Using a virtual fire extinguisher as a tool for safety training

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Abstract

Virtual Reality (VR) has recently become very popular and is an exciting technology with many unexplored applications. By wearing a VR-headset users could for example train on a certain exercise with reduced risk and at a much lesser cost than if it was performed in the real world. The objective of this thesis was to examine if VR can be used as an alternative method for training on how to use a fire extinguisher.

By using a user-centered design process, a VR-prototype was developed that teaches the basics of how to operate a fire extinguisher and lets users train on extinguishing virtual fires. To evaluate the prototype as an alternative training method for fire extinguishers, a demonstration was organized at the fire station in central Malmö where experts within fire safety tested and discussed different aspects of using VR. A larger user-test with 42 participants divided into two groups was also conducted to evaluate how well the prototype works as a training tool. The test consisted of two parts, training in VR and operating a real fire extinguisher in an imaginary emergency scenario. The first group started with training in VR and the second group began with operating a real fire extinguisher. The two groups performances were then compared to identify differences.

The result from the comparative study proved that participants performed better with a real fire extinguisher after first having trained in VR. The demonstrations and interviews with experts in fire safety also indicated a significant amount of interest in the technology and its potential. However, some limitations were discovered like the lack of louder noises and weight from real fire extinguishers. The training simulator where instead discussed as an interesting and an easily accessible complement to traditional methods for fire extinguisher education.

In the final stage of this project, a second prototype was also developed where the concept of augmented virtuality was explored. By attaching one of the VR controllers to a physical fire extinguisher, its movement could be tracked. When users held an actual fire extinguisher while training in a virtual environment their level of immersion increased. For future work, this technique should therefore be considered.

Keywords: Virtual Reality, Training simulator, Interaction Design,
User-centered design, Fire safety, Fire extinguisher

Sammanfattning

Virtual Reality (VR) har den senaste tiden blivit väldigt populärt och är en spännande teknologi med många outforskade användningsområden. Med ett VR-headset kan en användare till exempel träna på en speciell uppgift med både reducerad risk och till en mycket lägre kostnad jämfört med om det istället hade genomförts i den verkliga världen. Målet med det här examensarbetet var att undersöka om VR kan användas som en alternativ metod för att träna på hur man använder en brandsläckare.

Med en användarcentrerad designprocess så utvecklades en VR-prototyp som lär ut grunderna hur man använder en brandsläckare och låter användare träna på att släcka en virtuell eld. För att utvärdera prototypen som en alternativ träningsmetod för brandsläckare så arrangerades en demonstration på brandstationen i centrala Malmö där experter på brandsäkerhet testade och diskuterade olika aspekter av att använda VR. Ett större användartest med 42 deltagare indelade i två grupper genomfördes också för att utvärdera hur på bra prototypen fungerar som ett träningsredskap. Testet bestod av två delmoment, träna i VR och att använda en riktig brandsläckare i ett imaginärt nödscenario. Den första gruppen började med att träna i VR och den andra gruppen började med att använda en riktig brandsläckare. Gruppernas prestationer kunde därefter jämföras för att identifiera skillnader.

Resultatet från den komparativa studien bevisade att deltagarna presterade bättre med en riktig brandsläckare om de först fick träna i VR. Demonstrationen och intervjuerna med experter på brandsäkerhet uppvisade också ett stort intresse kring tekniken och dess potential. Några begränsningar konstaterades som saknaden av högt ljud och tyngden vikten från riktiga brandsläckare. Träningssimulatorn diskuterades istället som ett intressant och mer lättillgängligt komplement till traditionella metoder för utbildning.

I slutskedet av det här projektet så utvecklades en sekundär prototyp för att utforska möjligheterna med augmented virtuality. Genom att fästa en av VR-kontrollerna till en fysisk brandsläckare så kund dess rörelse spåras. När användaren istället håller en riktig brandsläckare när man tränar i den virtuella miljön så öker nivån av immersion. För framtida arbete så bör därför den här tekniken övervägas.

Nyckelord: Virtual Reality, Träningssimulator, Interaktionsdesign, Användarcentrerad design, Brandsäkerhet, Brandsläckare

Acknowledgements

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Abbreviations

VR .... Virtual Reality

VE .... Virtual Environment

AV .... Augmented Virtuality

HMD .... Head-Mounted Display

UCD .... User-Centered Design

Lo-Fi .... Low Fidelity

Hi-Fi .... High Fidelity

CHAPTER 1

Introduction

Fires have always been a large threat to public safety regarding potential death, injuries, and financial costs. In 1998, a fire at a nightclub in Gothenburg killed 63 and wounded 213 teenagers and is remembered as one the worst fire disasters in Sweden. The fire originated in the basement of an overcrowded facility and made devastating progress after a door was left open leading to the fire. Recklessness in respect to fire safety led to the catastrophic result [1]. However, the most common place for fatal fires are at peoples' home. 57% of all reported fire accidents in Sweden are residential fires and the most common cause are stovetops that are left unattended [2]. In Sweden, around 100 people are killed every year in fires [2].

According to the insurance company Trygg Hansa only around half of the population in Sweden have fire extinguishers in their homes [3]. Owning a fire extinguisher is an important safety measure but in case of an emergency it is also good to have experience on how a fire extinguisher works and how to operate it. For practical training with fire extinguishers there are courses that can be attended. Both the local fire departments in southern Sweden and manufactures of fire extinguishers arrange courses available to the public [4]. But these are quite expensive and are often targeted for larger groups and organizations.

Virtual Reality (VR) on the other hand is currently enjoying a resurgence of popularity with exciting new and relatively inexpensive VR-headsets and many unexplored applications. In VR, a user wears a head-mounted display (HMD) and with the help of various sensors the user's movement is tracked to give the immersion of actually being in a computer-generated virtual world.

Although people today mainly associate VR with entertainment the possibility to use VR in education has great potential. Training in VR is particularly attractive for real world situations that are impractical because they are inherently dangerous (e.g., firefighting, surgery), too remote (e.g., planetary exploration), or too small to enter (e.g., atomic structures). Using simulations for training is nothing new. During the Second World War a large number of pilots was in need of flight training and basic simulators were used to learn how to handle the aircraft and learn the different gages in the cockpit [5]. Training in flight simulators have been a crucial part of aviation ever since.

For fire safety education, emergency scenarios can be created with computer software where users can train with both reduced risk and at a much lesser cost then if it was performed in the real world. Previous research efforts have used computer generated environments and virtual reality to investigate different aspects of fire safety. The department of Fire Safety Engineering at Lund University used virtual reality in a recent study to examine the design of flashing lights at emergency exits for road tunnel evacuations. With a VR experiment participants evaluated different factors such as frequency and brightness of the evacuation lights. By using virtual reality as a research method significant amount of data was collected with good ecological validity and at a low cost. This was confirmed by the fact that most of the finding were in line with previous experimental research data from experiments conducted in real world environments [6]. Another example is a master thesis at Lund University where people's perception of fire growth in a virtual environment was examined. The data from the VR experiment was compared to results from a similar study performed in the real world [7]. In the simulation, minimal interaction was implemented since the objective was to measure perception of fire growth. The result from the thesis indicated poor performance from the test subjects in assessing fire growth in the virtual world. One of the question asked during the experiment with the VR-prototype was if the test person thought he or she could extinguish the fire with a fire extinguisher visible in the simulation.

The idea for this master thesis is that many people are insecure on how to use a fire extinguisher because they have no or limited experience using one and real fire extinguishers are often not available or too expensive for training purposes. Just like pilots use flight simulators to prepare for emergency situations ordinary people could train on using fire extinguishers in a virtual environment. So, can the new VR technology of today offer an alternative to traditional fire safety training where a virtual fire extinguisher is used instead?

1.1 Aim and Objective

The purpose of this master thesis was to examine if VR can be used as an alternative method for training on how to operate a fire extinguisher, and review if it has a positive effect on peoples' awareness of fire safety. By developing an easy to use VR-prototype, participants will be immersed in a virtual environment where they will learn how to operate a fire extinguisher and train on how to extinguish a virtual fire with minimal help from an instructor in the real world.

In addition, a series of sub-questions will be answered connected to the main research question.

- How does VR work as a training tool for fire safety and can it be compared to traditional training methods?
- How do you design software for VR and how do you get good usability for different types of users?

1.2 Limitations

The duration of this master thesis was limited to 22 weeks that once completed would deliver a fully functional VR-prototype. This meant some limitations was needed.

- The VR-prototype was developed to mainly be used with the HTC Vive, one of the recent released VR-systems with a HMD.
- To simulate a realistic fire many different aspects can be taken into consideration such as smoke development, fire spread, and extinguishing rate. However, for the VR-prototype the fire is limited in size and will not spread over time. The main goal with the VR-prototype was instead to let users learn how to operate a fire extinguisher and achieve good usability.
- Training with fire extinguisher in the real world is hard since it involves both a substantial risk and costs for the materials needed. In order to validate the VR-prototype a comparative study was used where differences in operating a real fire extinguisher was examined depending on if the test subject had trained in VR beforehand or not. However, the training scenario with a real fire extinguisher was limited to an indoor room where an emptied fire extinguisher was used on an imaginary fire. The goal instead was to evaluate how the test subjects operated the fire extinguisher and analyse if there were any differences between the two groups.

CHAPTER 2

Theoretical Background

In the following chapter a review of previous work in the area and related literature is presented to give a theoretical background to the project. The presented material below was collected during the initial phase of this project as part of a literature study.

2.1 Virtual Reality

There is no clear definition for Virtual Reality but it is often agreed as a computer-generated 3D-world that offers some kind of interaction. The Oxford English Dictionary defines Virtual Reality as *"The computer-generated simulation of a three-dimensional image or environment that can be interacted with in a seemingly real or physical way by a person using special electronic equipment, such as a helmet with a screen inside or gloves fitted with sensors"* [8].

A first example of virtual reality similar to what it is known today is Morton Heilig's Sensorama built in 1962. Sensorama recreated the feeling of driving a motorcycle using a stereoscopic display, stereo sound, a movable and vibrating chair and simulations of wind and smell, as can be seen in figure 2.1 [9].

Virtual Reality is an immersive medium that creates the sensation of being entirely transported into a virtual three-dimensional world. From a user's standpoint, there are three major components of a typical VR system. First, the user must have some way of seeing in the virtual environment. This is usually accomplished with a head mounted display (HMD). Second, the user must have some way of moving through the virtual environment. The user experience for moving around is called locomotion. In real life getting from point A to point B is relatively straight forward, but in VR it can be difficult to build an experience where moving feels natural and does not cause motion sickness. Teleportation is one of the most comfortable solutions for locomotion in VR. However, with teleportation users can move long distances at a very short time which could

Figure 2.1: Sensorama by Morton Heilig *(taken from [9])*

feel unnatural and the technique is therefore not suitable for all types of VR applications. With room-scale VR the user can move freely within a restricted area. Finally, there must be some way to identify the user's direction of view in the virtual environment. This is accomplished by means of a tracking device, often attached to the HMD [10].

Immersion and presence are two commonly used terms when it comes to VR. They are often used to describe the user experience of a VR application. Immersion is the objective degree to which a VR system and application projects stimuli onto the sensory receptors of users. Presence is a sense of "being there" inside a space, even when physically located in a different location. Because presence is an internal psychological state and form of visceral communication, it is difficult to describe in words. It is something that can only be understood when experienced [11].

One of the biggest challenges is to avoid sickness and nausea in VR. Sickness resulting from VR goes by many names including motion sickness, cyber sickness, and simulator sickness. The level of nausea in VR varies between users and the potential factors associated with simulator sickness in virtual environments can be divided into individual factors, simulator factors and simulated task factors [10]. Mismatches between senses can easily result in nausea. One example is when it takes too long to update the image of the display during head movement. Historically, sickness in VR has been attributed to sub-optimal VR hardware variables, such as system latency. Today's VR system resolves many of the issues from earlier systems but improperly designed content can still lead to uncomfortable experiences and nausea [12].

Reality takes many different forms and can be considered to range on a virtuality continuum from the real environment to virtual environments as can be seen in figure 2.2. The different forms of reality in between the real and virtual real-

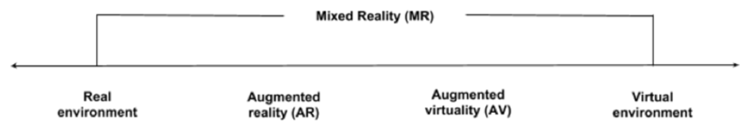

Figure 2.2: The virtual continuum *(adapted from [11])*

ity are broadly defined as “mixed reality” which can further be broken down to “augmented reality” and “augmented virtuality”. Augmented virtuality (AV) is the result of capturing real-world objects and bringing those objects into VR [11].

Even though VR has become a well-established method in various areas such as psychology and rehabilitation it is still a relatively young research area and its usefulness for applications like fire safety training needs to be fully validated. A SWOT analysis of VR as a research tool in human behaviour in fires has been recently conducted [13]. A SWOT analysis is a technique to identify and understand the Strength, Weaknesses, Opportunities and Threats of a certain area. The result from the paper can be seen in table 2.1. The concluded strengths of using VR is that it offers an easily repeatable simulation at a relatively low cost with ecological validity and with much better safety for participants compared with real world training. Some weaknesses worth mentioning is the inter-individual difference in ease of interaction with VR. It will take much longer for a first time VR users to get familiar with the interactions for a certain application. There are also technical limitations for typical VR systems, for example not feeling sensory input like touching things, smells, changes in temperature and the limited area of movement offered in the virtual world.

