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Abstract:

In this master thesis, we present the design, development, and testing of a Virtual Reality game aimed to distract teenagers and young adults (13+) when undergoing an epidermal puncture medical procedure or wound cleaning.

For the design direction, insights from a small-scaled focus group were gathered through a questionnaire. The overall methodology was approached from the users' subjective and objective perspectives. The first methodology focused on registering breaks of presence using a reaction time-sensitive secondary task. Finally, the Adapted Method achieved the objective approach for measuring presence.

The data gathered concluded that the proposed application distracts the user, increasing the minimum required stimuli for breaking presence. Lastly, the data show a difference in the minimum required stimuli to break presence based on the events occurring in the game; therefore, optimal timing for the epidermal puncture exists. This thesis contributes to a broader insight into how Virtual Reality and Medicine can develop embodied experiences to assist young patients.

ComfortXR

Master Thesis Report

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Abstract

In this master thesis, we present the design, development, and testing of a Virtual Reality game aimed to distract teenagers and young adults (13+) when undergoing an epidermal puncture medical procedure or wound cleaning. For the design direction, insights from a small-scaled focus group were gathered through a questionnaire. The overall methodology was approached from the users' subjective and objective perspectives. The first methodology focused on registering breaks of presence using a reaction time-sensitive secondary task. Finally, the Adapted Method achieved the objective approach for measuring presence. The data gathered concluded that the proposed application distracts the user, increasing the minimum required stimuli for breaking presence. Lastly, the data show a difference in the minimum required stimuli to break presence based on the events occurring in the game; therefore, optimal timing for the epidermal puncture exists. This thesis contributes to a broader insight into how Virtual Reality and Medicine can develop embodied experiences to assist young patients.

Contents

Thesis Details

Thesis Title:	ComfortXR
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Part I

Introduction

During the final academic semester of 2021, a Virtual Reality (VR) and Augmented Reality (AR) production house named Khora contacted me to develop a VR game in collaboration with them and Viborg Hospital.

The lead for this project is Thomas Saaby Noer, Head Of Healthcare at Khora, who introduced me to the project Comfort XR. Comfort XR is a product that is developed in collaboration with medical experts as a pain-distruction tool with the help of VR stimuli. The project has developed three different versions of the Comfort XR, for diverse age groups of young children up to the age of 12.

This study continues with the Comfort XR's product and focuses on teenagers and young adults instead (ages 13 and up).

Part II

Methodology

1 Research Methodology

Based on the academic research model, this thesis hypothesis delves from extended literature research on virtual reality, pain distraction in the medical field and the concept of 'presence' [38], [18],[33] as well as the way of measuring presence [3],[9],[4], [10],[33]. Through desk research on previews publications and relevant prototypes, the hypothesis of breaking presence with a stimuli was formed. To test that hypothesis a study was created and conducted with the purpose to analyze, generalizing the data, and drawing final conclusions regarding the development and the overall assumption.

2 Design Methodology

The first stages of the project development were very open-ended initially which allowed for experimentation and flexibility on the concept. That fluidity allowed the design process to evolve through continuous feedback from Viborg Hospital and the end users. An agile design process was chosen. This allowed for the design to be flexible and be changed based on feedback. When the base design was locked and the theme of the game decided, stretch goals were also created, elements and mechanics that would enrich the experience, but were not necessary for achieving the goal of the project. Through constant testing within the company initially and with focus groups in the later stages of development, the product's design got tested regarding its difficulty and overall game mechanics.

3 Development Methodology

The agile development process that was adopted for the creation of this project allowed the easier implementation of ideas that spawned from feedback sessions. The iterative nature of this pipeline required multiple feedback loops that updated the design based on user feedback. At an early stage of the development the minimum viable product was determined and stretch goals were established based on budget and time management. After the initial design document was drafted a time schedule was created with the most important milestones and deadlines. Each week an update and feedback meeting was held with the project lead for design evaluation and establishing new tasks, ensuring the project was progressing in a timely manner and towards the desired direction. 3D models, textures, sounds and VFX where created by the expert team at Khora, while all code and in engine development was done by me.

Part III

Analysis

To understand the field of Virtual Reality we will first have to study the Virtual-Real continuum as it has been defined [35].

4 The Virtual-Real continuum

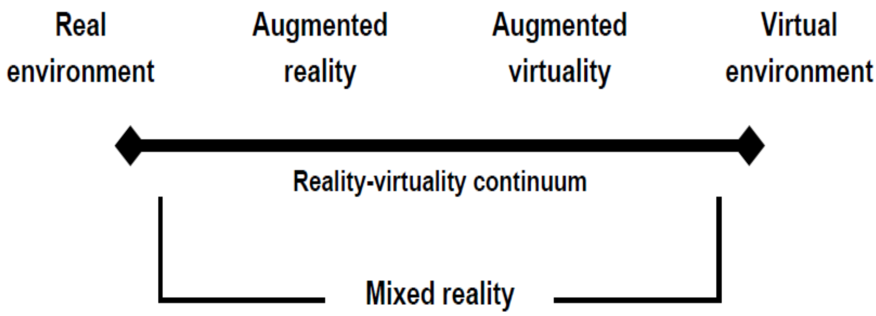

Fig. 1: Virtual-Real Continuum

In figure 1, we see the two pillars of this continuum. On the left, we have the Real environment that includes only real objects, and this environment we can conceive through the use of our senses. The real environment is not influenced or changed in its taxonomy by how we perceive it, even if the perception of it is not direct, e.g., through a technological device. On the diagram's right axis, we have the Virtual Reality pillar. In virtual reality, environments that are comprised only by virtual environments that have no physical presence in the material world, are included. Between these two pillars we encounter the Mixed Reality, comprised of Augmented Reality and Augmented Virtuality. In both those cases, Virtual environments and the Real environment are present in different percentages and experienced by the user.

Virtual Reality

In this chapter we will present definitions for the term "Virtual Reality" as well as how research in Virtual Reality have influenced the original graph that Paul Milgram et. al.[35] made.

"A Virtual environment is an environment in which the active user is full immersed in a completely virtual world, which could mimic or not the properties of the real world, ether real or imagined, but can also transcend the limits of the physical reality creating a world in which physical laws that govern gravity and material properties rare not upheld". [34]

The term "Virtual Reality" was used for the first time in 1989 from Jaron Lanier [5], member of VPL Research Inc., a manufacturer of stereoscopic head mounted displays for optic display of a virtual environment. He defined Virtual Environment as an: "Interactive, three dimensional environment, created in a computer, in which the user can be immersed".

The technologies of virtual environment immerse the user in a fully virtual world and don't allow the user to see or interact with the real world.

There have been a number of definitions for Virtual Reality:

- "Virtual reality is an alternative world full of images created using a computer that react to human movement. These electronically simulated environments are usually visited with the use of a precise data suit, which is comprised by a head mounted display and data gloves that transmit data through optical cables." [16]

- "Virtual reality is electronic simulation of environments which are experienced with use of head mounted displays and wired clothing, allowing the end user to interact with these environments in realistic three-dimensional conditions." [20]

- "The term "Virtual Wolds", "virtual cockpits" and "Virtual employment positions" were used to describe specific works. In 1989, Jaron Lanier, CEO of VPL [27], used the term Virtual Reality to encompass all these virtual works under the same term. Virtual Reality is typically corresponds in three-dimensional realities realized with the use of head mounted displays and virtual reality gloves." [25]

Stereoscopic head mounted displays as well as gloves, sensors, headphones and other peripheral devices have been used in the various attempts to define the term "Virtual Reality". This association of the term with technology should be avoided, as the technological advancements are limiting and quickly make it obsolete. In order to better define Virtual Reality, Jonathan Steuer[44] proposed the term of "Telepresence". Telepresence is defined as " The experience of presence in an environment through a means of mediation"[44]. As the physical comprehension of real environment is referring to presence, Telepresence is referring to the mediated comprehension of an environment. With the use of Telepresence proposed by J. Steuer[44], the term of Virtual Reality defined as:

"A Virtual Reality is defined as a real or simulated environment through which an observer experiences the feeling of Telepresence".

