Figure 6.1: Results From Tremor Simulation Testing

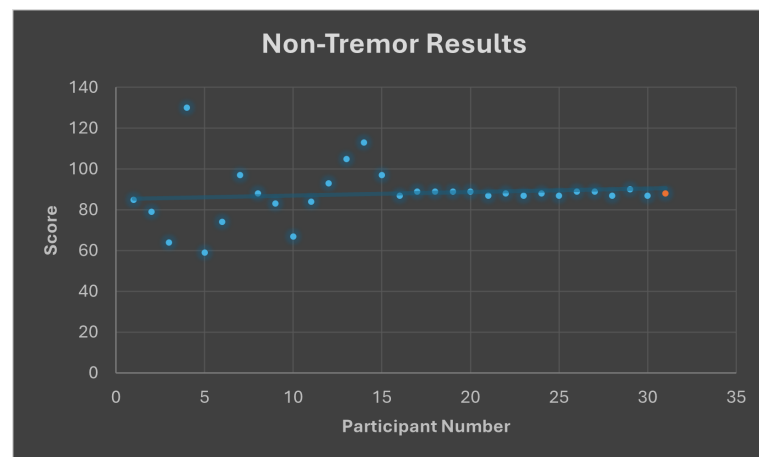


Figure 6.2: Results From Non-Tremor Simulation Testing

6.2 Interpretation of Findings

The results from the trials have clearly indicated that the VR aim trainer's tremor simulations has shown a significant effect on each of the user's performance. Throughout all the participants the introduction of tremors has caused a reduction in the accuracy and the consistency of the users scores. These results are very valuable as they demonstrate both that the system works as intended as well as validating the design choices that I made during the development of the system such as the target tremor controls having the circular tremor motions and the amplification methods.

The participants' performance drop in scores aligns with their qualitative feedback given by the participants. Many of the participants described the tremor experience as feeling "realistic", "challenging", or "frustrating" which shows that the tremor effect has achieved its objective goal of simulating the difficulties that was faced by individuals with real tremors. Interestingly some of the participants have commented that where they felt that they have less control they were more engaged due to the challenge. The gamification of the elements within the aim training system has helped in the offset of the negative feelings.

These emotional responses point to the potential for this developed tool to not only serve as a training system but also as a way to show others a brief insight into how it feels to experience these tremors, several participants had noted that they "never considered what it would be like" to live with a tremor and came away with a new understanding of the challenges that are involved with this. This suggests that an unexpected secondary benefit of the simulation being that it can be used for educational purposes and outreach.

The consistency of the scores among the non-tremor sessions has also offered an insight with most users scoring between 80 and 90 points without the tremors, showing that the system was usable and that it is easy to learn when not impaired. This supports the idea that the interface was well designed and that it is accessible, which is especially important when considering that this type of tool has the potential to be adopted by populations with varying levels of technical literacy.

Finally, the 30 second trial duration appears to have been a perfect choice, it shows that it was long enough to produce meaningful data but also short enough to avoid user fatigue or boredom. In the post-trial discussions, some of the users asked to try it again which suggests that the time limit maintains the user's engagement.

6.3 Comparison with Research Questions

This section evaluates how the collected results from the trial held relates to the research question outlined in Chapter 1.3, 1. How does the VR aim trainer compare to traditional methods of tremor management in terms of accuracy and usability? While this project did not directly deal with clinical tremor management methods, the constant decrease in the accuracy under the tremor conditions has suggested that the aim trainer to successfully replicate the challenges of a real-life tremors. The high usability of the non-tremor trials has suggested that the system is able to support the users effectively when properly calibrated. 2. Does regular use of the VR aim trainer contribute to measurable improvements in motor control and reduction of tremor-related difficulties? Due to the time constraints that had risen for the study design, the long-term impact of the regular use was not able to be measured. However, the system still provides a foundation for studies such as these. There is a clear scoring mechanism and an adaptable difficulty measure, this VR aim trainer can be easily used in longitudinal research which can evaluate improvements over time.

3. How accessible is the VR aim trainer for older populations or those with limited technical literacy? The participants across the various backgrounds of gaming/VR experiences were able to complete both trials with little to no guidance, the use of visual cues also having simplified controls and the automatic positioning has made the system developed approachable even for those with a limited VR experience. Some of the participants appreciated the audio feedback and the instructions given to them before they entered the trial.

4. What are the perceived barriers and facilitators to adoption of VR aim trainers by individuals with hand tremors? Feedback from the participants have highlighted several perceived barriers, including a difficulty hitting the target while it is under the tremor conditions and the learning curve that is required to adjusting to the jittering movement. However, the use of gamified elements with the scoring, sound effects and explosion effects has helped the counteract frustrations. The simplicity of the interface and the short session length were also said to be an encouraging factor for this system. 5. How does the design of the VR interface affect user comfort, satisfaction, and long-term usage? The users comfort levels were generally high, with the responsive design and clear visual elements and the absence of any unnecessary motion being reduced the chance for any motion sickness to appear. The satisfaction was also spun in a positive way by the clear feedback system with users knowing when they had successfully hit one of the targets and the sound and explosion effects added the sense of accomplishment for them.

6. What performance metrics are most relevant for evaluating the success of a VR aim trainer? The most effective metric that was used in this study was the scoring mechanism during the timed sessions. This allowed for the straightforward comparisons between the users with and without the tremors, additional calculated metrics such as reaction time, distance from centre and missed targets could be the potential for added parts of the system in the future for a more comprehensive analysis.

7. What psychological effects (positive/negative) might users experience while training with VR to manage hand tremors? Participants have reported a mix of emotions with the trial while some felt both challenged and frustrated while in the tremor simulation, some of the participants felt a sense of satisfaction when they performed well despite the difficulty suggesting that the system has the potential to offer motivational benefits and the potential to reduce the stigma or fear of failure through framing the challenge as a game.