VR is a relative young area compared to mobile and web development and as a medium VR has very few existing standards, protocols and workflows. In VR, the user is immersed in a virtual world without any traditional restrictions like a limited screen size. Design principles from other medium such as web design, architecture, interior design, theatre and motion graphics all have elements that can be seen as relevant and adopted for VR. Rather than just designing user interfaces with buttons and menus in VR complete environments needs to be sculptured [14].

Another aspect is the area in space where to place objects. In the paper “Visual Design Methods for VR”, Mike Alger introduced the following model of content zones for objects in VR, as can be seen in figure 2.3. The model was conceived in order to construct a VR operating system for a sitting user and consists of four different zones based on aspects such as head movement, field of view and the depth of where objects is visible. The model in figure 2.3 only show the

Table 2.1: Summary of a SWOT analysis for VR *(taken from [13])*

Summary of a SWOT Analysis for VR in Fire Evacuation Research			
Strength:	***Weaknessess:***	***Opportunities:***	***Threats:***
• Internal validity	• Need for confirmation/validation	• Intuitive and natural navigation	• Failure to show ecological validity
• Replication	• Non intuitive interaction methods	• Graphical developments	• Ethical challanges
• Ecological validity	• Inter-individual differences in ease of interaction with VR	• Multi-modal simulations and feedback	• Side-effects due to interaction with other medical conditions
• Safety for participants	• Technical limitations	• Usability for researchers	• Misleading expectations
• Real-time feedback	• Technology-induced side effects	• Exchange of 3D -scenes or experiments	• Technical faults
• Multi-modal simulations • Precise measurements • Psychophysiological monitoring • Low costs • Repeated measurements • Flexibility • Control of cofounding variables • Independent of imagination abilities/willingness of participants • Participant recruitment	• Efforts		

horizontal plane and should be imagined as a sphere enclosing the user. The "comfortable zone" is the recommended one for menus. The "no-no zone" is where object will be uncomfortable close to the user or in worst case scenario, through the user. Then there is the "peripheral zone" where objects usually still are visible and lastly the "curiosity zone" where the user must turn around to see an object [14].

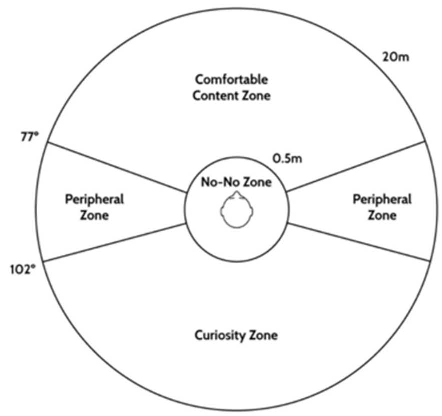

Figure 2.3: Model of content zones for menus in VR *(taken from [14])*

2.2 Interaction Design

Interaction design focuses on how people interact with technology and the goal is to enhance people's understanding of what can be done, what is happening, and what has just occurred [15]. Virtual reality creates an infinite set of possibilities of experiences. But in order to offer a good user experience for all types of users some fundamental design practices should be followed. Users in VR need to figure out how to work the system. Donald Norman's principles of interaction design is especially important for fully immersive VR because the user is blind and deaf to the real world, cut off from those real-world humans who want to help. Discoverability is exploring what something does, how it works, and what operations are possible. In VR, essential tools can guide the user into discovering how the system works through consistent affordances, unambiguous signifiers, constraints to guide actions and ease interpretations, immediate and useful feedback, and obvious and understandable mappings [11][15]. A common mistake VR creators make when creating VR experiences is that they assume what works for themselves will work for everyone else [11]. To implement a VR application with both good user experience and functionality the design instead needs to be centered around the end-user from the beginning. It is the real users and their goals, not just the technology, who is the driving force behind product development. User-centered design (UCD) is an iterative design process which focuses on the end-user's needs and requirements [16]. In 1985, Gould and Lewis stated three principles they believed would lead to a "useful and easy to use computer system" [17]:

1. *Early focus on user and tasks.* The designer must first understand who the user will be and how they will use the product.

2. *Empirical measurement.* The developed prototypes should be tested by

the end user and their performance and reactions are observed, recorded, and analysed.

3. *Iterative design.* The design and development is iterative and problems found in user testing are fixed and then more tests and observations are carried out to see the effect of the fixes.

These three principles are the basis for a user-centered approach [16]. The process of interaction design has four, fairly generic, activities that also can be found in other design disciplines. These are: establishing requirements for the user experience, designing alternatives that meet those requirements, prototyping the alternative designs so that they can be communicated and assessed, and evaluating what is being built throughout the process and the user experience it offers. The four activates can be seen in figure 2.4. The first activity is fundamental to a user-centered approach. In order to design something that supports people, the target users must first be identified to know what kind of support an interactive product could usefully provide [16].

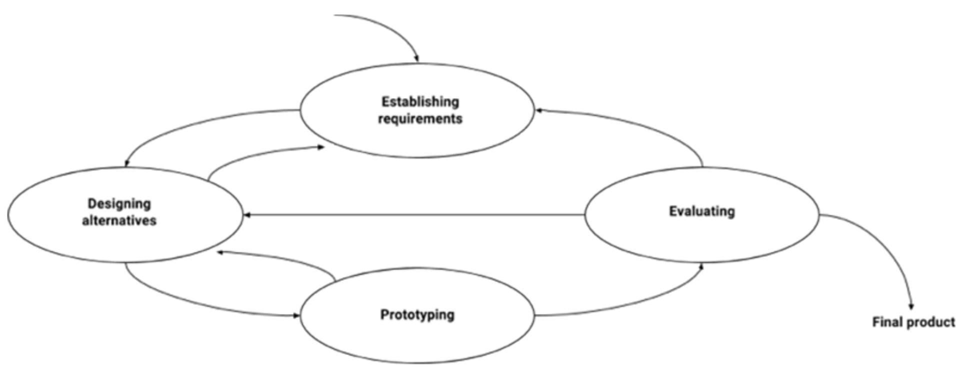

Figure 2.4: Model of the interaction design lifecycle *(adapted from [16])*

2.2.1 Prototypes

One of the main activates of interaction design involves creating interactive prototypes in order for users to evaluate their usability. There a different prototyping techniques. For example, paper-based prototypes can be effective to identifying problems in the early stages. Two types of prototypes are often used in the design process. A low-fidelity or Lo-Fi prototype does not look very much like the final product since it uses material such as paper or cardboard rather than computer software. They are useful early in a design process since they cheap and quick to produce. One example of Lo-Fi prototypes are storyboards to show different scenarios. High-fidelity or Hi-Fi prototypes on the other hand use materials that are expected in the final product. They take much longer to build and one drawback is that developers are reluctant to change something they have spent hours to create [16].

2.3 Basics of Fire Safety

Fire is a chemical reaction between three elements. There must be oxygen to sustain combustion, heat to raise the material to its ignition temperature and fuel to support the combustion. Remove any one of the three elements to extinguish the fire [18]. One rule for fire safety is to remember the three As. The three As are; Activate the building's alarm system and notify the fire department by calling 112. Assist any persons in immediate danger to exit the building. Only after these two are completed, attempt to extinguish the fire [18]. An efficient method on how to use a fire extinguisher is the PASS technique, as can be seen in figure 2.5. According to this method one should; pull the safety pin on the extinguisher, aim the nozzle of the extinguisher at the base of the fire, squeeze the operating lever to discharge the material, and sweep the hoose across the base of the fire from side to side [19].

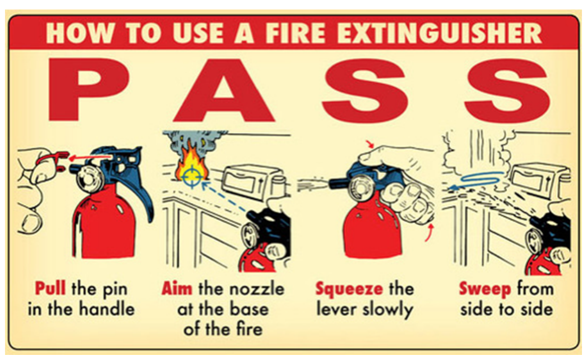

Figure 2.5: The PASS method for Fire Extinguishers *(taken from [20])*

The mutual European standard for hand-held fire extinguishers is called SS-EN 3-7 [21]. It includes classifications for fire extinguishers named A, B, C and F for different types of fires. An A-type fire extinguisher can for example be used in normal living and working environments and use water, foam or dry powder as an extinguishing agent. B-types on the other hand is used in environments with flammable products like gas stations and laboratories. Dry powder extinguishers are very effective but the powder is very hard to remove afterwards and in some public places foam is therefore used instead. The Swedish association for fire protection recommends a fire extinguisher with dry powder as extinguishing agent and with a capacity of at least 6 kg for homes and offices [21].

2.4 Research Concepts

To answer the research question and validate the VR prototype a number of research concepts needs to be explained. For example, a data collection enables the effectiveness of VR aspects to be specified, quantified, and compared. Data can be divided into qualitative or quantitative data and both are important as they each provide unique insight about a design's strength and weaknesses. Quantitative data can directly be measured and expressed numerically. Qualitative data on the other hand is more subjective and can be interpreted differently by different people [11].

Reliability is the extent to which an experiment, test, or measure consistently yields the same result under similar conditions. A reliable measure may consistently measure something, but it might be measuring the wrong thing. Validity is the extent to which a concept, measurement, or conclusion is well founded and corresponds to real application [11]. A constructive research approach construct understanding, meaning, knowledge, and ideas through experience and reflection [11]. Examples of methods of collecting data in order to better understand VR experiences and to improve are presented below:

- **Demos:** Are the most common form of acquiring feedback from users and get the general feeling of people's interest of the product. Demos also give something to work toward and to show progress is being made [11].
- **Interviews:** Are a series of open-ended questions asked by a real person. The best data is when conducted immediately after the person being interviewed experienced the VR application [11]. There are three different kinds of interviews: open, semi-structured and structured. For example, a semi-structured interview consists of a mix of open and closed questions. When creating interview questions, one should have in mind to avoid technical terms and leading questions and to keep the questions neutral [16].
- **Questionnaires:** Are written questions that participants are asked to respond in writing or on a computer. They are easier to administer and provide for more private responses [11].
- **Focus Groups:** Are similar to interviews but occur in a group setting. One advantage with a focus group compared to interviews are that they can stimulate thinking as participants build off of each other's ideas [11].
- **Expert Evaluations:** Are systematic approaches conducted by experts that identify problems from their perspective with the intent to improve the user experience. When done properly, expert evaluations are the most efficient method of improving the system [11].

CHAPTER 3

Method

This chapter of the report presents the methods used to answer the objective and defined scope in a previous chapter. The process was divided into several phases according to figure 3.1. In this chapter, the time line of the design process will be described, along with theory behind the design decisions. Since the development phases was a big part of this project it is described in more detail in chapter 4.

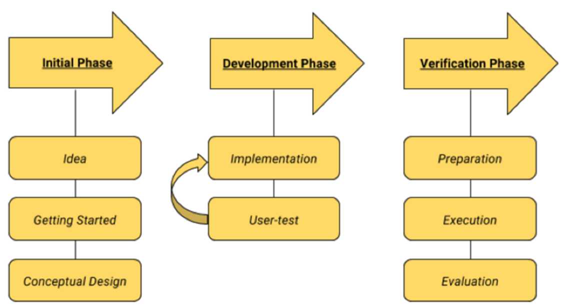

Figure 3.1: The different phases of the project process

3.1 Idea

The first step of the design process was to generate ideas for the project. During the first meeting with Pär Sikö, the supervisor for this thesis project at Jayway, the possibility to use VR for repetitive training for an industrial application was discussed. VR could here offer a solution were a newly employed industry worker could train on a certain exercise beforehand with no or very limited risk and at a much lower cost compared to alternative learning methods in the real world. After researching different alternatives of typical industry work a problem related to fire safety emerged instead. Fire safety training has a much larger audience and is not easily accessible for real world training since it involves both a substantial risk to get hurt or damage something and the cost to purchase the material needed. How to operate a fire extinguisher should also be a good fit with the VR technology of today and in a secure virtual environment it is possible to simulate situations with fires of different types and sizes. As an alternative, augmented virtuality (AV) could be used where the reality of the virtual world is extended with real physical elements. For example, instead of only grabbing a virtual fire extinguisher with one of the controllers a real fire extinguisher could be used tracked by the VR system to extend the immersion of actually lifting up and operating a fire extinguisher in the virtual environment (they usually weigh a lot).

3.2 Getting started

The next step was to gather information needed for the upcoming phases in the design process.