With this definition the term Virtual Reality is generalized and could include almost all forms of Mediated Reality. "Mediated Reality, is referring to a general way of artificial modification of the human perception through the enhancement, intentional reduction, or in general alteration of the optical sense". [29]

Taking the definition of Mediated reality in consideration the Reality-Virtuality continuation axis is expanded vertically with another axis, that of Mediation.

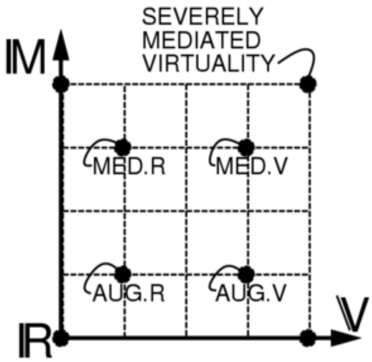

Fig. 2: Mediation Continuum

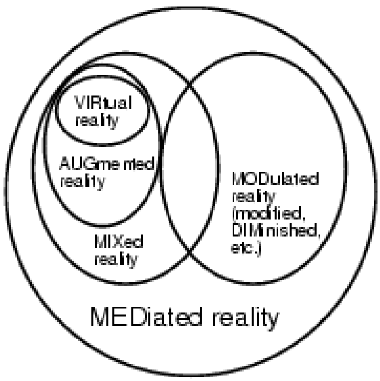

Fig. 3: Mediated Reality

4.1 Virtual Reality Head Mounted Displays

Head mounted displays include screens that project the virtual environment. Through the use of special optical lenses mounted in front of those screens, the majority of the user's field of view is occupied by the displayed environment, giving the illusion of being there. Sensors attached to those devices the movement of the head can be calculated while, most often than not, headphones can reproduce the sounds of the virtual environment.

4.2 Degrees of freedom

The sensors attached on a head mounted display are responsible of tracking the head and adjust the content shown to the end user.Depending on the movement that can be tracked by the sensors, the head mounted displays are divided in two categories;

- Three degrees of freedom; These devices are usually equipped only with a gyroscope, accelerometer and magnetometer, allowing the device to track the orientation of the head mounted display. This allows the device to track the rotation of the user's head, but is not capable to track the movement of the head in the physical three-dimensional space.
- Six degrees of freedom; These devices are usually equipped with a plethora of sensors. Usually a number of cameras are used to find the position of the headset in the three-dimensional physical space while a gyroscope, accelerometer and magnetometer are used to assist in the tracking of the orientation of the headset. Based on the implementation the cameras are either mounted on the head mounted display and are directly scanning the real environment for points of reference (inside-out tracking) or cameras placed on the real environment and are scanning for the headset (outside-in tracking). Triangulating between the register positions from each camera the true position of the head-mounted display is calculated. Note that in some implementations of outside-in head mounted displays tracking use lasers mounted in the physical world while cameras mounted on the headset are used to track the position of the headset.The details of the technology escape the scope of this thesis.

For this project a three degrees of freedom Mediated Virtual Reality application will be used to test the hypothesis.

5 Patients

In this section we will analyze the limitations and considerations for the creation and use of virtual reality applications for kids and teenagers between the ages of twelve and eighteen.

5.1 Age restrictions

Most VR headset manufacturers say the device is not suitable for children under age 12 or 13 years old.

Even if the content included on the applications is approved by PEGI for younger audiences the concerns around healthy development of the child's brain are the limiting factor and deciding force on age restrictions. Since a child's brain exhibits high plasticity, the exposure to virtual reality early in the child's development could lead to an alteration on the child's brain synapses, potentially causing harm. Due to ethical reasons a long term study of the effects of Virtual Reality on children has not been conducted.

- "Visual acuity, one of the most fundamental visual function, has plasticity up to 8 years old or later. Further, IPD of children is smaller than that of adults. IDP in 8 years child is about 54 mm. Stereoscopic images designed to IPD about 60 mm have too large depth for children." [45]
- "Most brain activity research related to depth perception concentrates on fundamental issues, such as identifying the exact pathways for binocular vision. There is little work done on depth perception of stereoscopic content on 3D displays and relating aspects such as visual fatigue."[26]
- "Children should be cautioned about stereoscopic images because they may not subjectively perceive a problem even if an eye is deviated. Although there is little evidence that viewing stereoscopic images causes irreversible damage to health, there is also no evidence that contradicts this contention. Ethically, it is not possible to conduct experimental studies using child participants, even although there is some evidence that visual/visuo-motor functions develop up to the age of low teens."[45]

5.2 Eye strain

Even though no evidence for long term damage to the eyes because of the use of Virtual Reality head mounted display can be confirmed by experts, Eye strain and fatigue is reported by a large amount of people trying it. The user while wearing the head mounted display blink less often and that causes the surface of the eye to dry out. "Viewers should be careful to avoid viewing stereoscopic images for extended duration because visual fatigue might be accumulated." [15] Another consideration is the fact that monitors can't reproduce the way eyes work entirely. The fact that the user has to focus for extended amount of time to a specific distance (that of the mounting point of the screens in the head mounted display), causes concerns for the progression of Myopia, "as accommodation adapts to a closer point in space." [15] The rapid advancement on the technology used for creating such head mounted displays makes it harder to study the long term effects of the technology on vision impairment.

5.3 Cybersickness

Cibersickness is the term used for the feeling of nausea produced in many cases when fully immerced in a virtual world. Early virtual reality (VR) systems introduced abnormal visual-vestibular integration and vergence-accommodation, causing cybersickness [30]. This miss-mach between the information sent to the eyes and the inner ears is also called "Sensory conflict" or "Sensory Missmatch" [36][37]. Nausea, dizziness, disorientation, or the loss of spatial awareness are typical symptoms of Cybersickness. The loss of spatial awareness is the most concerning of these symptoms for young teenagers in the long run, as it could alter the brain synapses as explained above. It was believed that with the advancement of technology this problem would be solved [6], but cybersickness is still a big problem for Virtual Reality. Cybersickness most often than not stops when the users leaves the Virtual Environment, but in some cases it can persist for several minutes or even days.

5.4 Design choices based on patients

These considerations lead to design choices that elevate most of these problems. As the player is not required to move around in the physical or the virtual world and at no point the application takes control over the camera of the game, thus avoiding sensory mismatch and cybersickness. As the application is meant to be used only on children above the age of 12 and for a limited amount of time, the risk of harm to brain synapses is minimal, and parent approval is required before the use of the application. Lastly the eye strain consideration is addressed by limiting the play time of each participant in only the necessary for the procedure time and the use of darker colors that would not strain the eyes unnecessarily.

6 Medical procedures

The medical procedures that this applications is aimed at are:

- Iv placement.
- Vaccines.
- Blood samples.
- K-wire removal.
- Wound cleaning.

The tree first use cases are very similar and can be grouped under the same category of epidermal puncture medical procedures or "Venipuncture procedures". These procedures require the doctor or nurse to locate a vein on the patient's arm and puncture the patient's skin with a needle. On the two first cases a liquid is injected to the patient's bloodstream while the third a blood sample is extracted. In the case of Iv placement the needle remains attached for a number of minutes based on the time required by the iv. The application will be played during the initial puncture and not for the full duration of the Iv.

In the case of wound cleaning the application is aimed for wounds not located on the player's head, as the head mounted display would make the cleaning impossible. The wound is usually cleaned using spirits and clean bandages. The application is not aimed at wounds that require stitches, but that doesn't exclude the possibility of its use in that case.

In the case of K-wire removal the application is used in collaboration with local anesthesia. The aim is to block the sense of vision and distract the user from the numbed sensation of movement of the wire. During this procedure the K-wire (a wire penetrating the skin of the user in order to hold broken bones in place) is removed completely, and while it does not hurt due to the anesthesia, most patients feel very uncomfortable.

6.1 Pain distraction in the medical field

Pain distraction using VR technologies is becoming a lot more common. A lot of proprietary applications have been developed and has been a research field for almost 20 years. In recent years a plethora of studies have been conducted in order to determine if Virtual Reality can be used to lessen the chronic or perceived pain felt by a patient during medical procedures such as IV placement or needle injections.