Chapter 7

Conclusion

7.1 Summary of Findings

This research project had set out to explore how XReality (XR) can be used to simulate the challenges that has been experienced by those individuals affected by hand tremors, with relation to the accuracy, usability and accessibility. The focus was placed on the development, implementation and the evaluation of a XR aim trainer tool which includes a simulated tremor system. The system was designed to reproduce the motor instability that is like experienced life by people affected by conditions such as Parkinson's disease with the goal of assessing how such users may be able to interact within an extended reality environment and identifying the potential improvements to accessibility design within the XR world.

Over the course of this study, 30 participants completed two VR aim training simulations with one including the simulated tremor system enabled onto the target and another simulation without any tremors. The findings of the trial have demonstrated that there is a clear and consistent drop in performance when the tremors were introduced. The average scores from each of the trials being 88 for the non-tremor trial and 40 for the tremor trial confirms that the tremor simulation has successfully introduced a meaningful challenge and has offered a reliable way to simulate the difficulties that can be experienced when fine motor controls are affected while in a VR environment.

From the user feedback supporting these findings. The participants have noted that the simulation feels realistic and many of the participants reported that the tremor conditions had made them feel more empathetic onto those who do have to live with similar conditions within their day-to-day life. The interface was generally well received, with users appreciating the simplicity and how intuitive the controls had felt. No participants had chosen to stop the trial at any time despite being allowed to with no difficulty which suggests that a solid baseline of the accessibility and the usability even among inexperienced VR participants has been well developed.

From these results it was shown clearly that the project had achieved its aims, the VR aim trainer accurately simulated tremor conditions, collected usable performance data, and maintained the accessibility and user engagement across the varied participant groups. This chapter summarises what this means in the terms of contributions to knowledge, the limitations of this current study and how future research could build upon these foundations.

7.2 Contributions to Knowledge

The findings of this project have contributed to several growing areas within research and development, the accessibility within XReality, rehabilitation technologies and the simulation of disabilities for educational or training purposes. The contribution to accessible XR design, one of the most important contributions of this project lies in the demonstration that XR systems can be adapted for any users with motor impairments without sacrificing any of its usability or interactivity.

Through implementing features like the automatic target positioning based on the user's height and a simplified point and click mechanism the system has made the task approachable to users of all technological abilities. These features offer a potential framework for future VR applications aimed at building the accessibility and inclusive design of its systems. The use of the visual and audio feedback (explosion and sound effects) also showed how multisensory cues can increase the engagement and make the interactions between users and the system more satisfying for the users with reduced precision. Advancing Simulated Tremor Systems within VR through this project has contributed to the technical side of simulated disability research in VR. The tremor system that I designed used a rotational jitter and movement amplification was successful in creating a realistic experience for users, based on both the objective performance metrics and subjective feedback although this tremor system was intended originally to be on the hands of the users but the failure to develop this the tremors were then applied to the targets. This shows that VR systems can be able to effectively simulate motor challenges without the need for complex or invasive setups. The dual component tremor simulation has offered a flexible base for the use in other types of VR tasks or games and can have the ability to be adapted to simulate different types of motor impairments or diseases.

Informing Therapeutic and training applications from the structure of the VR aim trainer with the emphasis on the scoring system and short session durations has offered the opportunity of a lightweight therapeutic tool. Although this research could not focus on the rehabilitation or long-term training outcomes the system is well suited for repeated sessions, where it could track progress of individual users over time through slight development put into it. This could be valuable for physiotherapists, occupational therapists or researchers studying motor controls within a clinical population. The potential to gamify the rehabilitation allows for the encouragement of an engaging, data-rich environment that is significant and aligns with the wider trends in healthcare technologies.

The promotion of empathy and awareness while not being the primary aim of the project, the emotional responses from participants showed that simulated experiences of tremors can lead to greater empathy and awareness. Several of the trial participants have expressed a newfound appreciation for the daily struggles that is faced by people who are affected by tremors. This opens the new potential for use cases for the system in educational settings such as caregiver training, medical student workshops or disability awareness campaigns.

7.3 Limitations

Despite the project's successes, the research conducted in this project is not without its limitations. These must be acknowledged and provide the context for the findings and can inform the future developments that may follow from this work. This study used a small sample of 30 participants with the majority of whom being young adults without any diagnosed motor conditions. While the tremor simulation was effective in replicating the difficulty of fine motor tasks, it was only tested on individuals who were not medically affected by those tremors. There is a limit of these findings when considered in the real-world users with the neurological conditions like Parkinson's disease. Testing with actual patients would be necessary to validate the therapeutic or training potential of the system more thoroughly. A short-term evaluation was only able to be done. This research involved a single session trial and therefore could not measure any long-term improvements, learning curves or adaptations over time. The benefits of repetition, muscle memory or desensitisation to tremor effects are unknown. This short-term focus restricts this project's ability to draw any meaningful conclusions about how long-term rehabilitation or training value can be gathered.

The scope of the performance metrics has one primary metric with the score in a 30 second trial was used to evaluate the performance of the participants. While this metric was clear and useful it does not capture all possibilities of user interaction data collection with other metrics such as reaction time, movement smoothness or targeting consistency has been omitted. A richer set of metrics would be able to provide a more nuanced understanding of user performance and could help in better diagnosing or supporting users with various abilities. The tremor simulation accuracy although participants generally reported that the tremor simulation feels realistic, it is not a medically validated model of how these hand tremors present across the different conditions. The jitter and amplification techniques that were introduced in this project were based solely on the visual observations and user perception rather than clinical data. While this does not undermine the effectiveness of the created simulation it does limit the validity of the use in diagnostic tools or medically accurate rehabilitation software.

7.4 Recommendations for Future Research

This project has begun to lay the groundwork for an accessible and effective VR aim trainer that has been designed to simulate hand tremors however, there is significant room to build on this foundation. The following recommendations outlines the areas where future research can expand and improve upon this work done. The inclusion of clinical populations, future studies should involve participants with real hand tremors or any neurodegenerative conditions such as Parkinson's disease. This would provide far more relevant data about the usability, realism and the therapeutic potential of the VR aim trainer. Collaboration with medical professionals and any patient support groups could have the ability to facilitate recruitment and ensure that research ethics are upheld. Longitudinal testing is vital in the understanding of the tool's potential as a training or rehabilitation device; future research should conduct this experiment through repeated trials over several weeks.