3.2.1 Fire Safety Exercise at Lund's Fire Station

To get experience and knowledge in fire safety and gather data a fire safety exercise was attended together with administrative staff from Lund University. The exercise was organized by the Fire and Rescue Service for the municipalities for Burlöv, Eslöv, Kävling, Lund, and Malmö *(Räddningstjänsten Syd)*. The Fire and Rescue Service offer several different educational exercises in the area of fire safety and healthcare and are often attended by employees from different companies [4]. The exercise took place at the fire station in Lund and included both theoretical and practical parts and gave a lot of useful information, especially the practical part where the most common types of fire extinguishers were explained and tested. To be able to analyse the attendees' performance and any issues during the practical part of the exercise, video was recorded.

During the practical part of the exercise the efficiency of different types of fire extinguishers was demonstrated. In figure 3.2, an exercise of comparing different extinguishers with foam and dry powder as extinguishing agents can be seen. The powder extinguisher proved to be more efficient and the attendee managed to extinguish the fire almost immediately while the other attendee with the foam extinguisher took much longer time.

Another problem of using fire extinguishers, demonstrated during this exercise, was that if a fire extinguisher is held with both leavers pressed together the safety sprint that needs to be removed before using the extinguisher will be very hard to pull out. According to the instructor it is common that people think the fire extinguisher is broken because of this, and in case of an emergency something that easily may be forgotten. During the exercise, the attendees were instructed to remove the safety pin with the fire extinguisher standing on the ground.

Figure 3.2: Comparison of different fire extinguishers at the fire safety exercise

Figure 3.3: Using a CO2 fire extinguisher on a larger fire at the fire safety exercise

3.2.2 Experiment with fire extinguisher

Data of the chosen type of fire extinguisher was also needed in order to make the virtual fire extinguisher accurate.

To gather data like weight, reach and capacity a fire extinguisher with foam as extinguishing agent was bought and tested as can be seen in figure 3.4. Video was recorded of the experiment in order to analyse for how long the extinguishing agent lasts. The summarized result from the test can be seen in table 3.1.

Figure 3.4: Testing a fire extinguisher with foam as extinguishing agent to measure its reach and capacity

Table 3.1: Test data from emptying a fire extinguisher

Data:	**Result:**
General information:	AB Fire Extinguisher with 6 litre foam as extinguishing agent bought at Biltema. http://www.biltema.se/sv/Hem/Sakerhet-och-larm/Brandslackare/Brandslackare-skum-6-l-AB-2000030973/
Weight at full capacity:	9.5kg
Weight when emptied:	3.9kg
Maximum spray reach:	6 meters
Minimum spray reach:	2 meters
Average spray reach (where the most foam landed):	3.5 meters
Spray time from full to empty:	55 seconds

One important discovery during this test was how the reach and performance decreased in relation to the level of foam left in the fire extinguisher. The spray time from full to empty was timed from the recorded video. However, during the last 10 seconds very little foam left the nozzle of the fire extinguisher and would not be enough to extinguish a real fire.

3.3 Conceptual Design

The gathered information about fire safety and fire extinguishers gave an idea of how the VR prototype could be designed and what functionality it should include. Since one of the objectives of the thesis is to compare fire safety training in VR to training in the real world, similar training tasks should be considered. The exercise at Lund's fire station also gave an indication of the possible end-users for the VR prototype.

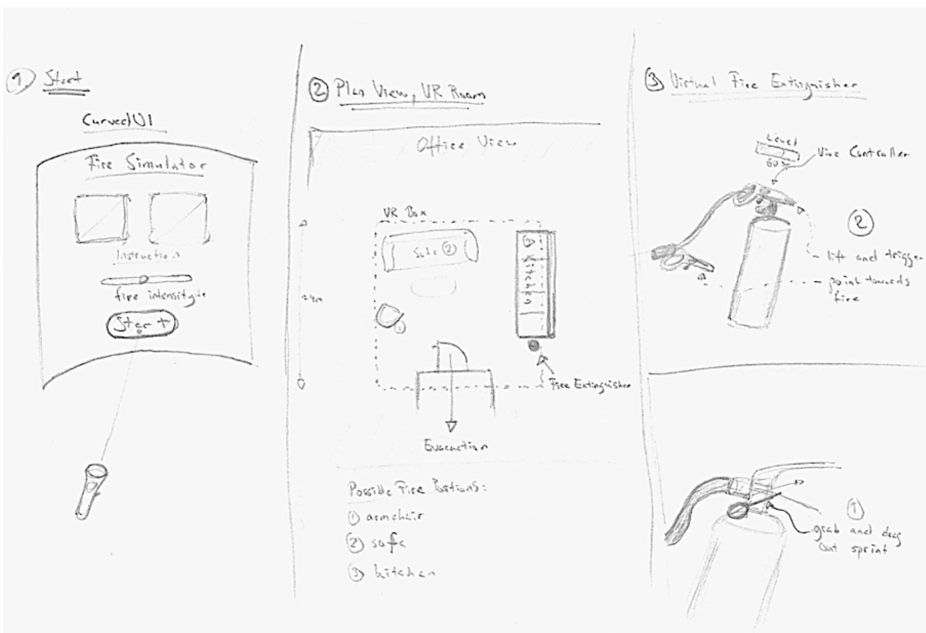

Figure 3.5: Initial Lo-Fi prototype showing the menu, floor plan, and how to operate a fire extinguisher

An initial question was which type of extinguishing agent the virtual fire extinguisher should use. During the exercise at Lund's fire station foam and dry powder extinguishers were compared and two attendees were asked to try and extinguish the fire as quickly as possible to show the difference between the two agents. The attendees also had to extinguish a larger fire inside a container with an B-classed CO2 fire extinguisher which can be seen in figure 3.3.

One idea for the VR prototype was to let a user make a choice between different types of fire extinguishers and choose the right one for a certain fire scenario. But since this is not accurate for most real situations where only one type of extinguisher is available the idea was dismissed. The choice of fire extinguisher type for the VR prototype instead became a AB-classed fire extinguisher with foam as extinguishing agent. Since foam generally is a less effective extinguishing agent it should make the training harder and should therefore better prepare users for real situations where either foam or dry powder fire extinguishers are available. According to the insurance company IF, fire extinguisher with foam as extinguishing agent is also recommended for public spaces since foam is much easier to sanitize in case of abusive use compared to powder [22].

The next question was what type of fire scenario should be implemented in the VR prototype. In VR, the simulation can easily be repeated and variables like fire intensity and burning object can be changed after each iteration. Here the user could be challenged with different levels where the difficulty of successfully extinguish the fire increases.

In order to start the development phase, Lo-Fi prototypes were sketched as reference points showing certain details such as the floor plan of the virtual environment. One of the initial Lo-Fi prototypes can be seen in figure 3.5. Since a VR application is in a three-dimensional space, Lo-Fi prototypes sketched on paper were not seen suitable for initial testing. Their usage can instead be seen as preliminary blueprints, used to implement the Hi-Fi prototype in VR.

3.4 Development Phase

The development phase followed an agile work methodology where requirements could easily be changed. The implementation was an iterative process divided into several implementation sprints. Every sprint is followed with an evaluation of the application in order to identify problems and improvements. The duration of each implementation sprint was set to two weeks.

Table 3.2: Risk analysis of the required functionality

Functionality:	**Importance: (1-10)**	**Probability of failure: (1-10)**	**Risk: (1-100)**
Fire Extinguisher: - 3D-model - Functionality: *drag out sprint, spray foam* - Animation: *handle is pressed down*	10	6	60
Realistic fire (extinguishable) that grows with time	10	4	40
Menu system	8	4	32
Evacuation Door	6	5	30
Time measurement functionality	5	2	10
Fire Alarm	6	1	6

To get a better understanding of what functionality is most important to implement early and to make a better effort estimation an analysis was made in order to rank the different functionalities based on a calculated risk, which can be seen in table 3.2. The risk is calculated as importance (1 - 10) multiplied by the probability of failure (1 - 10) to give a value of what functionality to prioritize. The probability of failure is an approximation based on previous experience and information found about how to implement the specific functionality.

Each implementations sprint was followed with a larger pilot test where colleagues and visitors at the Jayway office where asked to test the prototype. The outcome of this test procedure was that a larg variety of users tested each iteration of the prototype. This corresponds well with Gould and Lewis second principle about that the developed prototypes should be tested by the end-user [17]. During the user tests, each person's previous experienced in VR was noted together with encountered problems. The test person was also asked about problems they experienced and if they had any suggestions of improvements to make the application even better. More detailed information about the pilot tests will be presented in chapter 5.

3.4.1 Hardware/Software

In the following subsection an introduction to the hardware and software used during the project is presented.

HTC Vive

The preferred VR-system was the HTC Vive. The main reason being that the HTC Vive has a very good tracking system for room-scale VR. With room-scale VR a user can move within a limited area, defined by the position of the base stations and the available space in the room. As a safety feature the play area has chaperones as a boundary to prevent users from accidentally leaving the area. The HTC Vive hardware was released in 2016 and consists of three major parts, a headset, controllers and two base stations [23].

The headset uses dual AMOLED displays with a resolution of 1080 x 1200 pixels per eye. The refresh rate for the displays is 90Hz and the field of view is 110 degrees. The headset can be seen in figure 3.6. The headset also has a front-facing camera, adjustable straps and enough room to fit most glasses. The controllers are designed to exclusively be used in VR with intuitive controls and gestures and haptic feedback. The main buttons on the controllers are the trigger button, the grip button and the touch pad which are marked in figure 3.7.

The SteamVR tracking system, used by the HTC Vive, has two base stations (also called lighthouses) which together offer 360-degree play area tracking coverage. The base stations can be seen in figure 3.7. For room-scale VR the

Figure 3.6: The HTC Vive Headset *(taken from [23])*

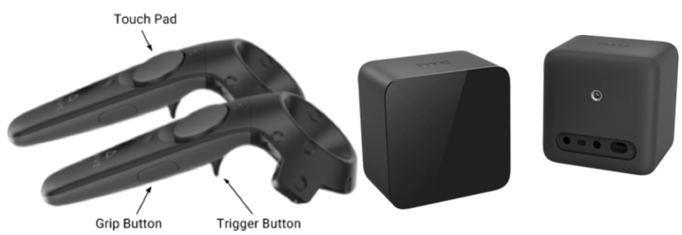

Figure 3.7: The HTC Vive controllers (left) and base station (right) *(taken from [23])*

minimum distance between the base stations is 2 x 1,5 meters and the maximum distance is 5 x 5 meters. The base stations are completely independent (besides a power connection) from the rest of the VR-system. With a 120-degree multiaxial laser-diode the base station sweeps the room with several sync-pulses and laser lines. The several ASIC-sensors on the controllers and headset use the light from the base stations to calculate the position with simple trigonometry. Together with an internal measurement unit (IMU) the tracking system can also calculate the tracked object's speed and angular velocity at a refresh rate of 1000Hz [24]. The schematics of the SteamVR tracking system can be seen in figure 3.8.

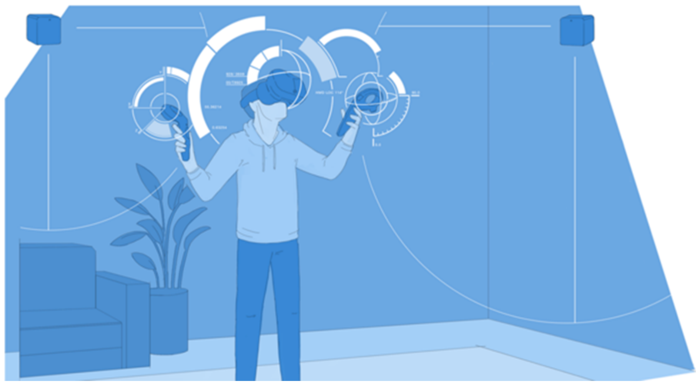

Figure 3.8: The SteamVR Tracking System *(taken from [24])*

Unity

For developing the VR-prototype Unity version 2017.1.1f1 was used [25]. Unity is a game engine from the company Unity Technologies which support game development in both 2D and 3D for multiple platforms such as mobile, console and VR. Unity is a free software to start using. They offer paid subscriptions with more functionality and for projects with an annual revenue exceeding $100k they are obligatory [25].

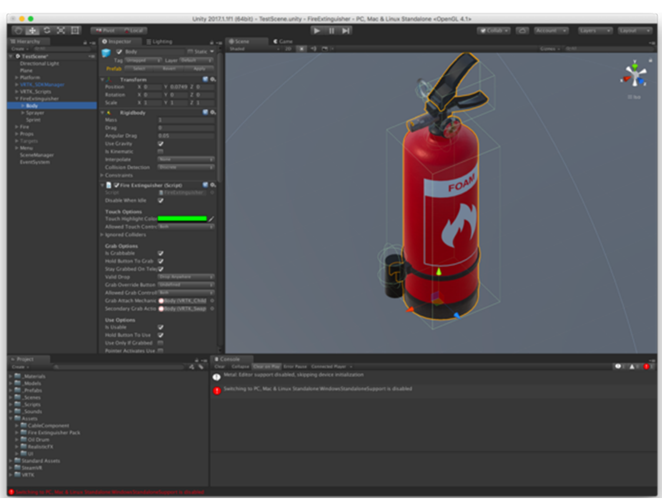

Figure 3.9: The Unity Game Engine Editor

The Unity editor can be seen in figure 3.9. It consists of different windows that can be customized by the user. The main windows are the Hierarchy view, the

Inspector, the Scene view, the Game view, the Project view and the Console. By first creating a new scene in Unity so-called GameObjects can be added into the Hierarchy view and thereafter be manipulated in the Inspector and Scene view. Scripts can be added to the GameObject written in either C# or JavaScript programming languages.