Even though these studies that focused on venipuncture/epidermal puncture (IV placement and injections) failed to produce significant evidence on the reduction of the perceived pain, it was clear form the studies that the patient was more comfortable during the procedure when a VR distraction element was present at J.Gerson et.al.[21] and K.Wolotzky et.al. [23]. The significant reduction of heart rate and the rating of the physicians pain observation leads us to believe that the VR distraction, makes these procedures less stressful for the patient and in turn makes them easier for the physician that is performing them. More over in the case of J.Gold et.al.[14] a significant change is reported on the perceived pain of the patient after the placement of the IV, with the non-Vr distracted patients reporting an increase in perceived pain of four times the original pain felt during the epidermal puncture. Another study[8] shows that the adoption of Virtual reality applications during immunization for children was positively received by medical stuff, the child patients and their parents, achieving lower levels of anxiety and pain reported from the kids that took part on the experiment. Similar findings were reported by H.Chu et. al.[17] when researching the use of VR for alleviating pain on children that had suffered small burns. More specifically a 2 points on the Wong-Baker™ VAS reduction was reported. Tuba Koç Özkan et. al.[24] reports that Virtual Reality googles were successful on lowering the perceived pain and reduced the anxiety levels on children during epidermal puncture procedures.

State of the art

The state of the art currently is applications that immerse the patient in a world using VR headsets with three degrees of freedom. These applications are usually made in collaboration with hospitals and are rarely readily available for other institutions. The applications are usually non interactive in a meaningful way though, failing to completely immerse the patient.

- HypnoVR: Aims to calm down patients before,during and after surgery or medical procedures.
- RelieVRx: First FDA approved medical VR app. Aims on chronic lower back pain relief using physical exercises.
- A lot of meditation and relaxation applications that claim to help with stress anxiety and chronic pain.
- ComfortXR: ComfortXr is created by Khora and is distributed to various hospitals around Denmark and Christopher C.Carlsen[7], the previous study that was conducted as part of the same product, found that during the experiment the attention of the child performing the test would fluctuate based on the state of the game, thus "providing opportune and inopportune moments for the epidermal puncture procedure". It also proved that there is a significant difference on the child's attention depending on how active the game was at the moment. Lastly, the increase in reaction times remained virtually the same, regardless of how long the game was played for. The application described and developed in this thesis will become part of the same product after its completion.

6.2 Presence

In this section the most common methods for measuring attention will be presented. Secondly the "Measuring distraction as a medium of presence" method proposed by [33] ill be presented. Lastly we will present the reasons for choosing the later in our analysis.

Presence

A number of definitions have been proposed for the term presence in the years that it has been studied [38] but it is most commonly described as the feeling of "being there" [18], or more accurately; "the sense of psychologically leaving a real location and feeling as if transported to a virtual environment" [33]. Presence has often been regarded as an important element for the success of a virtual reality experience, and early researchers thought a multi-sensory experience was enough to create presence [31], [19]. The cybernetic approach to VR as it is referred to has competing approaches for presence, in which the interactivity between the user and the environment play a key role to the achieving presence [41], while others support the claim that the quality and realism of the virtual environment play a key part [49]. Presence should not be confused with immersion or engrossment though. Immersion's aim is to let the user experience a computer-generated world as if it were real "to the degree which an individual is shut-off from the real world by a VR system but does not necessarily determine presence." (rolf), while a very attentive task that engross the user in the virtual enviroment will also not always translate to presence [2],[42],[32]

Measuring Presence

There are to classification commonly used, namely subjective and objective measures and are broken down to more subcategories.

Subjective measure of presence is through using post-test questionnaires [48]. This method of measuring presence has been heavily criticized against as they present a number of flows. More specificaly they are unable to quantitatively discriminate between virtual and real life experiences[46], are susceptible to alterations based on the memory of the user [47], are not sensitive to presence compared with objective measures [1],[39] and measure presence of the whole mediated experience, being unable to provide a continuous measurements of presence [33].

Objective measures try to find behaviours and biological measurements that could be related to presence. A variaty of biomarkers are used such as heart rate and recently even more advanced methods have been used in an effort to identify neural correlates of presence in VR such as neuroimaging (fMRI)[3], [9] and electroencephalogram (EEG) [4] [10]. These methodologies can provide important insights on user presence but the equipment used for measurement can pick up low signal-to-noise ratios.[33] "Behavioral measurements, namely observations of a person's behavior while being exposed to the test material the observer can misinterpret the behavior and that the test has to be specifically designed" [33] . The behavioral measurements are on the other hand susceptible to human error, with the observer can misinterpret the behavior of the user, and for such reason require specifically designed tests.

A very interesting methodology is proposed by Slater and Steed [40]. Their approach is to detect breaks in presence instead of tracking when the user is feeling present. That can provide some hints on the elements that brakes presence in a mediated virtual environment [43]. This approach though can only provide a binary result of presence or not, and there is no way to more accurately measure presence in a more analog way. In other worlds this method is not sensitive to different levels of presence[33] . In contradiction, the attention-based method of a measuring the time of a secondary task can provide a continuous measurement of presence in a virtual reality experience [22] but can be affected by a variety of other factors such as muscular tension [13], age [28], [12] and gender [11]

Adapted Method

The Adapted Method was proposed by Rolf Nordahl [33] and its a method for measuring presence. The main argument of this method is that "presence is as strong as the minimum amount of stimuli required to break it"[33]. In order to test this theory a secondary variable measurable stimuli is introduced to an experience. Then the algorithm tries to determine the maximum values this stimuli can have and remain undetectable from the user. The Adapted Method does not rely on time or timing and therefore all potential factors (such as age, gender etc) that effect reaction times are disregarded. To preserve this quality, tests that use the Adapted Method should decouple the intensity and frequency of the stimuli from time. Instead the authors proposed the stimuli to be adjusted across test participants by obtaining a general indication.

Reasons for choosing the Adapted Method.

This method has the potential to objectively measure immersive presence at specific events. As such it will allow us to find the minimum stimuli strength required to break presence when playing the game. It will also provide us with a reliable measurement and method to find scenes of presence that could work as optimal times for the epidermal puncture procedure. The method is also less intrusive and does not alter the original experience as much as the use of bio-markers for instance. It is important to note though that a proper a proper screening process should be included in the experiment in order to level out threshold variances [33] .

7 Hypothesis

The goal of this study is to create an evaluate the effectiveness of an application that can distract the patients during the specified medical procedures, reducing discomfort and making the experience better for both the patient and the doctor performing it. A break in presence method of measuring the time of a secondary task will be used as well as the Adapted Method proposed by Rolf Nordahl [33] to determine the minimum required stimuli for breaking presence while using the app. We expect to find an increase on the reaction times of the secondary task as well as the minimum required strength of the stimuli threshold for breaking presence. Last but not least, we will try to determine the optimal timing for the epidermal puncture procedure.

Part IV

Design

8 Design restrictions

The app was created in collaboration with Viborg Hospital and Khora VR. Both institutions are experts on their relative fields, with Viborg Hospital having implemented similar products on their medical procedures for younger kids, while Khora has developed said products.Relevant design limitations were created at the start of the project's development by the the medical experts of Viborg Hospital, but the content and game design decisions were left to the developer.

These restrictions were created to facilitate as many medical procedures as possible and where the following:

1. Require only one hand to play.
2. The game must comply with PEGI's recommendations for the age group.
3. The game must have a duration of between 3 - 15 minutes.
4. The game must be very simple to use for both clinician and patient.
5. The following procedures are intended for the game to be used in medical procedures: IV insertion ,Blood sampling,K-wire removal,Cleansing of wounds (whole body, except the phrased area where the glasses are located).
6. Able to be played on seated, semi-seated and laying positions.