Through tracking scores, user engagement levels and subjective feedback over time, researchers in the future can explore whether users can improve with practice whether the system builds a resilience or fine motor control and whether the participants motivation remains stable.

The expansion of performance metrics can be improved, with future iterations of the system, an expansion could integrate a more detailed performance analysis. Metrics such as time between hits, tremor compensation efficiency, hand movement paths, and reaction delays could offer a deeper insight into how the users perform. These could also be used for any diagnostics that could be sought out for the creation for personalised training plans based on an individual participant need. The adaptive difficulty and customisation of the system, through adding an adjustable setting would allow the system to be more easily tailored for individual users, for example a user with more severe tremors may wish to start with a larger target or slower timings. Adaptive systems that adjust to an individual's needs in real time based on performance would make the trainer more effective and inclusive. An improved onboarding and accessible features can be done, although the system was already generally accessible, future versions could include additional support features such as vocal instructions, adjustable text sizes, guided tutorials and haptic feedback with these features making the system even more accessible to older adults or users who are unfamiliar with VR technology.

7.5 Final Thoughts

This project has shown that an extended reality technology can hold the powerful potential for increasing the accessibility and understanding of physical disabilities. Through designing a VR aim trainer that is both functional and inclusive, this research has demonstrated that a simulation-based system can be more than just a game. It can be used for tools for empathy, education and even therapeutic intervention. As the field of accessible XR continues to grow, systems like the one I have developed here can play a key role in shaping how people with disabilities experience, navigate and thrive in virtual environments.

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Appendix A

Participant Information Sheet and Consent Form

Participant Information Sheet
Enhancing Accessibility in Extended Reality for Individuals with Tremors

Researcher: Ryan Beattie
Supervisor: Peter Butcher
Institution: Bangor University
Contact Information: ryb22pn1@bangor.ac.uk

Purpose of the study

This study aims to investigate how users will interact with a virtual reality aim trainer that will simulate hand tremors. It aims to understand the usability and the accessibility of VR environments for individuals who may experience motor instability, such as those affected by Parkinson's disease.

What Participation Involves

You will be asked to use a VR aim trainer in a 30 second session. This VR environment will simulate hand tremors by amplifying movement, making it more difficult to precisely aim at targets. Your score will be recorded, and you will be asked a short questionnaire about your experiences.

Risks and Discomfort

You may experience mild discomfort from the use of VR, including dizziness or motion sickness. You may stop at any time if you feel the discomfort is too great.

Voluntary Participation and Right to Withdraw

Participation is entirely voluntary. You can choose to withdraw at any point without explanation.

Data Handling and Confidentiality

All the data that will be collected will be made anonymous and securely stored. No personally identifiable information will be used in the final report.

Figure A.1: Participant Information Sheet Given To Participants

Consent Form

Please read the statements below and tick to confirm:

<input type="checkbox"/>	I have read and understood the participant information sheet.
<input type="checkbox"/>	I voluntarily agree to take part in the study.
<input type="checkbox"/>	I understand I can withdraw at any time without giving a reason.
<input type="checkbox"/>	I give permission for my anonymised data to be used in this research.
<input type="checkbox"/>	I agree to the session being observed and the results recorded.

Participant Signature:

Date:

Researcher Signature:

Date:

Figure A.2: Blank Consent Form Given To Participants

Appendix B

Participant Questionnaire

Questionnaire

Pre-Trial

- Age:
- Dominant Hand:
- Do You Have Any Diagnosed Motor Impairments (e.g., Parkinson's Disease)?
 - ☐ Yes
 - ☐ No
 - ☐ Prefer Not to Say
- Have You Used VR Before
 - ☐ Yes
 - ☐ No
- If Yes, How Often?
 - ☐ Rarely
 - ☐ Occasionally
 - ☐ Frequently
- Have You Played Aiming Games (e.g. Shooters, Aim Trainers)?
 - ☐ Yes
 - ☐ No
- How confident are you in your aiming abilities in VR?

1 Very Not Confident	2 Not Confident	3 Average	4 Confident	5 Very Confident
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- How difficult do you think it will be to aim with simulated tremors?

1 Very Not Confident	2 Not Confident	3 Average	4 Confident	5 Very Confident
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- Do you expect VR to be a helpful environment for training or testing tremor compensation techniques?

1 Very Not Confident	2 Not Confident	3 Average	4 Confident	5 Very Confident
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Figure B.1: Pre Trial Questions Given To Participants

Mid-Trail

For each mode:

- How easy was it to aim at targets?

1 Very Difficult	2 Difficult	3 Average	4 Easy	5 Very Easy
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- How accurate did you feel during the session?

1 Very Inaccurate	2 Not Inaccurate	3 Average	4 Accurate	5 Accurate
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- How in control did you feel of your hand movements?

1 No Control	2 Some Control	3 Average	4 Control	5 Full Control
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- Did you feel physically fatigued by aiming?

☐ [] Yes

☐ [] No

- Did you feel mentally strained while aiming?

☐ [] Yes

☐ [] No

- Did the simulated tremor feel realistic?

1 Very Unrealistic	2 Not Realistic	3 Average	4 Realistic	5 Very Realistic
--------------------	-----------------	-----------	-------------	------------------

- Did the environment feel immersive?

1 No Immersion	2 Not Immersive	3 Average	4 Immersive	5 Very Immersive
----------------	-----------------	-----------	-------------	------------------

- What did you find challenging about this segment?

--

- Do you have any suggestions to improve this mode?

--

Figure B.2: Questions Given To Trial Participants During The Trial

Post-Trial

- Which mode did you find easier to use:
 - ☐ Non-tremor
 - ☐ Tremor
- Which mode felt more realistic or closer to your expectations?

- Did you feel like you improved your aiming throughout the trial?