To start developing for VR in Unity, the SteamVR Plugin was downloaded and added to the project. SteamVR is a free asset available in the Unity Asset Store and contains both scripts and render models for the controllers making it easy to get started with VR development [26]. Another useful asset is VRTK which is an open-source library that expands the VR capabilities with scripts for many of the basic VR interactions, such as grabbing, pointers and teleportation. VRTK makes it easy to develop for different VR platforms and includes a simulator which makes testing possible without a connected VR headset [27].

Blender

Blender is a free and open source 3D creation suite [28]. It can be used to create and edit 3D models. The 3D models can thereafter be exported in the FBX file format to be used in Unity. For this project Blender was used both to create models and manipulate downloaded models.

Arduino and Mosquitto server

During the last iteration of the development phase a new VR-prototype was developed where a real fire extinguisher was used together with the controllers in the virtual environment. A joystick module connected to an Arduino board powered by a USB-connected battery was used as a trigger on the fire extinguisher and via a Mosquitto server running on the same Wi-Fi network messages was sent to the VR application. The components can be seen in figure 3.10.

Arduino is an open-source electronics platform based on easy-to-use hardware and software. Arduino boards are able to read inputs and turn it into an output [29]. Eclipse Mosquitto server is an open-source message broker that implements the MQTT protocol that provides a lightweight method of carrying out messaging [30].

The development phase resulted in two different VR-prototypes. The main prototype was developed to work with a standard HTC Vive system. For the second prototype the concept of augmented virtuality (AV) was used where a physical fire extinguisher was equipped with one of the Vive controllers in order to track its movement and a wirelessly connected Arduino joystick to work as the fire extinguishers trigger. The second prototype was only developed during the fourth and last iteration as a proof of concept. However, only the main prototype was used during the verification phase described below.

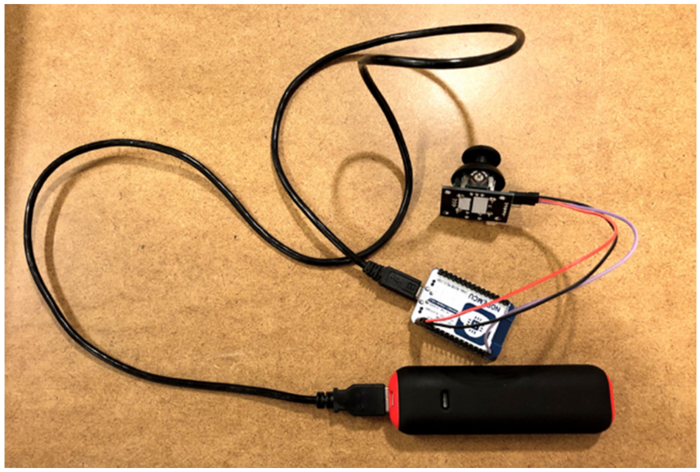

Figure 3.10: The joystick, Arduino board, and the USB-connected battery

3.5 Verification Phase

The last phase of the project was to evaluate the VR-prototype in relation to the defined objective and research questions. Two different types of research concepts were used to evaluate different aspects of the prototype.

Expert Evaluation

Interviews with experts in the area of fire safety was conducted to gather data about using VR as an alternative method for fire safety training. The VR-prototype was initially tested by a smaller group of people. Thereafter a semi-structured group interview followed where a number of prepared open and closed questions were discussed.

User-tests

The purpose with the final user-tests was to conduct a comparative study and analyse how the prototype prepares users for operating real fire extinguishers. Data from two groups were collected where the first group started with training in VR and the second group started with operating a real fire extinguisher. Another reason for dividing the test subjects into two groups where if one group perform similar tasks in a real-world scenario and compare to a group using VR it would make it easier to understand the validity of a prototype, as suggested by a paper about using VR for prototyping wearable AR interactions [31].

3.5.1 Preparation

A test plan was drafted for both types of evaluation methods and can be found in appendix A. The test plan contained information for both types of research methods such as interview question and tables for data collection. Writing a test plan made the execution of the verification phase easier since all steps had been prepared in advanced and the questions and data needed was already defined.

3.5.2 Execution

The execution of the verification phase would be split out over a number of weeks where the finished prototype was tested.

Expert Evaluation

The first expert evaluation took place the 12th of December 2017 at the VR Lab at Lund University. The VR-prototype was tested by a PhD student at the department of fire safety engineering at Lund University. The interview questions were answered via email after the test with the prototype.

The second expert evaluation took place the 17th of December 2017 at the fire station in central Malmö. Seven people in total tested the VR-prototype. The evaluation was divided into three interview sessions where three groups of fire-fighters first tested the VR-prototype and then discussed and answered the prepared interview questions. Audio was recorded from the interviews to later be transcribed and analysed. A photo from the expert evaluation can be seen in figure 3.11.

Figure 3.11: Expert evaluation at the fire station in Malmö

User-tests

The final user-test took place between 8th of January and 19th of January at the Jayway office in Malmö. Both colleagues at the office and guests were invited to take part in the test. The user-test was performed individually and took approximately 15 minutes per person. Depending on if the participant had previous experience with the VR-prototype he or she was divided into one of two groups and given an identification number. The first step during each test was to answer the first part of a digital questionnaire. Members of the first group then started with training in VR and members of the second group started with operating a real fire extinguisher. The fire extinguisher used during the experiment was the same one that was emptied during the initial phase of the project. Since a lot of weight was lost after emptying the extinguisher a 2.5kg barbell weight was taped on the bottom of the fire extinguisher.

During each test in VR notes were taken about the time to complete each level, if the fire alarm was activated, number of extinguished fire, and remaining foam left in the fire extinguisher. The test subjects completed the training in VR twice.

While the test subjects operated the real fire extinguisher video was recorded and the test subjects were instructed to talk out loudly what they were doing. A photo from the user-test where the test subject operates a real fire extinguisher can be seen in figure 3.12.

Figure 3.12: User-test examining how the test subjects operates a fire extinguisher

3.5.3 Evaluation

The last step was to evaluate the gathered research data and analyse it in relation to the defined objective of this project. The gathered research data from the different evaluation methods will be presented in chapter 5 and discussed in chapter 6. The recorded videos during the user-tests when the test subjects operated a real fire extinguisher was evaluate and grade from 0 to 5 in relation to the PASS technique for operating fire extinguishers. The complete research data collected during the verification phase can be found in appendix B and C.

CHAPTER 4

Development Process

In the following chapter, the development of the VR-prototype will be described in more detail. The main prototype was developed in four iterations. Each iteration ended with a user-test with co-workers and visitors at the Jayway office. The test started with a short introduction to the project and its objective. Notes were taken about each test subjects previous experience together with encountered problems. They were also told to speak out loudly about what they were doing and thinking. Afterwards, the test subject was asked about problems and suggestions of improvements to the prototype.

4.1 Iteration 1

The objective for the first iteration was to create a new project in Unity and start implement functionality needed for a working prototype. Since a lot of functionality was needed for a working prototype the risk analysis from previous chapter was used to prioritize in what order functionality should be implemented. The initial plan for the project was that each implementation sprint should be two weeks. However, since a lot of functionality was needed for a working prototype the first iteration was extended to three weeks in total.

4.1.1 Ideas

For the first iteration, the idea was to set up a new project in Unity and implement the most essential functionality such as the virtual fire extinguisher and an extinguishable fire. In addition, some other elements were also deemed necessary like a start-menu with a start button and a platform the user stands on.

Elevated Platform:

As mentioned about the HTC Vive, the room scale play area is defined by the placement of the base stations and the available space. The size of the play area will vary depending on where and how the HTC Vive is installed and affects where the user can move in the virtual environment. To limit the users' movement an elevated platform could be used since the fear of falling should subconsciously prevent users from leaving the platform's edges. The platform should also make the limited area for movement feel more natural since no other method of locomotion, like teleporting, is implemented. A Lo-Fi prototype of the imagined platform can be seen in figure 4.1.

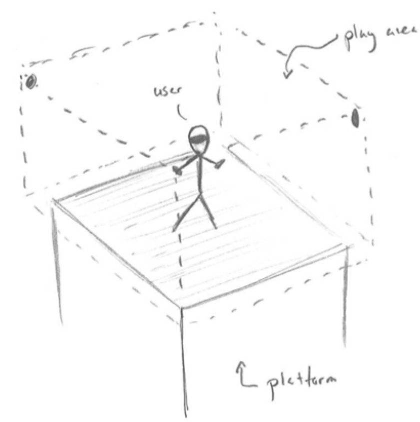

Figure 4.1: Lo-Fi prototype of the elevated platform

4.1.2 Prototype

The first iteration resulted in a working VR prototype where a user can pick up and use a fire extinguisher and extinguish a fire in the virtual environment. Minimal effort was spent on the surrounding environment in order to prioritize the required functionality for a working prototype. The implemented functionality during this iteration is presented below.

Buttons and tool tips on the controllers:

Three buttons on the controllers were implemented to be used in the prototype. The grip buttons on the controllers' side was implemented to grab the fire extinguisher, the sprint, and the nozzle. The touchpad was used to activate a pointer from the controller to interact with the menu when it is active. The trigger button was implemented to spray foam when the fire extinguisher is grabbed and act as a click button when the user points at the menu with the laser pointers. Tool tips where added to the controllers to give instructions on how to interact with the application and were only visible in the beginning together with the start menu. The controller tool tips can be seen in figure 4.2.

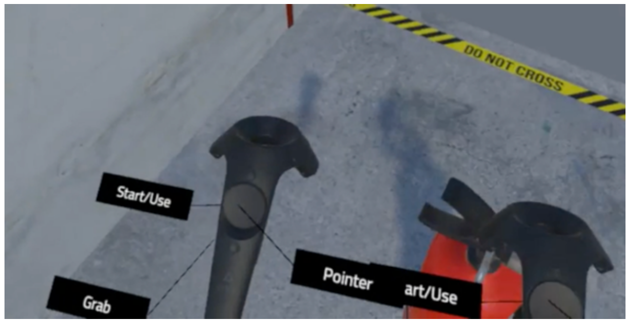

Figure 4.2: The controller tool tips showing the different buttons' functionality

Fire Extinguisher:

The fire extinguisher consists of three individual parts. The extinguisher body, the sprint and the nozzle. The 3D-models originates from a downloaded model of a fire extinguisher but has been modified in Blender with new textures and the extinguishers component was divided into separate parts. Each part of the fire extinguisher acts as an intractable object so it can be grabbed by the user by placing the controller close enough to the 3D model and pressing the grab button. In the initial stage the sprint and the nozzle are attached to the body of the extinguisher and thereby follow its movement. To start using the fire extinguisher the sprint must first be removed. By removing the sprint from the fire extinguisher, the user can start spraying foam from the nozzle by pressing the trigger button on the controller placed on the fire extinguisher. The foam is created with a particle system in Unity. One problem during the implementation of the fire extinguisher was how to create the hose between the fire extinguisher's body and the nozzle since there is no dedicated functionality in Unity for this. Instead a solution from an online repository was imported where the line renderer functionality in Unity is used between two positions together with physics simulation using verlet intergration [32]. To avoid creating an unnatural long hose, a break distance is calculated between the two attachment points and when the value exceeds a predefined limit the nozzle automatically transforms back to its original attachment position at the body of the fire extinguisher. The nozzle also automatically transforms back if it is dropped by the user. To enhance the immersion of using a fire extinguisher sound effects was added together with individual vibrations on the controllers. The upper handle of the fire extinguisher was also animated to close while using the fire extinguisher.

Fire:

The fire consists of several particle systems created in Unity. Each particle system represents different types of fire elements like flames, fire particles and smoke. In the centre of the fire a collider is placed to detect collisions from the extinguishing agent. When the collider registers collisions from the fire extinguisher the number of particles decreases and the fire can thereby be extinguished by lowering the number of particles to zero. The particle systems and the collider in Unity can be seen in figure 4.3. The fire also slowly increases to a fixed size by adding more particles to each particle system continuously.

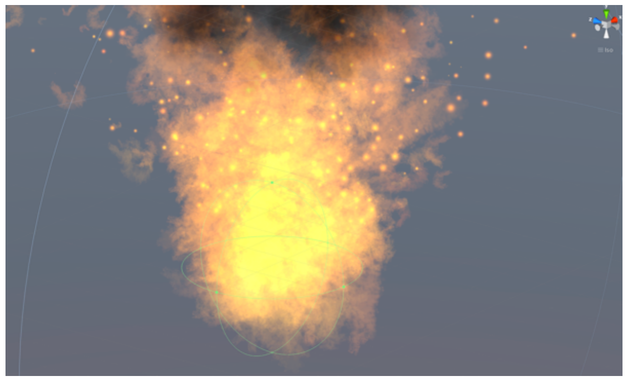

Figure 4.3: The virtual fire in Unity consisting of particle systems and a centered capsule collider to detect collisions from the fire extinguisher

Platform:

The idea of the elevated platform described in the previous sections was also added during this iteration. The platform was designed with an extra step up from the ground and a with wall behind the user. To enhance the feeling of not being allowed to leave the platform, “do not cross”-tape was placed on the ground. The texture on the platform and wall was created to look like concrete. The platform can be seen in figure 4.4.