These restrictions were further analyzed and translated to game design restrictions allowing the communication of game design decisions in more relevant terms. More specifically the following restrictions were added:

1. Elimination of the need for wide or fast movement of the hands or head
2. Intuitive actions, the user should know exactly what he needs to do to win the game at all times.
3. Intuitive controls, the user should not have to guess what buttons are needed for the game

9 Final App Design

With these restrictions in mind the first design document was drafted. The theme of the game was decided to be a space wave defender shooting game, in which enemies will spawn in waves and come towards you to destroy your spaceship. Your spaceship would be equipped with a gun that would allow you to shoot and destroy them. In order to comply with PEGI's recommendations for the age group, no blood will be shown at any point of the game and the explosions will be not rendered realistically but in a cartoon fashion. More over, the design of the enemies/ aliens will deliberately be more machine like than organic.

In order to support all required positions of play, the game was developed in such a way that it would be easy to reset the view of the player by manipulating the up vector of the world. More specifically the hardware equipment allowed for a reset of view's orientation with a press of a button. This could also be triggered by code. This allowed the game to be developed without the need for custom vector transforms or orientation changes.

9.1 Play area

In order to eliminate the need for fast movement of the hands or head, only rotational data is tracked from the controller, which makes aim a more deliberate movement than a random spastic movement. At the same time even if the field of view of the player remains a full 360 sphere, the game-play elements always remain in a small cone in front of the players cockpit. The angle of this cone was decided to be about 90 degrees horizontal and about 80 vertical, with most of the remaining view being blocked by the cockpit. Information about the state of the game has been added on screens inside the cockpit. Even though the goal was to keep the players attention to the front, an interesting environment was important to keep the player immersed and destructed. For this reason the cockpit was not oversimplified inside this predetermined cone, and has interesting design elements that the player could explore, but not interact with as it is important to keep him calm and in a seated and rested position. This contrasts the sides and back of the cockpit where there are no such elements, in an effort to keep the player from turning to the side.

9.2 Difficulty

In order to make the game vary in length, a level system was designed. The player will fight waves of enemies of increasing difficulty through out the game. The difficulty of the game will exponentially increase in order to reach the maximum difficulty as fast as possible, at which state it will stay until the procedure is finished. Each enemy wave rewards the player with points, based on how accurate the were at shooting the

Fig. 4: Cockpit view

enemies. If the player fails to hit the enemy within a time frame, the enemy will land on the spaceship and attack it, dealing damage to the player's health. The game will remain on the same difficulty even if the player loses. That means that after restarting the game the last wave that the player was able to achieve is spawned and his score is reset. This allows the player to be engaged and interested in the game as fast as possible after a loss. Moreover, the spawning of the levels was manipulated in a way that ensured that there were always at least one enemy the player could shoot at, even if not all enemies were cleared form the previous wave. This was done in an effort to eliminate the waiting time between each wave, that disrupted the passing of the game.

9.3 Interactions

In order to design intuitive actions the game design remained very simple. The goal of the player is to kill the enemies that fly towards him. The game only allows for one input interaction, aim and shoot. This is achieved by tracking the rotation of the controller in real time and by using the trigger button on the controller it spawns a bullet.

9.4 Enemies

Two distinct enemies were created for this game, one fast with low health and one slower that has more health points. A red spot indicates the weak point of the enemies that allows the player to kill them in one shot, otherwise the enemies have distinct health pools based on their type, which is easily recognized by the difference in their models. Killing an enemy rewards points based on its type and if it was killed in one or more shots. When the fast enemy is hit but not instantly killed it will become enraged, moving towards the player's cockpit. When he reaches a predetermined distance it will land and shoot at the cockpit dealing damage. After that the enemy will fly away. The slower enemy does not become enraged but instead it's speed is increased. If the enemy is not hit and allowed to roam for a while, it circles through predetermined points in space. The slower enemy spawns a box when killed. This box functions as a power up for the player. The box changes color on a timed interval and when shot, it gives the player a new gun for a few seconds based on the color it had when it was shot.

Two more enemies were designed as stretch goals but haven't been implemented yet. The first is another slower enemy that when shoot would remain stationary, turn and face the player's cockpit and shoot a projectile bullet, then continue moving around. The player would be able to shoot this projectile before it hit the cockpit to avoid damage, or get hit and lose health. The last proposed enemy would also function as an ending boss battle, with the enemy representing the alien's authorship. this enemy would take the majority of the available space in the play area and have multiple weak points. when a weak point was hit, the rest would be covered and a normal wave of enemies would spawn. when the player dealt with that wave the remaining weak points of the mother-ship would be again venerable. Design solutions for triggering this event were explored, with input of a specific code given by the physician being the most prominent one. This design was eventually abandoned though, as it goes against the restriction of flexible game time and ease of use from the player and physician.

9.5 Weapons

Input interactions remained the same for all weapon types, with slight differences based on the equipped weapon. There are three weapons implemented on the game currently. A normal gun, and two power ups; a machine gun and a grenade launcher.For the default weapon the player is allowed to shoot as fast as he can press the trigger on the controller.The first power-up was a machine-gun type weapon, that allowed the player to hold the trigger and continuously fire a stream of bullets. The second power-up launched grenades when the player pressed the trigger. If the player pressed the trigger again the grenade would explode dealing damage in an area. This feature was at first a stretch goal for the development of the game, but was also mentioned in the first feedback session with the target group as a proposed change in the design, therefor added to the game. The power ups have limited duration, and as soon as they are picked up a counter starts on the WeaponManager. Each weapon has its duration saved on its script. The machine gun has a duration of 6 seconds and the grenade launcher has a duration of 10 seconds.

Two more weapons were designed as stretch goals. A laser gun with a heat mechanic that allows for continues fire, dealing damage over time but building up heat the longer it stays on. Once a threshold is met the weapon is unusable for an amount of time, or even until is picked up again. Lastly a "lock and shoot" missile weapon has been designed. The user would hold the trigger and hover over enemies, marking them. Releasing the trigger would then fire a number of missiles equal to the marked enemies,up to three.The design proposes a limited number of bullets for this gun, making the weapon feel more like a strategic choice. These weapons have not yet been implemented or included in any way on the conducted tests, but they are considered a stretch goal for the delivery of the application.

Part V

Development

10 Development Restrictions

Since this study was a continuation and extension of an established product, there were a number of limitations regarding the technologies and hardware that could be used. More specifically the project had to be incorporated when finished to an existing Unity3D product, aimed at the Pico Neo 2 4K device. That meant that the project could only used 3 degrees of freedom as this is what the target device supports only. This was heavily considered when designing the application, and proved a valuable tool instead of a limitation,as the user is not incentivised to move around from his seat since the device does not track positional data. Additionally the project should be developed in a way that would allow its integration with the previously created projects. For that reason a branch of the previous project was created and kept separate form the previous projects. This allowed for the coo-existence of the new project with the previous one, but in a way that the new project would not effect the preexisting projects. When the new project gets finished, it will be added to the main menu of the app and the branch will be merged to the main GitHub repository. By making the project a branch of the main repository, conflicts were avoided as the project made use of the same settings and plugins as the main branch, and the rest of the project is continuously been updated with new features. Scripts and plugins as well as models, animations, sounds and other assets that are used for this project were added under the same folder, keeping them separate from the file structure of the main branch. Technical limitations also included the inability to use models with high polygon count, complex shaders, transparent materials and complicated VFX particles. This became apparent during development, as the assets used in the beginning of the project had to be optimized multiple times in order to achieve an acceptable frame rate for the limited in power Pico New 2. More specifically, transparent materials were removed, when possible, models had their polygon count reduced dramatically and the enemies had to be rigged again as one rigged mesh. The later was also the biggest optimization for the application.

11 Unity Development

In regards of the development tasks, Khora provided all the 3d models, animations, VFX and sounds that were used in the game. A script that allows the game to be played solely on the editor was provided by Khora, speeding up the development as it allows testing without the need of building and testing on the target device. The in-engine development and coding was a task that was solely taken by me, including but not limited to lighting, asset placement, coding, UI ,bug fixing and optimization.