1 Very Not Confident	2 Not Confident	3 Average	4 Confident	5 Very Confident
----------------------	-----------------	-----------	-------------	------------------

- Did you develop any strategies to compensate for the tremor?

- How enjoyable was the experience?

1 Very Not Enjoyable	2 Not Enjoyable	3 Average	4 Enjoyable	5 Very Enjoyable
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- How useful do you think this kind of VR simulation could be for tremor training or research?

1 Very Not Useful	2 Not Useful	3 Average	4 Useful	5 Very Useful
-------------------	--------------	-----------	----------	---------------

- What did you enjoy most about the experience?

- Do you have any suggestions for how the simulator could be improved?

- Would you be interested in participating in similar VR experiments in the future?
 - ☐ Yes
 - ☐ No

Figure B.3: Questions Given To Participants After The Trial

Appendix C

Raw Data Tables

Participant No.	Tremor Results	Non-Tremor Results
1	63	85
2	52	79
3	15	64
4	30	130
5	57	59
6	85	74
7	25	97
8	54	88
9	37	83
10	10	67
11	35	84
12	20	93
13	55	105
14	40	113
15	34	97
16	39	87
17	41	89
18	40	89
19	40	89
20	41	89
21	38	87
22	42	88
23	40	87

Participant No.	Tremor Results	Non-Tremor Results
24	41	88
25	39	87
26	39	89
27	40	89
28	41	87
29	37	90
30	41	87
Average	40	88

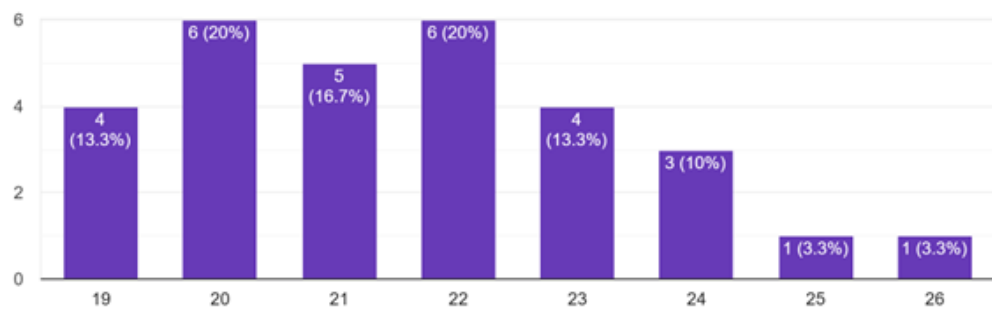
Appendix D

Questionnaire Results

D.1 Pre-Trial

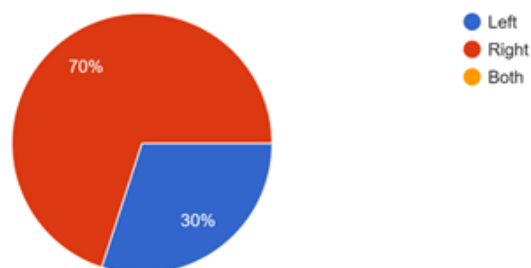
Age

30 responses



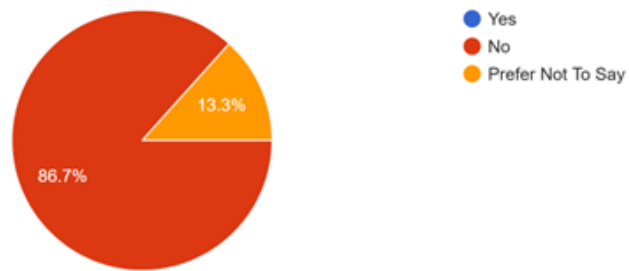
Dominant Hand

30 responses



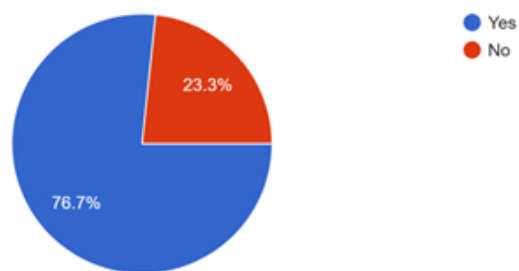
Do You Have Any Diagnosed Motor Impairments? (e.g. Parkinson's Disease)

30 responses



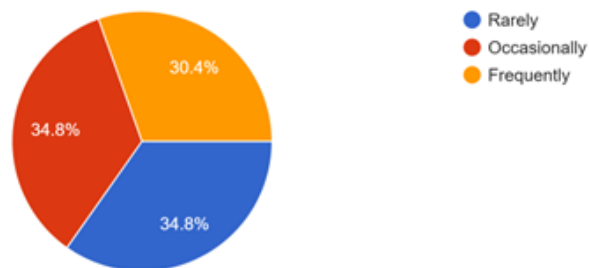
Have You Used VR Before?

30 responses



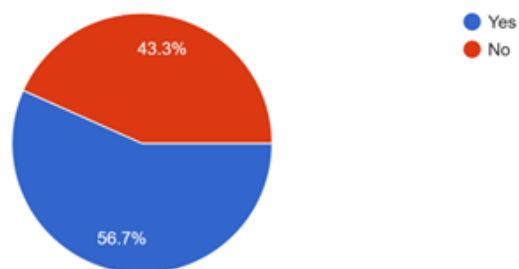
If Yes, How Often?

23 responses



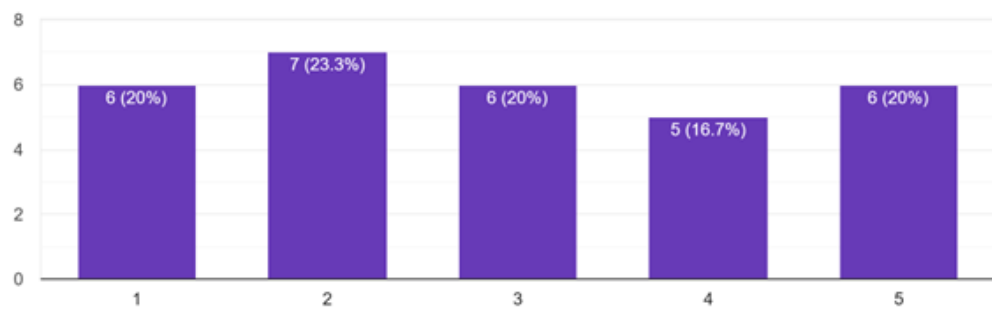
Have You Played Aiming Games (e.g. Shooters, Aim Trainers)?