Alarm:

A fire alarm was added to the scene in Unity on the wall placed together with the platform. The alarm is place in the user’s curiosity zone behind the initial start menu. The alarm can be activated simply by touching it with one of the controllers and the alarm sound starts playing. The fire alarm can be seen in figure 4.5.

Menu:

When starting the VR prototype the user is presented with a floating menu in front of them as can be seen in figure 4.4. The menu has two functions. It is used to start the training by pressing the start-button on menu with the pointers from the controllers. After the fire is extinguished the menu reappears and presents the time it took to extinguish the fire and if the fire alarm was

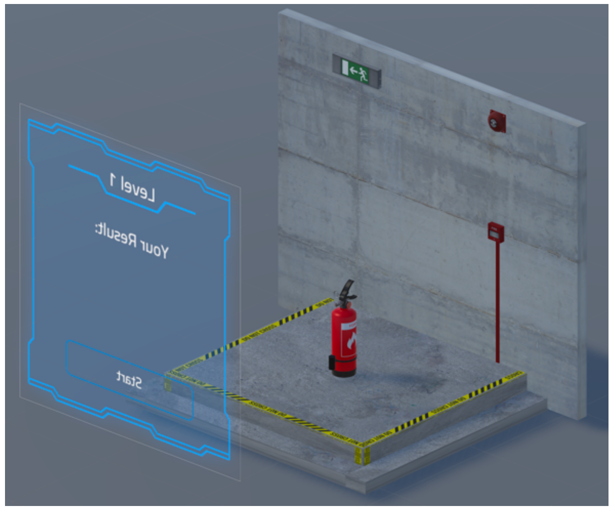

Figure 4.4: The scene in Unity during the first iteration showing elements such as the menu and elevated platform the user stands on

Figure 4.5: The fire alarm can be activated by touching the 3D-model with one of the controllers

activated. The user can then restart the training exercise by again pressing the start button.

4.1.3 User-test 1

The first user test took place the 12th of October 2017 during an event organized at the Jayway office where VR was showcased. During the event both co-workers and visitors where introduced to the project and asked if they wanted to try out the prototype in VR. During each test, the test persons was observed to identify any issues. Notes was taken with identified issues and suggestions the test persons had when using the prototype. Approximately 10-15 persons tried the prototype and the majority of these had never tried VR before. A summary of the issues and suggested improvements are presented below.

Issues:

- Even though tool tips where added to the controllers to show the buttons functionality a lot of people had problem to figure out which button to use. Especially the grab button was very hard to find and some people just tried with every possible button combination to make something happen. There are VR-applications for the HTC Vive that use the trigger button to grab items and this confused some users with previous experience with the HTC Vive
- The menu was also a bit tricky to interact with. Pressing the start button on the menu requires finding both the touchpad and the trigger button. Some test persons thought just pointing at the start button was enough and other tried clicking with other button combinations.
- Another observed problem common with newcomers to VR was where to put the controller in order to grab an object. Even though the objects that can be grabbed are highlighted in a green colour when the controllers touch the object some tried to pick up objects without actually touching them.

Suggestions:

- The controllers could be presented in a better way. It easy to just start the application without reflecting on what each controller button is for. One suggestion is a separate introduction level where the controllers and the intractable parts of the fire extinguisher is presented step by step.
- Another suggestion was to skip the touchpad to activate the laser pointers together with the menu. Instead the pointers could always be on and the user would only have to find the button to click the menu's start button.
- Some other VR applications for the HTC Vive use the trigger buttons for grabbing objects which confuse some users. One suggestion was to instead use the touchpad above the controller to actually use the fire extinguisher and use the trigger for grabbing objects. On real fire extinguishers, the actual spray handle is placed above the grab handle so using the touchpad could therefore correlate better.

4.2 Iteration 2

During the second iteration ideas and suggestions from the first user-test was taken into consideration when further developing the VR prototype. The plan for the second iteration was to add more 3D-models to the scene and start building up the surrounding virtual environment. The duration of the second iteration was two weeks and ended with the second user-test to evaluate the application and its new additions.

4.2.1 Ideas

The first user-test resulted in new ideas for the prototype. Presented below are the most important ones to solve some of the found issues and further develop the application.

Introduction Level:

During testing, a lot of people found it hard to learn the controllers and how to interact with the fire extinguisher. To make it easier to understand the VR application a separate introduction level was imagined that step by step guides the user which buttons on the controllers to use and how to interact with the fire extinguisher.

Environment:

In addition to the elevated platform the virtual environment needed more 3D-models and assets to make it feel more immersive and exiting. The chosen theme for the virtual environment was to look like the inside of an abandoned industrial warehouse which should suit the type of training exercise in a real-world scenario.

The Fire Container:

One idea for the application was to place the fire inside a shipping container. At the exercise at Lund's fire station where a larger fire was extinguished inside an actual shipping container which can be seen in figure 3.3. The idea is to let the user train on several different fire situations presented in different levels. If the fire is placed inside the container the user won't know the type of fire situation until the doors of the container opens. This introduce a level of surprise which could relate to real fire situations.

4.2.2 Prototype

The second iteration resulted in a prototype with a more immersive VR experience since a surrounding industrial warehouse environment was created. A separate introduction level was also implemented that can be accessed from the menu in addition to the first training level. Details about important functionality implemented during the second iterations are presented below.

The Introduction Level:

The introduction level can be started from the menu that is visible in the initial state of the prototype. As can be seen on the left photo in figure 4.6 instructions are also given on how to press the start button with an attached tooltip on the controller to "point at the menu" and a highlighted and animated trigger button to see what button to press to click the start button on the menu. It is also possible to navigate between the introduction level and the first level using the arrow button placed on each side of the menu. The touchpad is no longer needed to activate the laser pointer to interact with the menu. Instead, the user only needs to point towards the menu and the laser pointer automatically activates. After starting the introduction level, the menu disappears and instructions are placed directly on each intractable object step by step. In the first step, the user is instructed to grab the fire extinguisher as can be seen in figure 4.6. The grip buttons are here also highlighted in yellow to make them easier to find. After completing all four steps the introduction level ends and the start-menu shortly becomes visible again.

Figure 4.6: The introduction level with highlighted buttons on the controllers and instructions what to do step by step

The Fire Container:

The fire container is placed in the middle of the virtual environment and just in front of the elevated platform at distance that makes it possible to reach the fire inside with the fire extinguisher. The container is always visible but only after the user starts the first level does the doors open automatically to reveal the fire inside. The doors open with an animation in Unity together with a sound effect of a larger metallic door. Only one training level was implemented during the second iteration. In this training level, a fire is presented burning on wooden euro pallets as can be seen in figure 4.7. The wooden euro pallets were chosen to fit the industrial warehouse theme. After the fire is extinguished an achievement sound is played before the level ends.

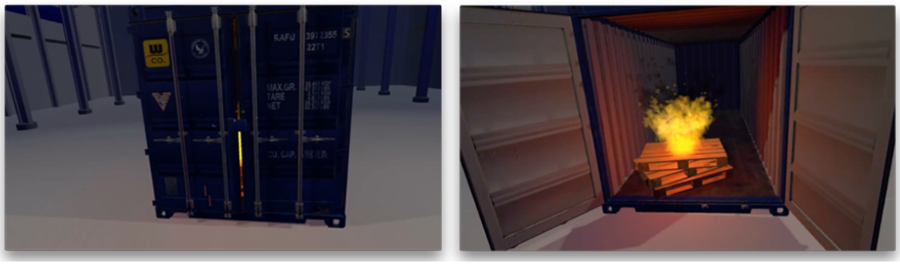

Figure 4.7: The fire container with both closed *(left)* and opened doors *(right)*

4.2.3 User-test 2

The second user test took place the 30th of October 2017 at the Jayway office where co-workers were asked to try out the VR prototype. Just like during the first user-test the test persons were instructed to complete the levels with minimal help and to speak out loudly about what they were doing to identify any problems. Notes were taken about occurred problems and given suggestions. A total of eight people tried the prototype during the second user-test. Three people had not tested the prototype before. All had tried VR in some form before the user-test. A summary of the issues and suggested improvements are presented below.

Issues:

- It is hard to know where to aim with the fire extinguisher. Since there is no feedback when hitting the fire, the user does not know if they are actually extinguishing the fire until it decreases enough in size.
- If the fire extinguisher is dropped outside the reachable play area it will not be accessible to grab again and the application needs to be restarted.
- Even though the trigger and grab button are highlighted in yellow they are only visible if the user rotates the controllers left and right. The grab button is still hard to find, especially for users not familiar with the HTC Vive system.
- The fire extinguishers nozzle is hard to find and some people found it hard to reach it.
- The menu takes some time to get used to. Some users did not find the arrows to switch between levels and instead restarted the introduction level when asked to proceed to the next level.

Suggestions:

- There should be some kind of feedback when the fire is hit by the extinguishing agent, otherwise the user will be uncertain about their performance. One suggestion was to add more smoke and play some kind of sound effect when the collider inside the fire is hit.
- Another suggestion was to redesign the introduction level. For example, the menu could still be visible during the level and instead give instructions. The next level could also start immediately after completing the introduction level.
- The button hints during the introduction level could be more visible. For example, by making them glow or blink and with added text explaining their functionality.

4.3 Iteration 3

The third iteration resulted in an easier VR application to use since a lot of the previous interaction with the menu was reduced. The application instead starts directly with the introduction level and after completing all steps the application automatically starts the next level without the need to interact with a menu. The decision to reduce the menu's functionality was taken after the second user tests where the menus necessity where discussed. The menu's colour was also changed from blue to green to better fit the theme of an industrial environment and other colours used in the prototype. During the third iteration, an evacuation door was added offering an additional way to complete a level without extinguishing the fire. A second level was also added that starts immediately after the first one but only if the first fire is extinguished. The duration of the third iteration was three weeks and ended with the third user-test to evaluate the application and its new additions.

4.3.1 Ideas

The second user-test resulted in couple of new ideas on how to make the VR prototype easier to use and further extend the user experience. A more detailed description of the most important ideas during the third iteration is presented below.

Introduction Level:

Since most users will only use the prototype once and to reduce unnecessary menu interaction the idea was to start the application with the introduction level. Instead of pressing a start button on the menu the user has to complete the introduction level step-by-step to start the next training level. In the previous iteration, users found the instructions hard to find since they are placed directly on each intractable object. Instead the menu could present the instructions in a more informative way compared to before.

User Feedback:

Another idea was to add visual and audible feedback to extend the feeling of actually extinguishing a fire. So when the extinguishing agent hits the core of the fire steam should appear together with sound effects.

Evacuation Door:

The idea of having an evacuation door was imagined early during the initial phase of the project. Together with the fire alarm the evacuation door would offer additional functionality valuable for fire safety training.

4.3.2 Prototype

In addition to implementing the ideas presented in the previous section the virtual environment was improved. For example, more 3D-models of different industrial themed props were added such as work lights, pallets, tires, oil drums and an old armchair. The menu's colour was also changed from the previous blue to a green colour to better match the industrial theme. Details about important functionality implemented during the third iterations are presented below.

Improved Introduction Level:

As can be seen in figure 4.8 the menu was redesigned to give instructions together with informative photos to help new users understand the controllers and how to use the fire extinguisher. Initially, only the first instruction is visible. When the first step is completed an achievement-sound plays, and a checkmark is placed on the menu, and the next instruction is displayed underneath. Only after completing all four steps does the next level starts.

Feedback when the fire is hit by the extinguishing agent:

A new particle system in Unity was added to the fire to look like steam when hit by the extinguishing agent. Only when the capsule collider inside the fire registers a collision from the extinguishing agent does the new particle system emit particles as can be seen in figure 4.9. To enhance the user experience, a fitting sound effect was also added to sound like water being poured on fire.

Evacuation Door:

A 3D-model of an industrial door was downloaded and imported to Unity and can be seen in figure 4.10. Scripts were implemented so when the user places a controller on the door handle it is highlighted in a green colour and when

Figure 4.8: Menu with instructions during the introduction level

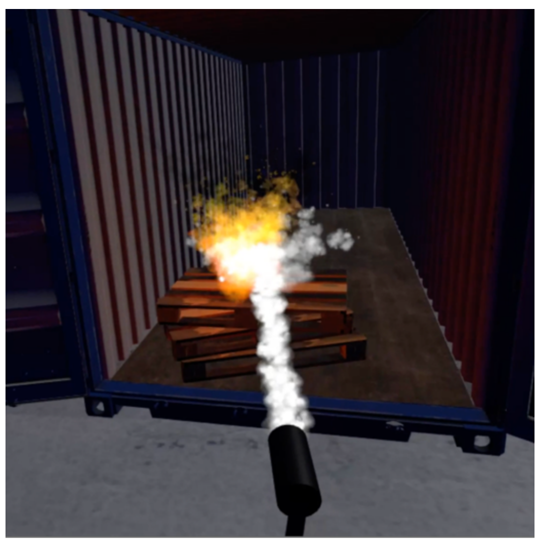

Figure 4.9: Steam appears on the fire when it is hit by the extinguisher agent

grabbed the user can open the door by pushing it forward. The door also automatically closes when the handle is not grabbed by the user anymore to keep the door closed throughout the different levels. The SteamVR play area in Unity was also adjusted so it would be possible to walk behind the door. The evacuation door can be used as an alternative way of completing a level. By using a box collider behind the door, the headset is registered and trigger the result menu and ending the training level.