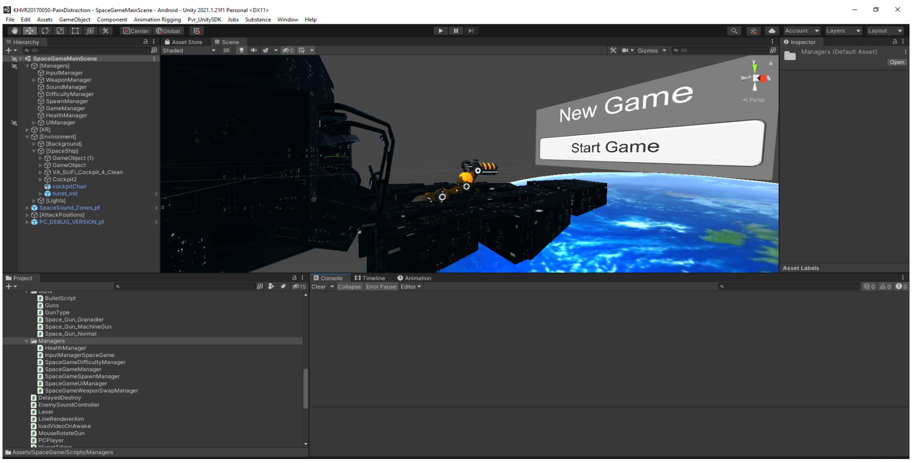

Fig. 5: Unity Development

11.1 Managers

The iterative nature of the development process that was adopted meant that scripts had to be easily modified and features easily added or removed. For that reason prefab objects were used when possible. The system was also designed in a way that decoupled the functionality as much as possible. For that reason different manager scripts were created for each aspect of the game.

Game Manager

A GameManager script is responsible for tracking the state of the game. It is also responsible of updating other managers with the state of the game. It also has information about the game state such as the current level and point score. It also holds the necessary functions to start, stop and restart the game, as well as update the score. When the player loses the GameManager stops the game, destroys all remaining enemies and resets the high score to zero. The Level variable of the GameManager though doesn't reset, that means that when the player restarts the game, the first level spawned will be the one that the player reached on the last play through.

Difficulty Manager

The DifficultyManager script is responsible for setting the game's difficulty. It was created to allow the levels to be easily swapped and changed during development and it stores an array of levels.This allowed for fast iterations, fine tuning the experience accordingly by changing the order of the levels in the array or simply adding more. The levels are created as prefabs and contain a number of waves as well as the delay between each wave.

Spawn Manager

The SpawnManager script is responsible for spawning the enemies. It iterates through all waves of each level and then creates an instance of each enemy on that wave. Then it copies the path of that wave to the instantiated enemy. Between each wave there is a small delay defined in the SpawnManager. The waves are saved as a prefab and contains an array of enemies. This array can contain all types of enemies and they are ordered, which means that their position on the array is the order of which each enemy is spawned.

Level

The level script has a list of Waves that correspond to all the waves that this level has as well ass three variables that are used to check if the level is cleared or not. When the level starts the EnemyCount is updated by itterating on the wave list and adding the length of each wave.Enemies list. This gives us the total count of the enemies on the level. When an enemy dies or fleds they are tracked on the variables enemiesFled and enemiesDead respectably, allowing us to progress to the next level when needed.

Wave The wave script has four lists, one with the enemies on the wave, one for the spawn locations, one with the path locations of the wave and one with the points that are needed for the fleeing of the enemies. The spawner uses those lists in order to spawn and populate the relevant fields on each enemy.

Input Manager

The InputManager is responsible for capturing the players input and by using events. The weapons subscribe to those events and based on the weapon's type the bullets are fired.

Weapon Manager

The WeaponManager keeps track of the currently equipped weapon as well as making sure to change to the appropriate weapon when the player picks up a new weapon. By keeping the input separate form the actual gun, it is possible to use the same base logic for all guns and make sub-classes with only the functionality that is different in each weapon. This also means that the input doesn't care about which weapon you are using, only when you press the trigger and when you release it. Apart from the array with all the weapon types, the WeaponManager also keeps track of the duration of each weapon power up, swapping back to the normal weapon when the duration ends.

Health Manager

The HealthManager keeps track of the player's health. A public function allows the Health variable to be updated any time it's needed. The Health variable is also public, allowing the GameManager to check if the player is alive or not, and the UIManager to display the health on the in-game user interface.

UiManager

The UiManager was created in order to easily display all the user interface elements that the game needs. It has references to the UI elements and enables, or disables them as needed. More over it gets the health value and updates the value of the health bar according to that value.

11.2 Weapons

Each weapon has it's own script that derive from the same base class. By overriding abstract functions on the base class it is possible to group all the weapons on the WeaponSwapManager. This means that it is very simple to change form one gun to the other. By subscribing to events invoked by the input manager it is possible to alter the result of each input. Each weapon has all the necessary variables for it's functionality, such as the spawn position, hit sound, vfx explosion etc.

At the tip of the weapon model a line renderer is attached. This line renderer is manipulated through the LineRendererAim script and is used to help the player aim his shots. When the Normal or Machinegun weapons are equipped the line renderer is a straight line. when the Grenade weapon is equipped the line renderer take the form the arc that corresponds to the grenade's trajectory if fired.

11.3 Projectiles

The Bullet and Grenade scripts are responsible for all collision checks. When the player presses the trigger on the contoler a projectile is fired based on the currently equipped weapon as it was previously stated. These projectiles move using the physics engine of Unity.

11.4 Enemies

The enemies share the same logic script but a number of variables allow for different perceived behaviour, as well as toughness. More specifically the HealthPoints variable allows the enemies to resist more hits, while the speed controls how fast the enemy moves. The CurrentState variable is an Enum that describes what the enemy should do, something that through code is achieved with the use of the switch statement. On Normal state Enum, the enemies move around towards the defined positions as described earlier. An interpolation and ease in algorithm is used to create a smooth movement. A timer counts how long the enemy is on the Normal state to determined if the enemy should become enraged. The second state is called Enraged. When an enemy becomes enraged it flies towards one of the two available positions on top of the cockpit, if not already occupied. When it reaches that position the enemy shoots a laser at the player dealing damage over time.

Other variables are used to control the logic of the enemy. The most important variable is the isCargo Boolean variable that completely removes the ability of the enemy become Enraged, while the RageTimeMin, RageTimeMax, RageReset control how fast the enemy charges at the cockpit. The FleePath array contains all the positions that the enemy should move towards when on the Normal State and is populated on instantiation from the wave it spawned it. Hit VFX, sounds and animator is stored in this script in order to achieve the desirable opticoaudiovisual result. Lastly the Lootbox variable is a reference to the loot-box prefab that spawns when an enemy with the variable isCargo set to true, dies. Lastly the array TailAnimators stores the references of the script TailAnimator that is only responsible for making the enemies limbs move in a more realistic and based on physics way. These scripts are all disabled when the enemy lands, and an animation is played during that time.

12 Development of testing device

For the testing procedure a physical device was created. It was composed by an Arduino Uno micro-controller designed by Elegoo, a round physical push button and two 24mm NFP-RF-300CHV 5V vibration motors in parallel, making the maximum available vibration intensity impossible to ignore.

Measurements of the electronic components where taken and a custom 3D case was build in PTC CREO Parametric program by an expert 3D modeler. The case was then 3d printed using PLA+ plastic on Creality Ender3Pro printer. Then the electronic components where soldered together and fitted in the case. The code was written in

C++ programming language and tested in TinkerCad before the device was built. The circuit of the device for the testing procedures is shown in figure 7.