30 responses



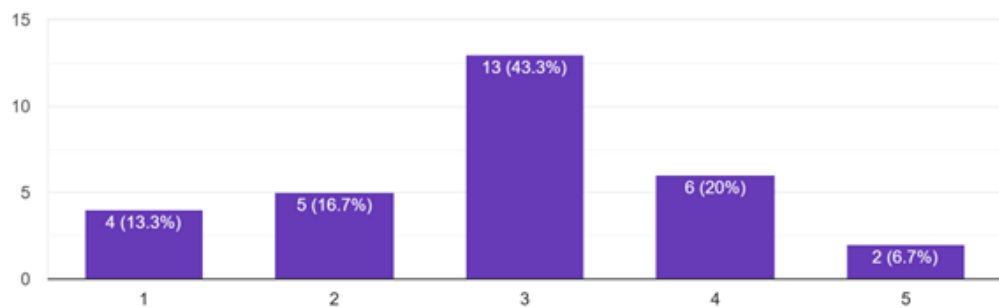
How Confident Are You In Your Aiming Abilities In VR?

30 responses



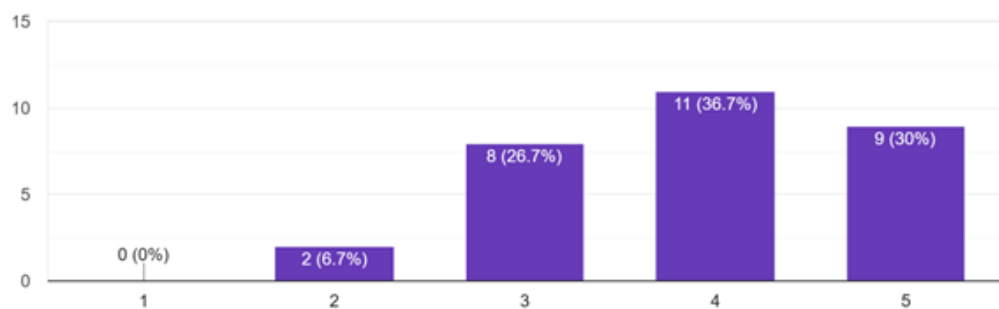
How Difficult Do You Think It Will Be To Aim With Simulated Tremors?

30 responses



Do You Expect VR To Be A Helpful Environment For Training Or Testing Tremor Compensation Techniques?

30 responses



D.2 Mid-Trial Tremors

What did you find challenging about this segment?

- Tracking the target

- overshooting targets
- Compensating for drift
- Couldn't aim properly
- Felt Unnatural
- Unpredictable movements
- Keeping the aim correct was difficult with the tremors
- Making any hits with tremor
- Target shaking unpredictably
- Learning how to aim in VR at all
- Felt disabled
- Adjusting hand speed
- Compensating for drifting targets
- Arm got tired
- Too hard
- Couldn't hold hand steady
- Adaptive aim timing
- Frustration balancing accuracy
- Overcompensation of hand
- It had a lot of mental strain

- Precision aiming
- Coordinating with shaking
- Hard to Adapt
- Frustrating to adapt to the tremors
- Managing shaking
- Micro-adjusting aim
- Overwhelming
- Holding focus on moving targets
- Predicting motion timing
- Tremor made it frustrating

Do you have any suggestions to improve this mode?

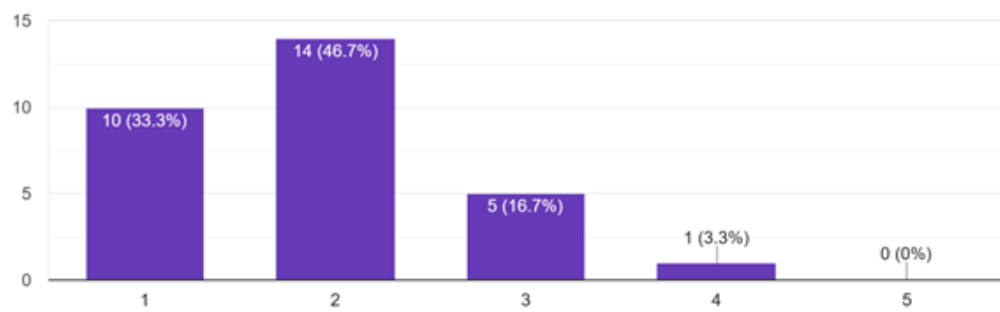
- Include slow-motion training option
- add score feedback
- Add tremor data visualisation
- Stabilisation tips
- More Explanation
- visual guides
- Adding different levels of tremors
- Training segment with score feedback

- Adjustable tremor severity
- In-game tips or prompts
- More feedback
- Include brief tremor calibration
- Adjustable tremor frequency
- Rest breaks
- Adjustable AI
- Visual cue on stable zones
- Add feedback for overcorrection
- Vibration feedback for training
- Add visual feedback loop
- shorter sessions
- Add aim tracking feedback
- Visual assistive reticle
- Assist Options
- A slower introduction to the training
- Break between sequences
- Add visual feedback for tremor strength
- Slower Progression

- Introduce target hold time
- Time based scoring
- Add tutorial with tremor tips

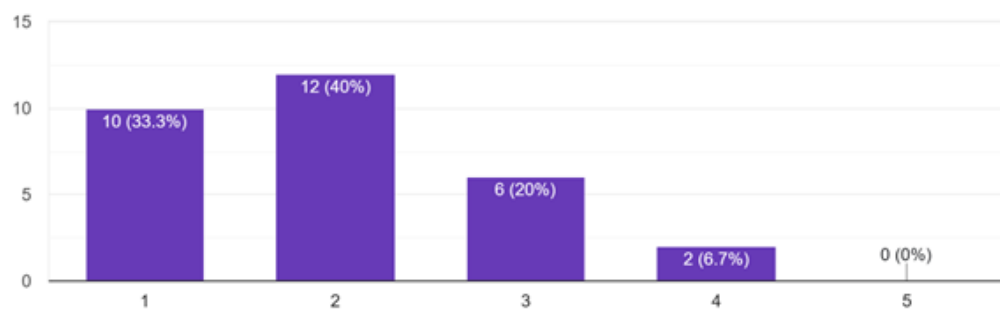
How easy was it to aim at targets?