To make the evacuation door feel more exciting to use one idea was to make it work as a portal between two different worlds. With a downloaded asset in a different Unity project, a 360-video was captured showing a virtual environment of a forest with trees and a blue sky. By placing the captured 360-video inside a sphere in Unity with its normals inverted the users are tricked into believing that they are transported into another virtual world by simply opening the evacuation door and stepping into the sphere. The sphere can be seen on the right photo in figure 4.10. To enhance the illusion of the portal, the sound of birds singing was added to play every time the evacuation door opens. The portal functionality is only active during the training levels where fire either needs to be extinguished or evacuated from. If the evacuation door is for example opened during the introduction level only the backside of the industrial warehouse would be visible.

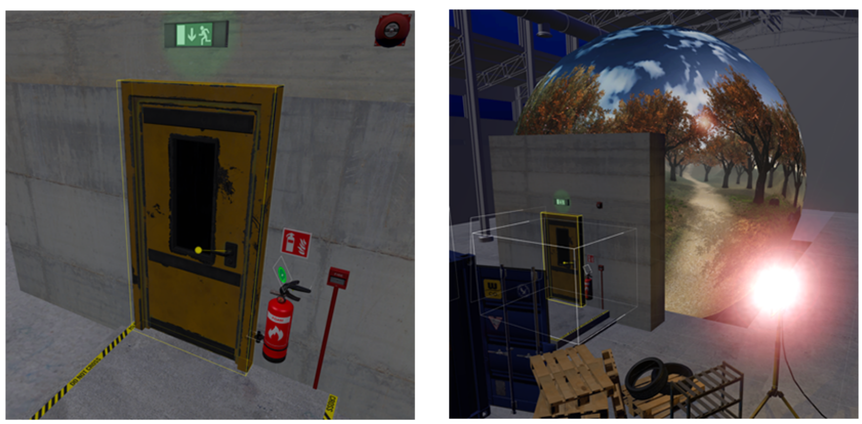

Figure 4.10: The evacuation door that can be opened and entered *(left)* and the sphere with a 360-video playing to work as a portal *(right)*

Limited Foam in the Fire Extinguisher:

To make the prototype more realistic the amount of available foam in the fire extinguisher was limited to last for approximately 40 seconds if sprayed continuously based on the data from the experiment with a real fire extinguisher described in chapter 3. A circular foam indicator was also placed above the fire extinguisher's operating leaver showing the percent remaining in the fire extinguisher as can be seen in figure 4.11. The circular indicator is only visible if the fire extinguisher is grabbed and the sprint is removed. By limiting the available amount the second level also became harder to complete, especially if unnecessarily foam was wasted on the previous levels. If a user manages to empty the fire extinguisher the only other way to complete the level is by using the evacuation door.

Figure 4.11: The circular foam meter showing how much extinguishing agent is left

Returning the Fire Extinguisher:

Another problem from the previous iteration was that if the fire extinguisher is accidentally dropped or thrown outside the reachable area, it would not be possible to grab it again. Therefore, a box collider in Unity was placed on the ground surrounding the platform to detect collisions with the fire extinguisher and if so it would be transformed back to its original position on the wall.

4.3.3 User-test 3

The third user-test took place the 27th of November 2017 at the Jayway office where both co-workers and guests visiting the office tried out the VR prototype. Just like during previous user-tests the test persons were instructed to complete the levels with minimal help and to speak out loudly about what they were doing to identify any problems. Notes were taken about occurred problems and given suggestions. In total 21 persons tried out the prototype during the third user-test. 15 of these were guests unfamiliar with both the project and VR in general. From the six co-workers that took part, four of them had tried the prototype before, and all of them had tried VR before. A summary of the issues and suggested improvements are presented below.

Issues:

- People only used the evacuation door when instructed. Since the fire only increases to a certain size one of the people testing did not see the point in using the evacuation door.
- The evacuation door was also hard to use. Since the door closes automatically when the handle is no longer grabbed some users got trapped inside involuntarily. It is also hard to know what direction the door opens.
- People tended to grab the fire extinguisher with their right hand which made it harder to remove the sprint and operate the fire extinguisher. For example, instead of switching hand by placing the fire extinguisher on the ground people instead twisted their hand holding the fire extinguisher in order to reach the sprint placed on the opposite side.

Suggestions:

- Add a push sign on the evacuation door to indicate what direction the door opens.
- The fire extinguisher should transform back to its original position between levels.
- The fire alarm should be possible to activate during the introduction level otherwise some user might think it has no function during the two training levels.
- The instruction photos on the menu during the introduction level are a bit hard to understand and could be more detailed and in colour.

4.4 Iteration 4

During the fourth and last iteration of the VR prototype suggestions from the user-test was taken into consideration together with some new ideas presented below. The fourth iteration also included work on a new prototype where the concept of augmented virtuality (AV) was used where the user instead holds a real fire extinguisher in the virtual environment.

4.4.1 Final prototype

The third user-test resulted in a couple of new ideas and suggestions to improve the user experience and make the prototype easier to use. A summary of the implemented improvements to the main VR-prototype is presented below.

Figure 4.12: The improved menu with the PASS technique during the introduction level and the new nozzle

Figure 4.13: The push sign on the evacuation door

Improved introduction level with the PASS technique:

The photos on the menu during the introduction level was changed as can be seen in figure 4.12. The instruction text on the menu was also extended to include the different steps of the PASS technique that should be used to efficiently extinguish a fire.

New nozzle on fire extinguisher:

The nozzle on the virtual fire extinguisher was also redesigned to better resemblance a real fire extinguishers with foam as extinguishing agent. A photo of the new nozzle can be seen in figure 4.12.

Push sign on the evacuation door:

A push sign was added above the door handle of the evacuation door to indicate in what direction the door opens and to make it easier to use. The sign can be seen in figure 4.13.

4.4.2 Augmented Virtuality Prototype

One problem imagined with using VR for training with a virtual fire extinguisher is that real fire extinguishers are quite heavy and in a critical situation this could surprise users. Instead, the virtual world could be extended with the help of a real fire extinguisher tracked by the VR system that users can lift up and interacts with. The concept of adding real elements to the virtual environment is called augmented virtuality (AV) and would in this scenario enhance the feeling of actually holding a real fire extinguisher.

Figure 4.14: The augmented virtuality prototype with a real fire extinguisher

A new Unity project was created to start developing a new AV-prototype where a real fire extinguisher was used. The idea was to create a proof of concept by attaching one of the Vive controllers onto the real fire extinguisher to track its position. For control input on the fire extinguisher, a joystick module connected to a Arduino board was used powered by a USB-connected battery. The Arduino board communicates with an Mosquitto-server running on the same

Wi-Fi network. The VR-application also listens to messages from the server so when the joystick is triggered by the user a message will be sent via the server to the VR-application that activates the virtual fire extinguisher. The AV prototype can be seen in figure 4.14.

By letting the user hold a physical fire extinguisher and use it as a controller in VR the immersion of actually operating a fire extinguishing was improved. Fire extinguishers are quite heavy and the previous prototype did not prepare users for actually lifting and statically holding a fire extinguisher during operation. This was also a common comment during user-testing.

However, using AV introduces some other problems. First of all, the AV-prototype can not just be downloaded and installed to work with a standard HTC Vive system. Instead, special equipment needs to be used, attached to the fire extinguisher in the real world. Another problem is the different sizes of fire extinguishers, they come in all shapes and forms, and they all need to be mapped in Unity to their virtual equivalent.

CHAPTER 5

Results

The result from the experiments and trails, derived from the verification phase explained in chapter 4, is here presented and in the following chapter discussed.

5.1 Expert Evaluation

The full transcribed interviews during the expert evaluations can be found in appendix B. A compiled version of the interviews is presented below.

- Q1: Do you think VR could have a positive effect on people's interest in fire safety?
  - R1: Definitely an interesting approach that makes it easier to train with a fire extinguisher, especially the technique one should use.
  - R2: Yes, since VR is something new. The classic answer for not being interested in fire safety is because people think it will not happen to them.
  - R3: People are generally interested in fire safety but the problem is that they don't take the time and effort to learn about it.
- Q2: What do you see as the main advantages of using VR compared to traditional training methods for fire extinguishers?
  - R1: Environmental, ease of access, repetition.
  - R2: You can repeat the exercise. Real fire extinguishers are expensive for training purposes. You can also train on different sizes of fires in VR more easily, both small and big ones.
- Q3: What do you see as the main disadvantages of using VR compared to traditional training methods for fire extinguishers?
  - R1: You do not get the same level of feedback from the extinguisher, e.g. resistance in pulling the sprint or pressing the handle.

  - R2: It is a good complement but it is not the same thing as learning in the real world. But for learning the techniques it is a good alternative since you do not have to start a real fire.
  - R3: Fire extinguishers are heavy, so you should still hold and feel a real fire extinguisher to learn the weight and how the different parts like the handle and sprint works. But the extinguisher part in VR feels like it would in the real world. People are usually not prepared for how much a real fire extinguisher sounds, especially a C02-extinguisher. So perhaps somehow adding louder sound effects to the prototype.

- Q4: How well do you think the VR prototype prepares for situations in the real world where a fire extinguisher is needed?
  - R1: With additional instructions of general usage, repeated VR attempts and perhaps a real dummy to get the feel of the weight I would equal or better than a person that gets real life training once or twice
  - R2: You would know the different steps of how to operate a fire extinguisher but it also important to get the feeling of a real fire extinguisher, how much they weigh and sound for example.

- Q5: In VR most people will have a lowered perception of threat, how do you think that affects the training?
  - R1: It does have a negative impact for sure, but by setting a serious tone in the lead up (when the instructions and information is given) I think this can be lessened.
  - R2: There could be a risk that people get overly confident and thinks they can handle a real fire just because they managed to extinguish one in VR. Using VR is a good complement but people should still also train with real fire extinguishers on real fires.

- Q6: Do you think the possibility to easily repeat exercises in VR could weigh up its technical limitations compared to traditional training in the real world?
  - R1: Absolutely to some degree, people who used a real fire extinguisher once are likely less capable than someone who has done it several times in VR, especially repeated with time in between.

- Q7: Are there elements from real fire situations you think are missing in the VR prototype? And in that case, which ones?
  - R1: Physical feedback (heat, weight etc.), 1:1 feedback of how the fire reacts with extinguishing agent.

  - R2: It should be possible to walk closer to the fire. The distance between the fire and where the fire extinguisher is operated should have an effect on the performance.

- Q8: One idea for further development is to extend the virtual environment with real object. For example, instead of using the Vive controllers a physical fire extinguisher could be used. How do you think that would affect the training?
  - R1: I think that would be a very worthwhile addition as people get used to the actual weight and handling.
  - R2: It feels surprisingly realistic either way. And as mentioned before, adding a louder sound to the extinguisher is just as important.

5.2 User-test

The result from the user-test are presented below. The full data collection during the user-test can be found in appendix C. A total of 42 people participated in the user-test.

5.2.1 Questionnaire before the test

During the first step for each participant was to answer questions to give information about themselves and their background. In figure 5.1, the participants' division of gender and age can be seen. In figure 5.2 and 5.3, the participants' previous experience with VR and video games can be seen. In figure 5.4, the participants' previous experience of fire extinguishers can be seen. The participants also answered questions about training with fire extinguishers.