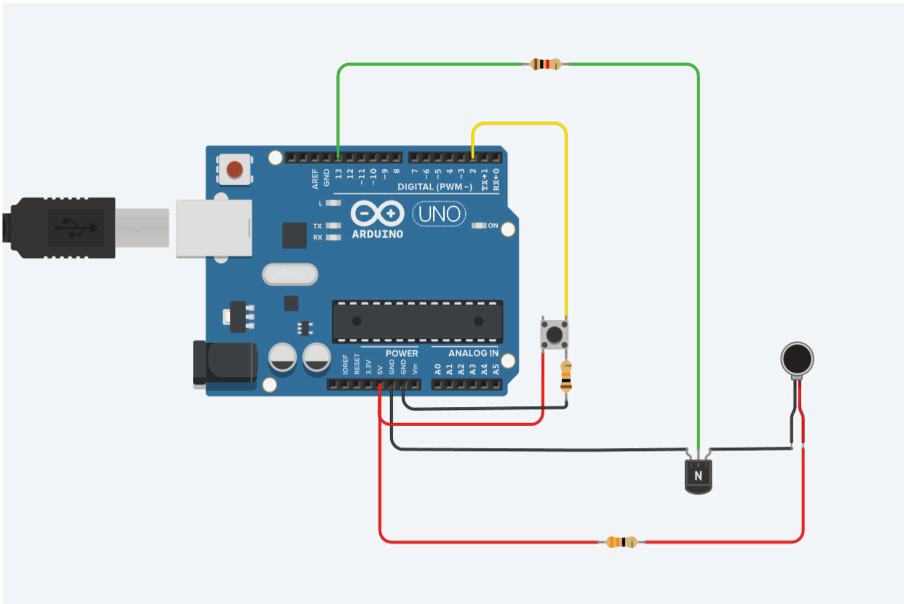

Fig. 6: Circuit of Arduino device

On the second test the device would vibrate randomly, once per few seconds, for a fixed duration of 5 seconds. If the button was pressed during that time the vibration would stop. An array would then store the time between the start of the vibration and the button press. If the button was not pressed until the start of the next vibration, the entry on the array would be -1. Presses of the button per vibration after the first would be ignored.

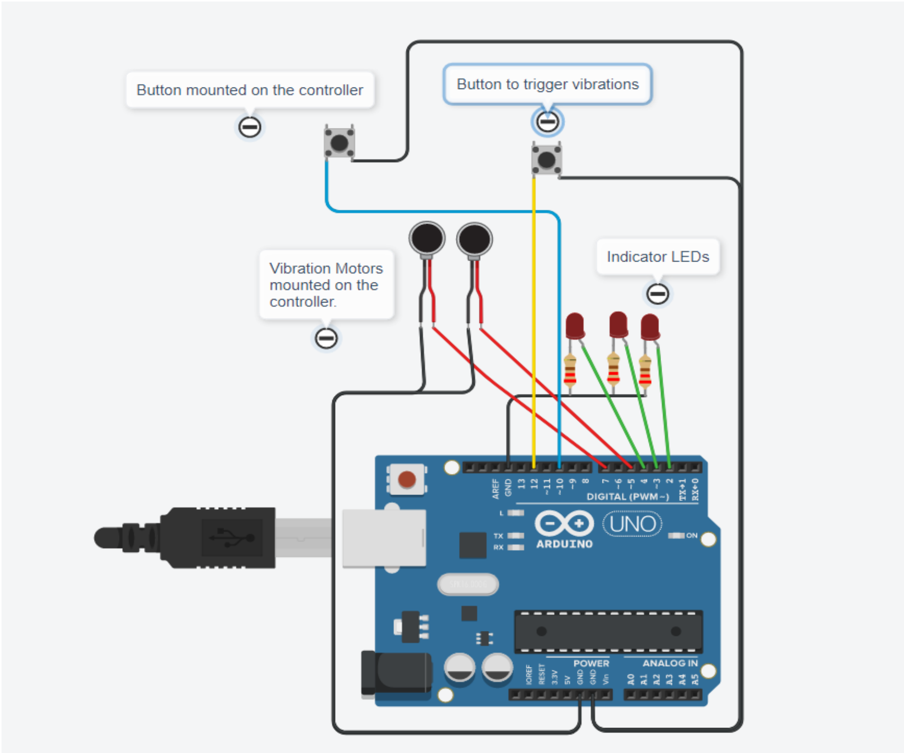

Fig. 7: Circuit of Arduino device

On the third test the hardware used for the device was the same. One more button and three more LEDs were added, one for each event that we wanted to track. The additional button allowed for a more controlled trigger of the vibration based on the state of the game. When a vibration was triggered the corresponding LED would light up. The vibration would be on for five seconds. If in these five seconds the users pressed the button the vibration would stop and the LED would remain on. If they failed to notice the vibration and didn't press the button then the LED would turn of along with the vibration.

Part VI

Tests

13 Testing procedure

Three tests were designed. The first test was done early in the development of the project and as soon as the minimum viable product was ready. This subjective test was made in order to get early feedback from the hospital and the test group of the target age group. This was a simple play through of one level and one enemy type with no additional power ups. It was held by Viborg Hospital on First test 25/4 and a simple questionnaire was then filled by the participants, aiming on the the difficulty of the game, the ease of use of the game in terms of game play and lastly on the environment they experienced and emotions it created for them.

This test was made to change design elements if needed .Nine users aged 13 to 18, as well as eight older users, took part in the first testing. The users played the game and answered the questionnaire (see appendix). The test had a fixed duration of 10 minutes per player.

The second test would have two parts and a questionnaire. In the second testing a subjective methodology and a break in presence approach was used. 13 users aged 19 to 30 took part. The tests where held in 20/5 and each testing part took about ten minutes. The test was split in two parts. Then they played the game while also using the testing device. During each testing part 20 vibrations where fired with random intervals between them with the first vibration taking place after 2 minutes of game play had elapsed. Each time the vibration was detected by the user, they had to press the button logging their reaction time. Only one user was in the room of the testing at any time and few instructions about the game were given. The users where also instructed to restart the game immediately in case they died. Then they were asked to fill in the questionnaire.

At the first part of the test, the users used the testing device in order to establish a base line for their reaction time. The user would sit in a chair blindfolded and would be given the testing device, held on their offhand. They would be instructed to press the button as soon as they felt the vibration. The test finishes after 15 minutes and the array is extracted, saved on an excel sheet and reset for the next part of the test.

For the second part the user would be sited in a chair wearing the headset. The testing device would be held on their off-hand, while their main hand would hold the controller of the headset. They would again be instructed to press the button as soon as they felt the vibration. The players would then start the game on the headset. The player's would get instructed about the enemies and the special weapons as well as restarting the game after they died.

After the second part of the game the players would be asked to fill a questionnaire focused on the game play and how easy it was to find the controls and features of the game, gaining more insight for further development of the app. Some questions about the vibration device would also be asked, specifically they would be asked to rate the intensity of the vibration during the two test phases and if they felt a difference, gaining a subjective measure of presence.

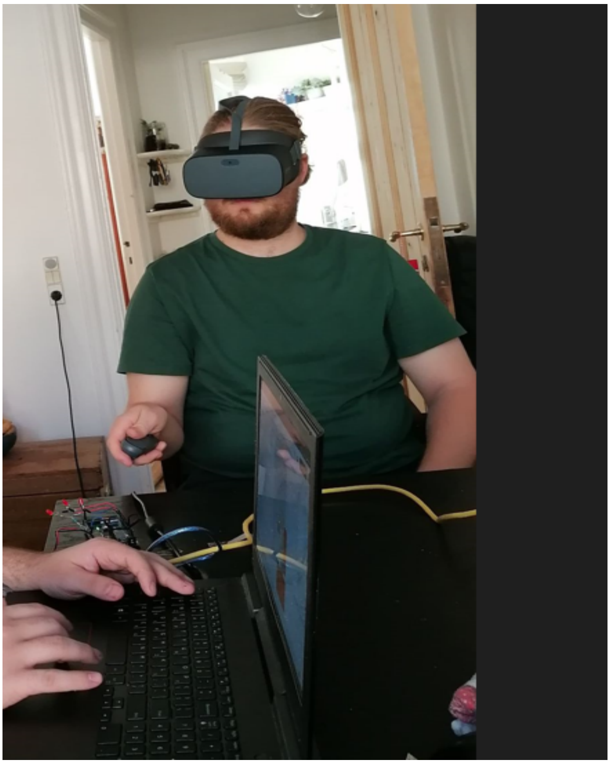

Fig. 8: Testing with users

The third and final test was designed using the Adapted Method proposed by Rolf Nordahl [33]. This would be an objective measurement of presence and was aimed to explore the feeling of presence of the user in specific events of the app. 15 users took part. The minimum perceivable vibration was first calculated without the use of the developed game. First each participant was blindfolded and asked to press the button when they feel a vibration. Then different values of vibration will be introduced. This is the baseline in order to level out threshold variances.