30 responses



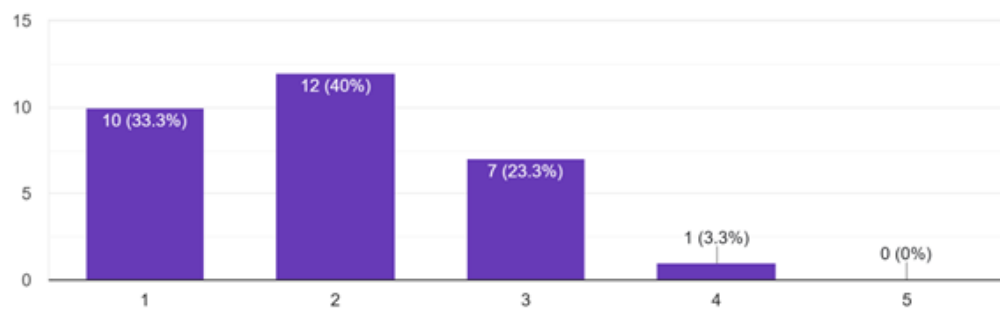
How accurate did you feel during the session?

30 responses

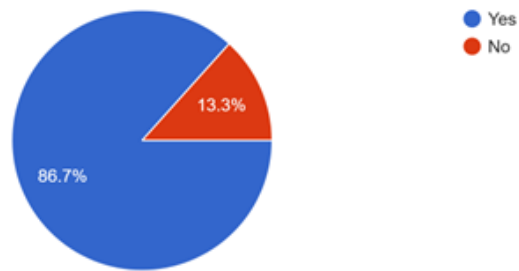


How in control did you feel of your hand movements?

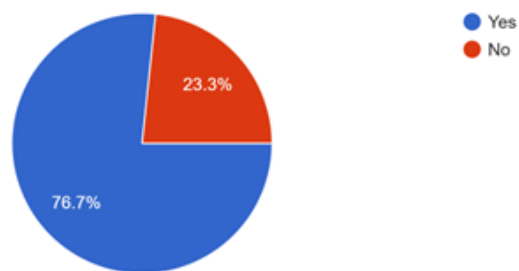
30 responses



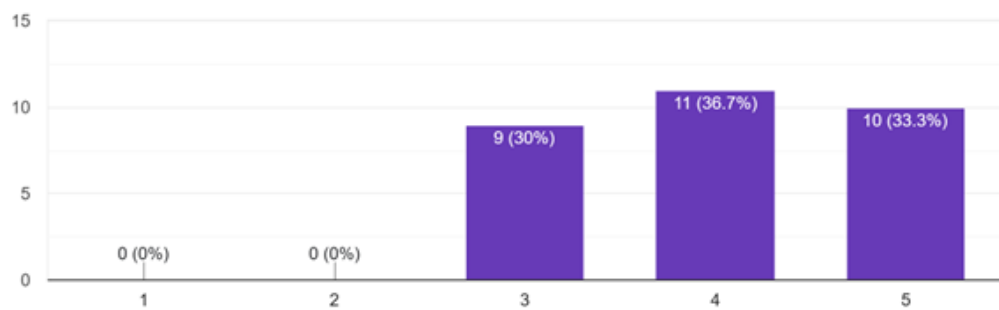
Did you feel physically fatigued by aiming?
30 responses



Did you feel mentally strained while aiming?
30 responses



Did the environment feel immersive?
30 responses



D.3 Mid-Trial Non-Tremors

What did you find challenging about this segment?

- None
- Adjusting to initial depth perception

- Aiming quickly
- slight delay
- Minor Discomfort
- occasional lag of tracking
- Getting used to VR was challenging
- Learning to aim in 3D space
- Depth and coordination
- Still adjusting to headset and controls
- Target distances
- Hitting small distant targets
- Hand strain issues
- No challenge
- Getting used to control
- Adjusting aim height
- Slight controller lag
- Aligning sights with depth
- Too easy, needs difficulty
- Adjusting to 3D space
- Pacing shots

- Minor tracking lag
- None, felt very natural
- Visual clutter
- Predicable patterns
- Boring after a while
- Motion tracking latency
- Understanding VR controls

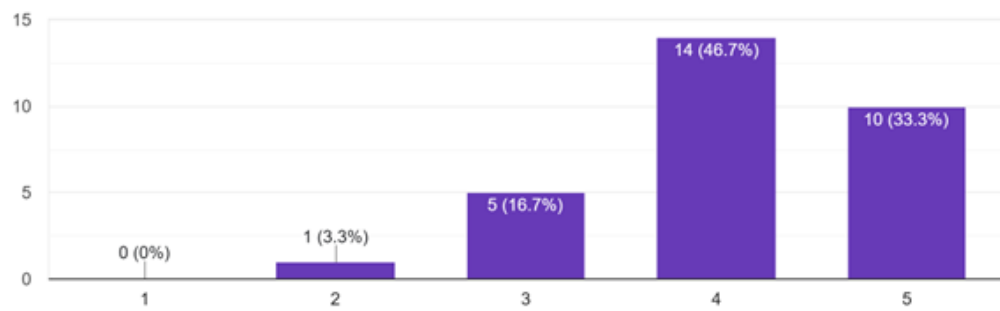
Do you have any suggestions to improve this mode?