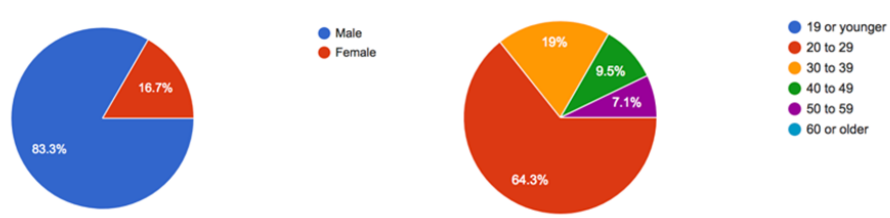

Figure 5.1: The participants' division of gender and age

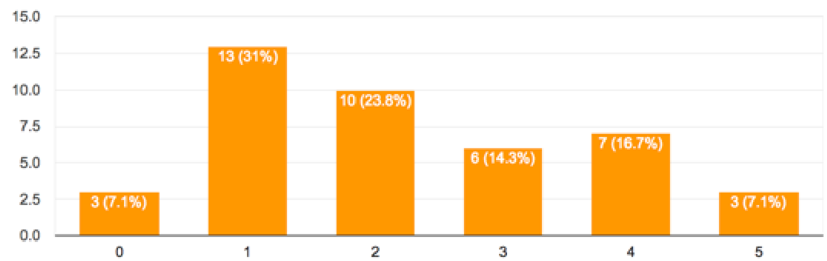

Figure 5.2: Between 0-5, what is your experience with VR? *(5 being the most experienced)*

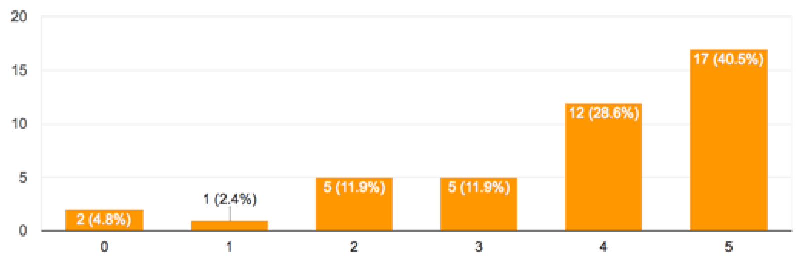

Figure 5.3: Between 0-5, what is your experience with computer- and video games? *(5 being the most experienced)*

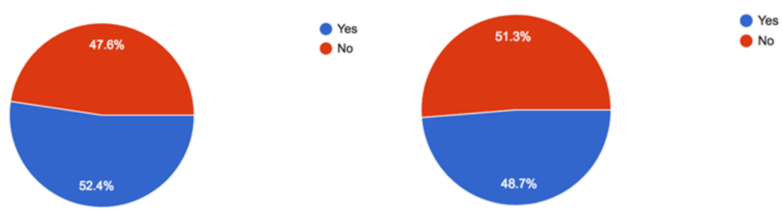

Figure 5.4: Do you have a fire extinguisher at home? *(left)* Have you ever used a fire extinguisher before? *(right)*

Figure 5.5 show how important the participants thinks training with a fire extinguisher is. An important question answer was how secure the participants feel about operating fire extinguishers in critical situations. This question was also answered after completing the test for the sake of comparison and to verify the prototype. The result from the question asked before the test can be seen in figure 5.6.

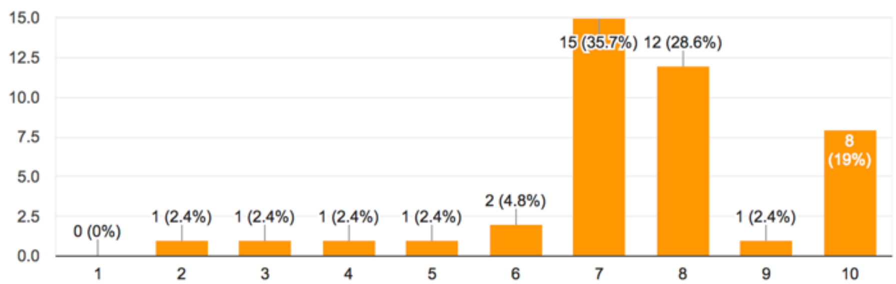

Figure 5.5: Between 1-10, how important do you think training with a fire extinguisher is? *(10 being the most important)*

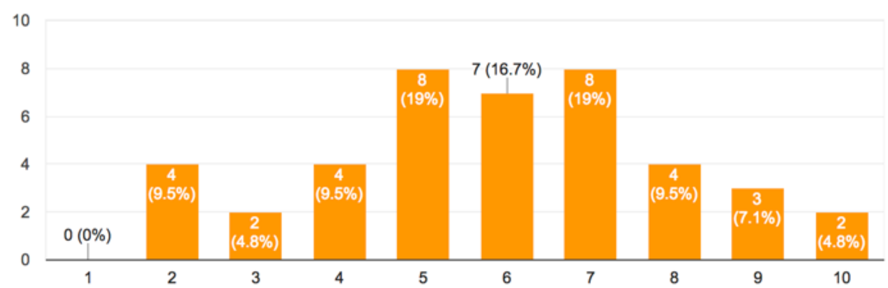

Figure 5.6: Between 1-10, how secure do you feel about operating a fire extinguisher in a critical situation at home or at work? *(10 being the most secure)*

5.2.2 Test result

In the following section the test result for the two groups will be presented. Group 1 started with training in VR and thereafter operated a real fire extinguisher. Group 2 started with operating a real fire extinguisher and then trained in VR.

In table 5.1 the average result from training in VR for the two groups can be seen. Table 5.2 shows the average time difference between the first and second training attempt in VR. The evaluated average performance on operating a real fire extinguisher can be seen in table 5.3.

Table 5.1: The average result for training in VR

	Group 1:	**Group 2:**
Time – *Intro Level:*	00:32,9	00:25,7
Time – *Level 1:*	00:33,1	00:30,1
Time – *Level 2:*	00:33,9	00:38,1
Total Time:	01:39,9	01:33,9
2/2 fires extinguished:	90,5%	69%
Alarm Activated:	31%	16,7%
Foam Left:	13,22%	14,03%

Table 5.2: The average improvement between the first and second training attempt in VR

	Group 1:	**Group 2:**
Time – *Intro Level:*	00:26,2	00:17,9
Time – *Level 1:*	00:12,3	00:09,2
Time – *Level 2:*	00:01,4	00:07,6
Total Time:	00:39,9	00:34,7

Table 5.3: The result from operating a real fire extinguisher in relation to the PASS technique

	Group 1:	**Group 2:**
Pull:	100%	90,5%
Aim:	85,7%	81%
Squeeze:	100%	100%
Sweep:	47,6%	28,6%
Distance:	71,4%	33,3%
Grade:	**4.05/5.00**	**3.33/5.00**

5.2.3 Questionnaire after the test

After completing the user-test the participants answered the final questions of the questionnaire. Figure 5.7 shows the result for how secure the participants feel about operating fire extinguisher after training in VR and should be compared with the result in figure 5.6. Another question answered after completing the user-test was if the participants felt more interested in fire safety after training in VR. This question correlates to one of the research questions for this project and the result can be seen figure 5.8.

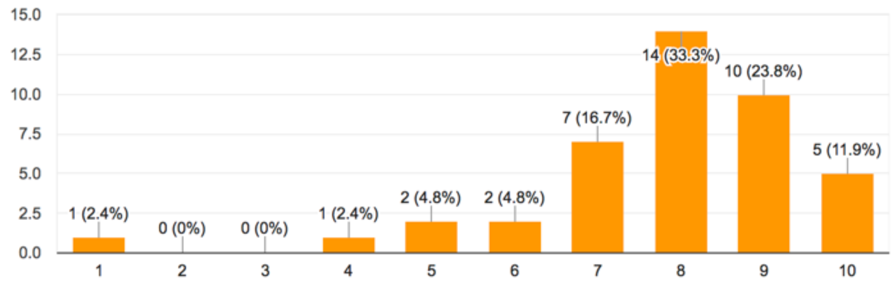

Figure 5.7: Between 1-10, how secure do you feel now about operating a fire extinguisher in a critical situation at home or at work? *(10 being the most secure)*

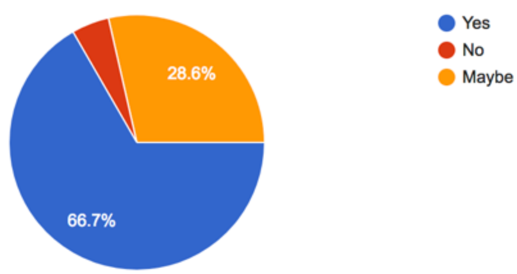

Figure 5.8: Do you feel more interested in fire safety after training in VR?

The final question of the questionnaire gave the oppertunity to give general feedback. A summary of the received answers is presented below.

- Q. Other feedback:
  - I have used a fire extinguisher before but found the instructions clear and good.
  - Might have been more inclined to search for a fire alarm button if the fire wasn't in the enclosed space of the container.
  - I think that it was a great idea to compare the different situations of extinguishing a fire both in VR and in reality.
  - Fun activity, good to have some experiences with fire extinguishers!
  - From here on, I will remember to set off the fire alarm if a fire incident would occur.
  - It was good that you had to pick upp the fire extinguisher after each step. This helps in remembering the safety pin.

- Very good. Great graphics and realism. Better learning than reading ordinary instructions only.
- Nice to test without real fire.
- During introduction if the steps of pulling the sprint and holding the nozzle are displayed with animation it would help the trainee a lot to remember during real life event.
- I think I was a bit overconfident about how you put out a fire with an extinguisher before taking the test. I've been a little humbled. And I also learned. So, cool :)
- Very good feedback in the controllers and the environment felt very convincing. I recognized the situation when I used the real fire extinguisher.
- Great app. The sound and smoke helped to make me understand where to aim.

CHAPTER 6

Discussion

In this chapter, the method used for developing the VR-prototype will be discussed together with the result from the verification phase and future work.

6.1 Interaction design for VR

VR introduces both new possibilities and limitations not relatable with traditional interaction design areas. For VR applications complete virtual environments, filled with 3D-models, needs to be sculptured in order to make the user experience feel exciting. Knowledge from many different areas, usually not relatable to software development, should be considered such as architecture, interior design, and theatre.

One of the research questions for this project was to evaluate how to create a VR application with good usability for different types of users. Virtual Reality is still a relatively young area of software development with few rules and guidelines. This quickly became obvious in the initial phase of this project while reviewing previous projects within VR.

As for any software project that aims for good user experience, VR application should be designed in an iterative process. During this project, a user-centered design process was followed to achieve good usability. It was important with an early focus on the imagined end-user and understanding the context of the application. During the early stages of the design process, a lot of ideas was generated for how the VR-prototype could be designed. For example, information collected during the fire exercise at Lund's fire station was later used to design the training levels in VR.

Designing software for VR with good usability takes a lot of time and requires a large amount of user-testing. While implementing new functionality in a virtual environment, it is hard to know what works for users not familiar with the system. Developing software for VR means a lot of switching between implementing scripts and testing with the headset. This lead to a degree of immunity in understanding typical problems for newcomers not as familiar with the application or VR in general. Therefore, regular user-tests during the development phase became very important where a lot of suggestions were collected. In the end, this resulted in a more user-friendly VR-application. But it was also hard to redesign or even remove functionality that had previously been worked on for hours.

Since users are fully immersed in VR it is difficult to give instructions from the outside. Instructions or hints are therefore needed in the virtual environment for discoverability, but at the same time, they should not break the immersion of being in a different world by appearing in an unnatural way. While developing the prototype, a lot of effort was spent on making the application as easy to use as possible. The goal was to design a VR application where a typical user should be able to figure out the applications objective and how to operate the controllers while in the virtual environment with minimal help from the outside world. One recurrent problem during the user-tests was how to get people comfortable with the VR controllers and which buttons to use in order to interact with the objects in the virtual environment. The solution was that each training sessions in the prototype begins with an introduction level. During the introduction level, a floating screen in the virtual environment shows both written instructions and photos for each step. The buttons on the controllers are also highlighted to make it as easy as possible to understand their functionality and minimize confusion.

6.2 Training in a VR simulation

Using VR as a training tool in different forms has great potential, especially for training on real world situations that are otherwise impractical. Fire safety is just one example of a scenario that could be easier to create in VR compared to the real-world. With a VR solution, users can train on a dangerous situation in a much safer environment and at a lower cost. The training exercise can also more easily be repeated compared to similar training in the real world.

The objective of developing a training simulator in VR was to evaluate how well it prepares users and review if it has a positive effect on peoples' awareness of fire safety.

The results from the verification phase indicated that the prototype in VR worked as a training tool for fire safety and had a positive effect on both peoples ability to operate a real fire extinguisher and their awareness of fire safety. 66.7% of the participants of the final user-test answered yes, and 28.6% answered maybe on the question if they felt more interested about fire safety after training in VR according to figure 5.8 which is a very good start. The idea behind the project was that real fire extinguishers are not easily accessible and cost-effective for training purposes and people in general feel insecure about how fire extinguishers should be operated which could result with serious consequences in emergency situation. This was also confirmed where a majority of the participants answered that they think training with fire extinguishers is important *(85,7% answered seven or higher on a 10 level scale, see figure 5.5)* and felt insecure about operating a fire extinguisher in a critical situation at home or work *(59,5% answered six or lower on a 10 level scale, see figure 5.6).*

After training with the VR-prototype the participant should have better knowledge of how a fire extinguisher works and the technique to use in a real-world scenario. The result from the questionnaire also confirms this statement. 85,7% of the participants answered 7 or higher on a 10 level scale on the question how secure do you feel about operating a fire extinguisher after training in VR according to figure 5.7. The average grade for operating a real fire extinguisher in relation to the PASS technique was also substantially higher for the group that had trained in VR beforehand in the comparative study. Especially for operating the fire extinguisher at a proper distance from the source of the fire. The participants without any previous training in VR simply underestimated the high pressure when spraying foam from a fire extinguisher and would probably have to adjust their position in a real emergency.

During the comparative study both groups performance when training in VR was registered to analyze if there was any difference depending on if the participants had recently performed similar tasks in a real-world scenario. However, for training with the VR-prototype, no significant difference between the two groups could be identified. The minimal difference in favor of group one could be explained with that a few participants had tried the VR-prototype before the test.

In addition to teaching how to operate a fire extinguishers the VR-prototype also includes a fire alarm and an evacuation door. The idea behind adding these elements to the training simulator relates to the fire safety rule to remember the three As. The first A is to activate the building's alarm system and notify the fire department before attempting to extinguish the fire. However, during testing very few activated the alarm in the VR training simulator. In the final user-test, only 23,8% of all test rounds were the alarm activated and often only during the second attempt. Instead, the majority of the participants focused on operating the fire extinguisher and extinguish the virtual fire without noticing the fire alarm that could be activated.