Then, each participant played the game for about 5 minutes. The game was mirrored in an external monitor, making it possible to trigger a vibration on specific events of the game. More specifically a vibration was triggered when the player cleared the first wave, later when they equipped one of the special guns for the first time and again when they cleared the 5th wave. A fourth candidate for an event was while the player was under attack by the enemies. The event was rejected as it would be impossible to predict if the player would survive the attack or not. This made the even unfit, as performing the procedure the moment the player lost would defeat the purpose of the application.

The vibration intensity for the first round was half of the maximum vibration. If a vibration was felt by the majority of the group the vibration intensity was then halved and the test went to the next round of testing. If a vibration was not felt by the majority of the group half of that vibration intensity was added to the original value. If the state for the vibration was changed (from one participant not feeling it to the next noticing the vibration and vice versa) half of the difference of the last two values was added or subtracted from the original value accordingly. Each event was tracked separately using this algorithm. This would allow us to compare the minimum required stimuli to break presence, for the specific events of the game that we were interested in. An explanation of the game and the power ups was given to each participant before playing the game. Then the participant was asked to press the button on the Arduino device that was created for the testing procedure if they felt any vibrations. Between each participant the vibration intensity was adjusted according to the algorithm explained above.

Part VII

Results

14 First test results

The first testing gave a great indication about the feelings the game created on the users and also helped to fine tune the difficulty of the game so the player stays engaged for longer. The test more specifically concluded that the users liked the environment, felt calm while inside the cockpit but lacked the need to act. The enemies felt too passive and they reported that they felt no consequence was implemented for not taking them down fast. In order to address those concerns, the enemies where made faster and tougher and the delay between waves and levels was removed, making the enemies spawn faster. The Health of the player was also made more visible and the enemies shooting was changed, from a single bullet and run away to a constant firing of a laser to the cockpit that deals damage overtime, making it a call for action from the player.

15 Second test results

The second test revealed a small increase in the reaction times of all participants. There was no particular demographic categories noted that effect these results such as gender or age. The median of the base for all participants was 0,322 seconds while the media for all in game measurements was 0,732 seconds. During play it was apparent that the players liked the game and had fun, something that is supported by the fact that all participants decided to play for a couple more minutes or until they lost, when they were informed that the test had finished and could stop whenever they want. Only one participant said they felt a bit uncomfortable inside the cockpit when enemies shoot at her. We have to note though that none of the participants suffered from claustrophobia or any other similar anxieties. All participants liked the concept and theme of the game as well as the game-play. Eight participants like the speed of the enemies while two mentioned that it was a bit fast for them, while three participants mentioned that they would like the enemies to be a bit faster in some or all parts of the game. 61.5% percent of the participants liked the grenade gun more than the rest, while 15.4% liked the machine gun more with the rest 23.1% preferring the normal gun, or failing to equip a special weapon at all. Most of the users failed to remember their high-score, with only participants that had higher than 3000 points remembering it. Two users rated the notability of the vibration the same before the game and while playing, while all others rated the vibration to be lower while playing the game. Six participants noted that their ability to notice the vibration was lowered during play while, while the rest noted a small or no difference.

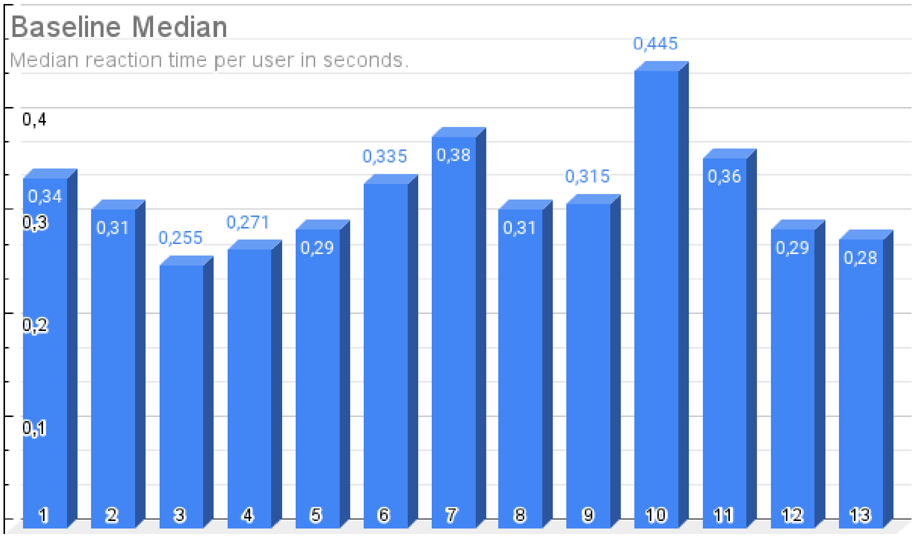

Fig. 9: Median Baseline

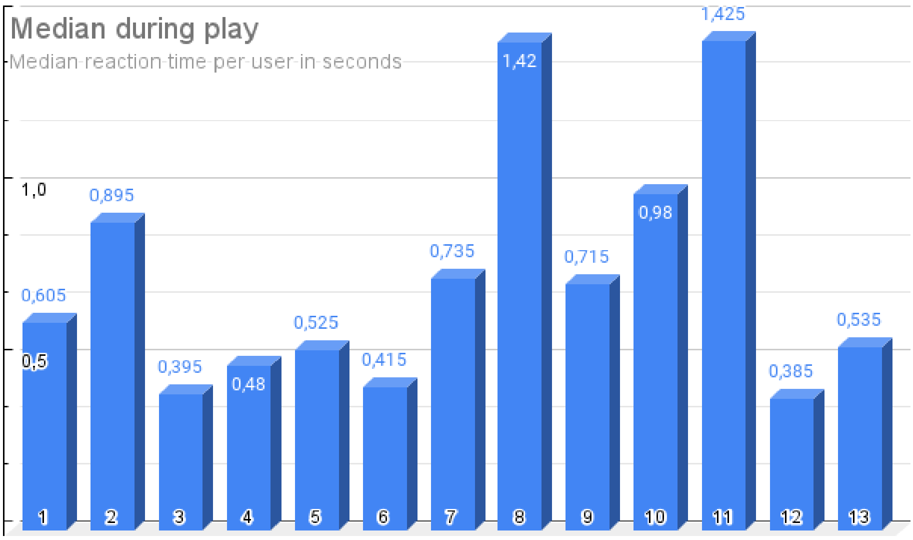

Fig. 10: Median During Play

15.1 Second test observations

During the second test it was apparent that players had their concentration split. Some players focused more on the reaction times and even died in game a couple of times, while others tried to get a high-score and stay alive for as long as possible and their reaction times were marginally worse. A competitive element between the participants was apparent, comparing reaction times and high-scores after the tests were done. This competitive behaviour may have affected the results as participants tended to focus on the reaction times more than the high-score, something that is apparent in their answers of the questionnaire as well. That said, it is important to note that some participants failed to notice the vibration completely when playing the game. The best results were produced by people with great multitasking abilities. Therefor the tests were biased in terms of multitasking ability and ambidexterity. It is important to note that while playing the game users where particularly slow on their reaction times when they had equipped one of the two special weapons, or when they died and had to restart the game. These are because of the interruption of flow, something that could be used both against and towards the immersion. In the case of the losing, the interruption was simply based on confusion and the fact that the participants in question thought the vibrations were somehow part of the game. In the case of the power up weapons though, the participants were deeply immersed in the game that the vibration was less important or noticeable to them. This is inline with the findings of C.Carlsen[7] regarding the timing the epidermal puncture procedure should happen. Lastly its important to note that not all participants used both power ups as they failed to kill the special enemy that spawns them.