- Add crosshair customisation
- Add difficulty modes
- Add challenge mode
- optimise tracking
- Adjustable UI
- better calibration
- A pre training mode to get used to the vr controls
- Add calibration phase
- More target variety
- Add motion sensitivity settings
- More visual Feedback

- Add depth scaling
- Vary target sizes
- rest breaks
- Dynamic Difficulty
- Add beginner mode
- More dynamic targets
- Better controller calibration
- Show hit accuracy per shot
- No
- Add aim calibration
- Add more modes
- improve the responsiveness
- Add regular moving targets
- Simplify UI
- Increase speed for advanced users
- Add a competitive mode
- Calibrate more precisely
- More reactive targets
- Add beginner onboarding

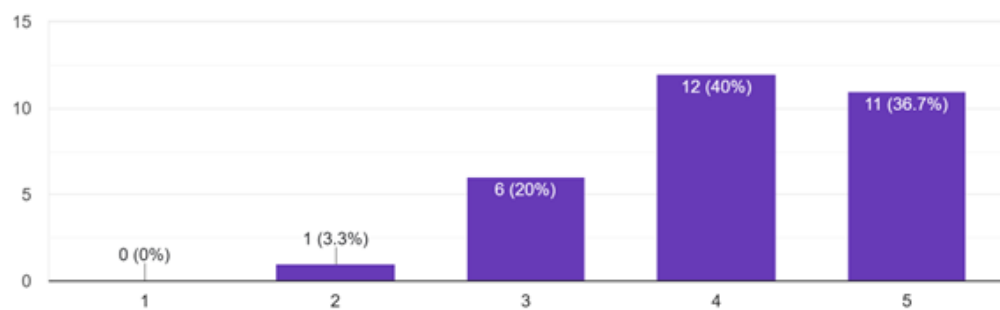
How easy was it to aim at targets?

30 responses



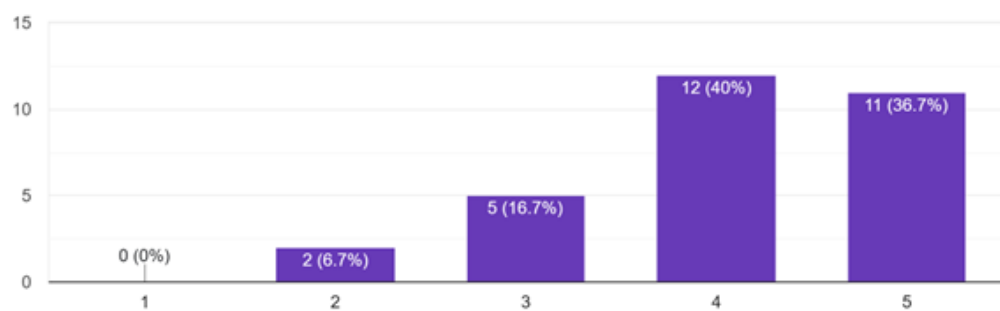
How accurate did you feel during the session?

30 responses



How in control did you feel of your hand movements?

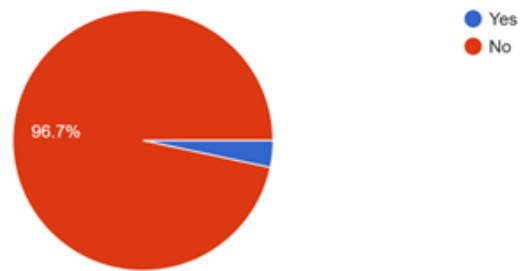
30 responses



D.4 Post-Trial

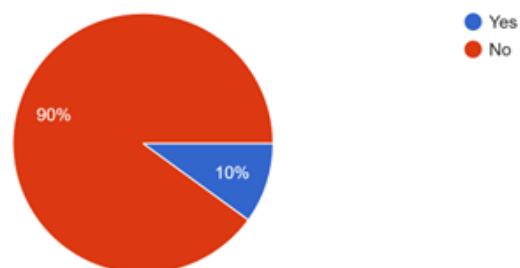
Did you feel physically fatigued by aiming?

30 responses



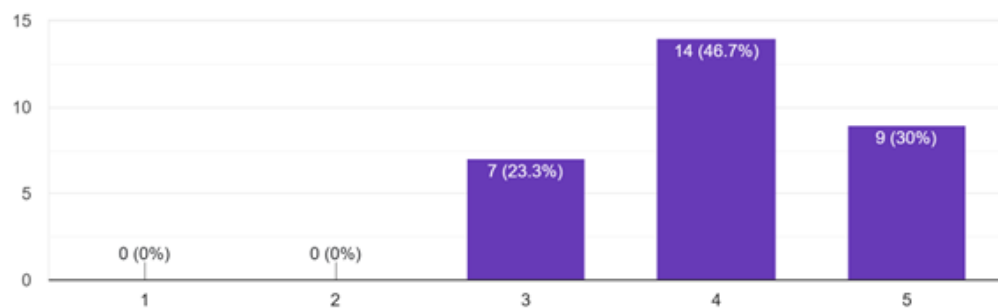
Did you feel mentally strained while aiming?

30 responses



Did the environment feel immersive?

30 responses



Which Mode Felt More Realistic Or Closer To Your Expectations?

- Tremor
- Non-Tremor
- The tremor mode felt like I was experiencing how tremors feel for people who have them

- Tremors

Did You Develop Any Strategies To Compensate For The Tremor

- Used more deliberate hand movement and anchoring
- Anticipated hand drift
- Adjusting rhythm of movement
- Deep breaths
- Gave Up
- Timed Shots
- I tried to predict where the target was going to move to
- Tried bracing hands
- Tried stabilising by resting hands
- Tried shorter bursts instead of long aim holds
- None
- Used shorter bursts of motion
- Countered tremor with slower aim
- tried resting elbow
- Reduced motion range
- Pressed elbows against torso
- Slower aiming, predictive movement

- Held controller closer to body
- Tried lowering wrist position
- Two handed grip
- Held controller tighter
- Focused on predicting oscillations
- Slower Movements
- Steadying my arm helped
- Slowed movements
- Braced arms and slowed movements
- Focused on stability
- Braced arms
- Used breath to steady
- Tried breathing and slower movement

What Did You Enjoy Most About The Experience?