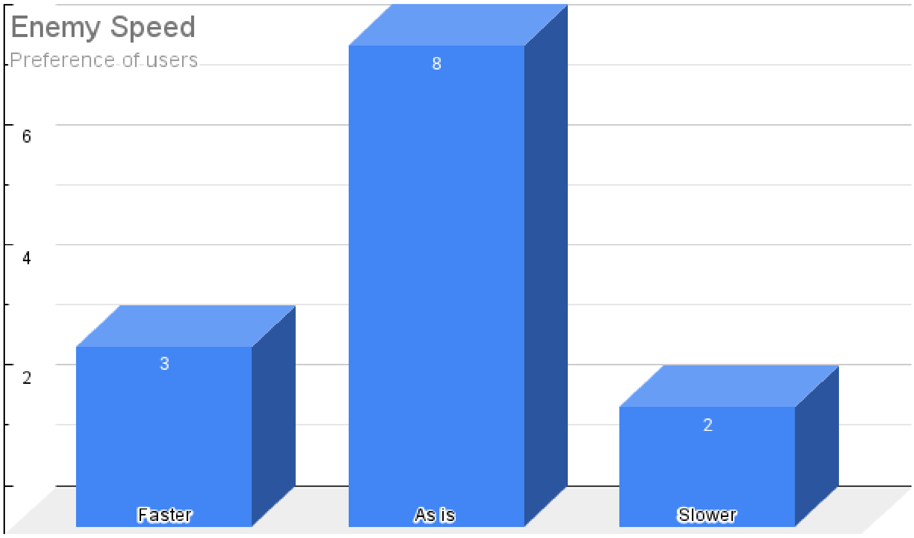

Fig. 11: Enemy speed preference

16 Design changes

In order to remove the interruption of flow when the participant loses the game, the game-over menu is only be shown for a few seconds and the game will restart automatically, removing the need to press any button. In this menu the High-Score of the player is also displayed. The speed of the bullets as well as fire rate for the normal gun is adjusted to make it easier to aim. Also a indicating laser is added to help with aiming and is color coded based on the equipped weapon. New models for the exterior of the spaceship were implemented and new animations were created for the landing of the enemies. A soundtrack and new sound effects were added.

17 Third test results

The baseline vibration intensity value that the test could identify was 45/256. The third test shows an increase to the minimum value of vibration intensity required in order to be felt by the user while playing the game. In other words, the minimum vibration intensity required to break presence during play was higher than the baseline. The more interesting measurement though is comparing the minimum vibration intensity required to break presence between events of play. More specifically, while in the first stages of play an intensity of 69/256 was required while equipped with a special weapon a minimum of 85/256 intensity was required. Lastly on the 5th level of the game and while not having a special weapon equipped a minimum of 58/256 vibration intensity was required to break presence.

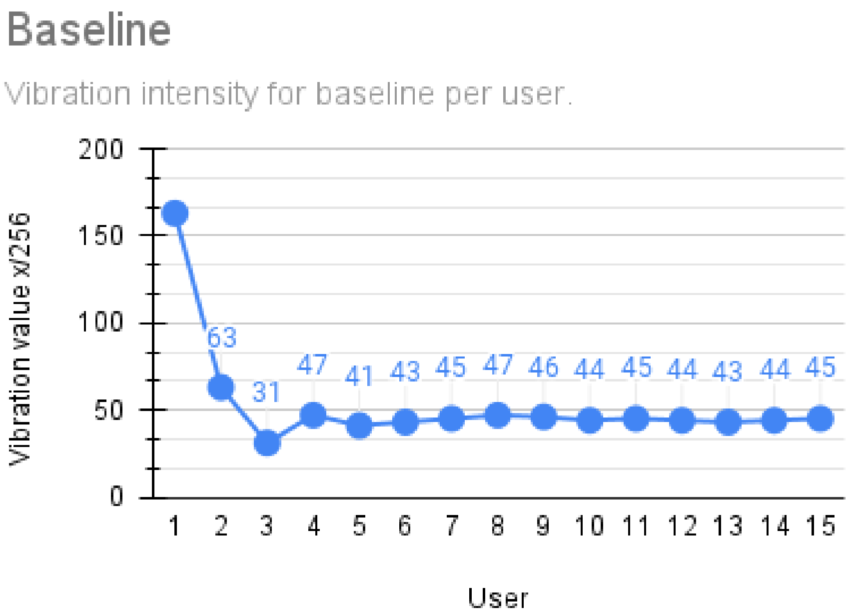

Fig. 12: Vibration Baseline

17.1 Third test observations

In contradiction to the second test the users were focused only to playing the game. It was very apparent that the desire to get the fastest reaction times or to get all the vibrations correct was not there. Some participants expressed that they can't feel any vibration and questioned if the device was even working. The device was tested before and after each test in order to make sure that the test was valid, something that was the case for all of the conducted tests. The values of the first event tested were mostly unexpected. The higher values needed than the baseline are expected but the numerical difference between those and the baseline were not. This could be explained due to the player/user been bombarded with new information or trying to adjust to the controls or learning to aim. In general the values of this event were expected to be closer to the baseline as the game is not exiting during this event. Every participant managed to get a power-up while playing, while a small percentage died during play. As the game restarted automatically though, they were put back into the game immediately. Only the players that died at least once noticed the fact that the game has a high score system before the end of the test.

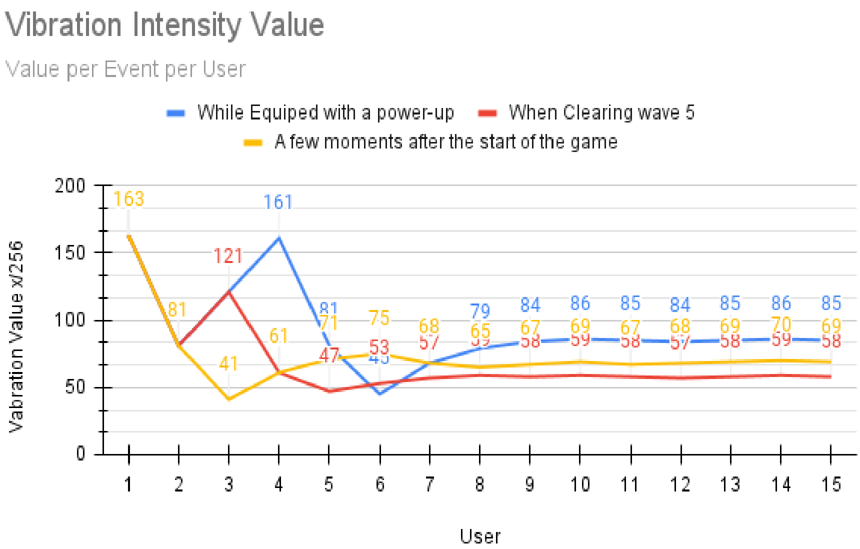

Fig. 13: Vibration Intensity Value

Part VIII

Conclusions

The findings of the second test confirm the findings of previous research. The competitive nature that the participants had during the second test might prove a nice incentive for focusing more on the game with the integration of a high-score display at the menu of the game. The enjoyably of the game was a big talking point among the participants, the majority of who had tried VR experiences before. That said, they were made aware that the game is in pre-alpha stage and lacks polishing. The difficulty of the game was in a good state over all, with no major complains, though as it was noted, the special enemies were found to be harder to kill than the normal enemies. If we take into account that the power ups were the the cause for the longer response times on all participants that managed to get them, we conclude that the enemies that spawn these power ups need to be easier to kill, something that was changed in the next stage of development of the game before the third test.

The findings of the third test confirm that a higher vibration intensity is required in order to be felt by the user while playing the game, breaking the user's feeling of presence. Additionally it proves the assumption that an optimal time for the epidermal puncture procedure exists. Even though the findings don't show a huge numerical difference between the first and the second event tested, it is very apparent that once the users played the game for a while, it was easier for them to register the vibration during the third event. In all cases the second event, equipping a special weapon, was the event that required the strongest stimuli to break the users sense of presence, making it the best time to perform the epidermal puncture procedure, out of the three events that were tested.

Future Work

Clinical tests with teenagers and young adults in collaboration with a hospital should be arranged. The users will undergo epidermal puncture procedures while using the Virtual Reality application and rate their experience in pain compared to previous procedures they have taken part of previously in their life. This would create a definitive subjective result on the alleviation of pain while using an immersive Virtual Reality application. Last but not least, the practicality and usefulness of the designed application should be reviewed by nurses and doctors.

Acknowledgments

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