- Seeing progression across modes
- Feeling improvement over time
- High sense of control
- realism
- Nothing

- overcoming the difficulty
- Being a part of the trial was fun
- Challenge of adaptation
- Challenge aspect
- Learning how tremor changes play
- Graphics
- sense of challenge
- Realistic difficulty
- science aspect
- Adaptation
- Being in VR for the first time
- Tactical adaption
- Challenging to control movements against tremors
- Testing accuracy under pressure
- the progression of my score shown on the screen
- Overcoming the difficulty of the tremors
- sense of realism
- Immersion
- It was challenging but it made it fun

- The experience of how tremors may feel
- Adapting to tremor mechanics
- Achievement
- Trying new aiming approach
- Gained a new empathy for those affected by natural tremors
- I gained a new view on what it is like to live with tremors

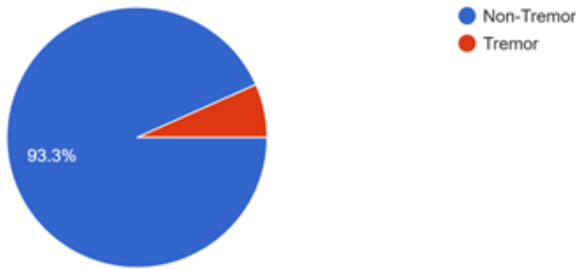
Do You Have Any Suggestions For How The Simulator Could Be Improved?

- Add tutorial for tremor compensation
- Add co-op or social setting
- Add adaptive difficulty
- more feedback
- Easier Mode
- adaptive A.I
- A preshow to get my feel of the simulation before it started
- More assistive settings for beginners
- Add visual indicators of tremor strength
- Slower-paced warm-up level
- Less intensity
- allow customisation of tremor pattern

- Adding aim assistance mode
- longer trials
- Custom Tremors
- Simplify tremor for beginners
- Optional guided assist during tremor
- Include different strengths for tremors
- Add pause between shots
- Multiplayer functions
- Option to replay practice segment
- adjustable challenge curve
- Better instructions
- More tremor levels
- Add practice with tremor
- Replay previous trials for learning
- Export data
- Reduce Fatigue with shorter sessions
- Multiplayer mode
- Tremor adjustment settings

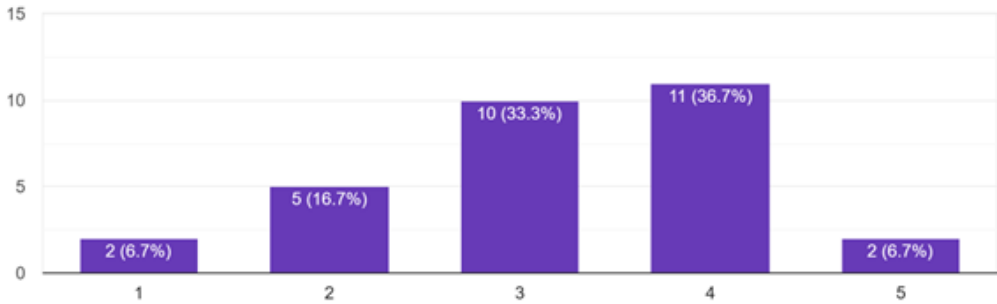
Which mode did you find easier to use?

30 responses



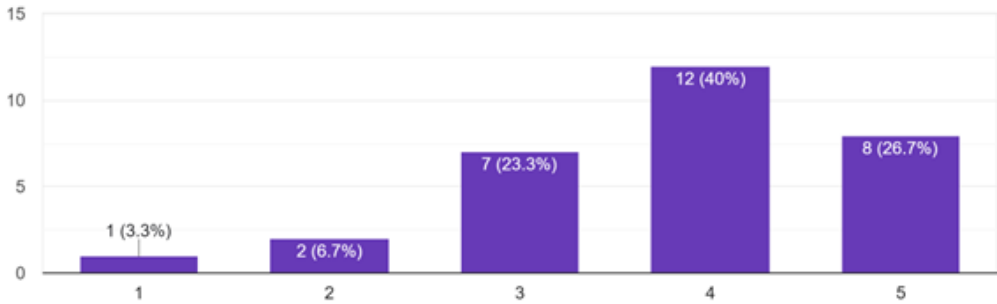
Did You Feel Like You Improved Your Aiming Throughout The Trail?

30 responses



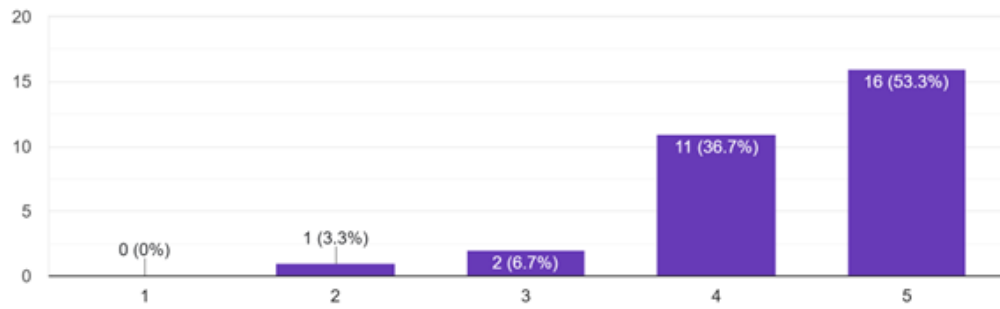
How Enjoyable Was The Experience

30 responses



How useful do you think this kind of VR simulation could be for tremor training or research?

30 responses



Would You Be Interested In Participating In Similar VR Experiments In The Future?

30 responses