Another aspect of learning how to operate a fire extinguisher is the problem of removing the safety sprint if the two operating leavers are pressed firmly together. During the fire safety exercise at Lund's fire station the attendees were instructed to remove the safety sprint with the fire extinguisher standing on the ground. This problem was considered for the training simulator in VR. However, if the sprint only could be removed with the fire extinguisher on the ground this could result in a constrained interaction and potentially instead confuse a large number of users, and was therefore ignored. During the comparative study, only one of the participants had problem removing the safety sprint while holding the fire extinguisher the wrong way.

In order to compare the VR-prototype to traditional training methods for learning how to operate a fire extinguisher a demonstration at the fire station in central Malmö was organized. Just like in Lund, the fire station arranges exercises in fire safety. The overall result from the interviews was that VR could offer an interesting alternative to training with extinguishers and has the potential for a more easily accessible training tool. The VR-prototype was agreed as a possible complement for practical training but does not replace the training methods used at the fire station and it is still important to lift and operate real fire extinguishers to prepare for fire emergencies.

A VR system where the user is fully immersed in a virtual environment is the next logical step for training simulators. In relation to previous research efforts, VR proved during this project to be a good method where a repeatable training simulation at a relatively low cost is used to collect large amounts of data with good ecological validity. As mentioned, training simulators are nothing new but the relatively inexpensive VR-systems of today offers the possibility to create new types of training scenarios not possible with other types technology. But there are some drawbacks and limitations worth mentioning.

6.3 Limitations and difficulties

One limitation of this project is the lowered risk assessment and level of stress when using a simulator in VR. Participants will always know that the training scenario is artificial and there is no risk of actual physical harm from the fire. The consequence might be people not taking the fire safety training in VR as seriously as it should. This was a topic discussed during the expert evaluations. The conclusion regarding this subject was that it would depend on how the training is introduced. If an instructor beforehand explains the training objective with a serious tone most people will probably take it seriously.

Trying to extinguish a real fire at home with a fire extinguisher will for most people result in a very high level of stress. The same psychological discomfort cannot be simulated since virtual reality is not reality and people will know the danger is not real. It is therefore important to acknowledge that training in VR will not fully prepare for an emergency in the real world. Only experiences in the real world may have this effect.

To create a realistic fire extinguisher in the VR-prototype its capacity was limited so after spraying for a certain time the virtual extinguisher would stop working. As an alternative way to complete the training levels, an evacuation door was implemented in the prototype. However, partly explained by the limitations in the fire simulation, some users did not understand its functionality since the fire did not pose any threat.

It was also difficult to achieve a variety of the participants taking part in the comparative study. Because of limitations in recruitment the majority of the participants where male in the age of 20-29 with experience in computer and video games. The test where the participants was instructed to operate a real fire extinguisher was also limited. Preferable, these experiment should have included extinguishing a real fire for a more accurate result. This was however not possible during this project. Instead the participants used a emptied fire extinguisher on a imaginary fire. These factors should be considered since they have an effect on the result and the reliability.

6.4 Future work

The last iteration included work on a new AV-prototype where the user instead holds an actual fire extinguisher tracked by the VR system. For a training simulator in a virtual environment that aims for the highest level of realism possible, the concept of augmented virtuality should be considered. Holding an actual fire extinguisher in a virtual world had a substantial impact on the immersion of operating a fire extinguisher in the virtual environment. This type of system could also potentially add fire elements like heat release and extend the sensory stimuli. However, this results in a more complex VR-application with added components and is complicated to adopt for general use.

Another idea is to implement a second type of fire extinguisher in the simulation. The reason for only implementing one fire extinguisher in the VR simulator was that this would be more accurate for emergencies where only one fire extinguisher is available. The technique for operating fire extinguisher is also very similar between the different types. However, the VR simulator does not teach how the types fire extinguishers perform differently depending on the type of fire. This could be included in a future version with training levels where the right type of fire extinguisher must be chosen.

CHAPTER 7

Conclusion

The purpose of this master thesis was to examine if VR can be used as an alternative method for training on how to operate a fire extinguisher and review if it has a positive effect on peoples' awareness of fire safety. A VR-prototype was developed where participants could train on fire safety in a virtual environment. The user-tests during the verification phase indicated great potential for using VR as a training tool in the future. The result from the comparative study proved that participants performed better with a real fire extinguisher after first having trained in VR. The demonstrations and interviews with experts in fire safety also indicated a significant amount of interest in the technology and its potential. However, some limitations were discovered like the lack of noise and weight from real fire extinguishers. The training simulator where instead discussed as an interesting and an easily accessible complement to traditional methods for fire extinguisher education.

The recently released VR-headsets, like the HTC Vive, has aroused a substantial interest in the exciting technology that is VR. But there is still some insecurity and inconvenience regarding actually using the headsets, and it will take time until VR becomes a viable platform. When more training tools are developed in VR, and people get used to these kinds of applications, training in VR might become more efficient due to peoples general experience of VR.

References

[1] J. Cassuto and P. Tarnow, "The discotheque fire in gothenburg 1998 a tragedy among teenagers," *Burns 29*, 2003.

[2] MSB - Myndigheten för samhällsskydd och beredskap, "*Räddningstjänst i siffror 2015*." https://www.msb.se/RibData/Filer/pdf/28203.pdf. Accessed: 2017-12-01.

[3] Trygg Hansa, "*Tre av fyra lägenheter saknar brandsläckare*." http://media.trygghansa.se/tre-av-fyra-lagenheter-saknar-brandslackare/. Accessed: 2017-12-01.

[4] Räddningstjänsten Syd, "Utbildning." https://www.rsyd.se/utbildning/. Accessed: 2017-09-15.

[5] R. L. Page, "Brief history of flight simulation," *The SimTecT 2000 Organising and Technical Committee*, 2000.

[6] D. Nilsson and E. Ronchi, "A virtual reality experiment on the design of flashing lights at emergency exit portals for road tunnel evacuations," *Lund University*, 2015.

[7] F. D. R. Naraez, "Assessment of people's perception of fire growth: A virtual study," *Lund University*, 2017.

[8] Oxford Dictionaries. https://en.oxforddictionaries.com/definition/virtual_reality. Accessed: 2017-09-18.

[9] M. Wallergård, J. Eriksson, and G. Alce, "Kompendium till kursen virtual reality i teori och praktik (mam101)," *Lund University*, vol. vr. 06 ed, 2017.

[10] E. M. Kolasinski, "*Simulator Sickness in Virtual Environments*." http://www.dtic.mil/cgi-bin/GetTRDoc?AD=ADA295861. Accessed: 2017-09-22.

[11] J. Jerald, *The VR Book - Human-Centered Design for Virtual Reality*. Morgan Claypool Publishers - ACM, first ed., 2015.

[12] Oculus, "Oculus best practices," vol. 310-30000-02, 2017.

[13] M. Kinateder, E. Ronchi, M. Kobes, M. Muller, P. Pauli, and A. Muhlberger, "Virtual reality for fire evacuation research," 2014.

[14] M. Alger, "Visual design methods for virtual reality," *MA Moving Image*, 2015.

[15] D. A. Norman, *The Design of Everyday Things*. MIT Press, revised and expanded ed., 2013.

[16] Y. Rogers, H. Sharp, and J. Preece, *Interaction Design - beyond human-computer interaction*. Wiley, 3rd ed., 2013.

[17] J. D. Gould and C. Lewis, "Designing for usability: Key principles and what designers think," *Communications of the ACM*, vol. 28, 1985.

[18] Fire Equipment Manufactures' Association. http://www.femalifesafety.org/fire-extinguishers.html. Accessed: 2017-09-26.

[19] BU, Environmental Health Safety, "The pass method for fire extinguishers." https://www.bu.edu/ehs/ehs-topics/fire-safety/fire-extinguisher/the-pass-method-for-fire-extinguishers/. Accessed: 2017-09-26.

[20] Metro Fire Lifesafety, "Using an fire extinguisher? remember p.a.s.s.." http://www.metrolifesafety.com/using-an-fire-extinguisher-remember-pass.html. Accessed: 2017-09-26.

[21] Brandskyddsföreningen, "Goda råd om handbrandsläckare." https://www.brandskyddsforeningen.se/globalassets/goda-rad-blad-pdf/gr_handbrandslackare.pdf. Accessed: 2017-09-19.

[22] IF, "Rekommenderad brandsläckare för offentliga miljöer." https://www.if-sakerhet.se/rekommenderad-brandslackare-for-offentliga-miljoer.html. Accessed: 2018-01-08.

[23] HTC Vive, "Vive vr system technical specification." https://www.vive.com/us/product/vive-vr-system/?utm_expid=.1PjDKbMLSx2bjg591Dmldw.1&utm_referrer=https%3A%2F%2Fwww.vive.com%2Fus%2F#vive-spec. Accessed: 2017-09-20.

[24] Steam, "Steamvr tracking." https://partner.steamgames.com/vrtracking/. Accessed: 2017-09-20.

[25] Unity, "Unity - game engine." https://unity3d.com/. Accessed: 2017-09-20.

[26] SteamVR Plugin. https://www.assetstore.unity3d.com/en/#!/content/32647. Accessed: 2017-09-20.

[27] VRTK. https://www.assetstore.unity3d.com/en/#!/content/64131. Accessed: 2017-09-20.

[28] Blender. https://www.blender.org/about/. Accessed: 2017-10-05.

[29] Arduino, "What is arduino?." https://www.arduino.cc/en/Guide/Introduction. Accessed: 2018-01-16.

[30] Mosquitto, "An open source mqtt v3.1/v3.1.1 broker." https://mosquitto.org/. Accessed: 2018-01-18.

[31] G. Alce, K. Hermodsson, M. Wallergård, L. Thern, and T. Hadzovic, "A prototyping method to simulate wearable augmented reality interaction in a virtual environment - a pilot study," *Avestia Publishing*, 2005.

[32] Github, "Noxwings/cable-component." https://github.com/NoxWings/Cable-Component. Accessed: 2017-19-03.

APPENDIX A

Test Plan

A.1 Purpose

The test plan is divided into two parts with different purposes. The first part of the plan will use a combination of a focus group and expert evaluations in order to evaluate if the VR-prototype could be used as an alternative training method. The second part will be a larger data collection on how well people perform with a real fire extinguisher before and after having trained in VR. The second part is a comparative study with two groups that aims to answer the main question of this project; evaluate if VR can be used as an alternative training method, and review if it has a positive effect on peoples' interest for fire safety.

A.2 Selection of participants

For the expert evaluations participants with knowledge about fire safety should be selected. For the second part of the test two larger groups needs to be constructed. Both groups should reflect the aimed user-base which is adult people in all ages in need of training with a fire extinguisher.

A.3 Structure of the first part of the tests

The first part of the test with expert evaluations is planned to take place at the fire station in Malmö 22th of December. The number of people available for the test is beforehand unknown but hopefully 3-5 people should be enough. The structure of the test can be seen in table A.1.

Table A.1: Test structure for the expert evaluation

Step:	**Description:**	**Material:**	**Time:**
Demo of the VR prototype	Let people try out the VR prototype. Introduce the VR-controllers before in order to make it as easy as possible to get started	Computer with the HTC Vive system installed	60 min (depending on the number of people available)
Semi-structured interview with the group	Let people give their feedback and use the prepared interview question and hopefully start a discussion between the participants	Audio Recorder (iPhone) and prepared interview questions	60 min (depending on the number of people available)

A.4 Prepared interview questions

In preparation for the expert evaluation a number of opened and closed questions is defined in the following section. The questions is asked to start a discussion after the test subject has tried the VR prototype.

- Q1. Do you think VR could have a positive effect on people's interest in fire safety?
- Q2. Between 1-10, how important do you think training with a fire extinguisher is? (10 being the most important)
- Q3. What do you see as the main advantages of using VR compared to traditional training methods for fire extinguishers?
- Q4. What do you see as the main disadvantages of using VR compared to traditional training methods for fire extinguishers?
- Q5. How well do you think the VR prototype prepares for situations in the real world where a fire extinguisher is needed?
- Q6. In VR most people will have a lowered perception of threat, how do you think that affects the training?
- Q7. Do you think the possibility to easily repeat exercises in VR could weigh up its technical limitations compared to traditional training in the real world?
- Q8. Are there elements from real fire situations you think are missing in the VR prototype? And in that case, which ones?
- Q9. For future improvements, is there anything missing from the VR prototype?
- Q10. One idea for further development is to extend the virtual environment with real object. For example, instead of using the Vive controllers a physical fire extinguisher could be used. How do you think that would affect the training?

A.5 Structure of the second part of the test

The second part of the test is a comparative study with two groups. One group will initially train in VR and then immediately afterwards with a real fire extinguisher and the second group will do the opposite for comparison. This test will take place at the Jayway office in Malmö between 2nd to 19th of January. Since the training will be indoors the real fire extinguisher will be emptied in advance and be used on an imaginary fire scenario. The structure of the test can be seen in table A.2.

Table A.2: Test structure for one of the groups:

Step:	**Description:**	**Material:**	**Time:**
Training in VR	Each test person will be introduced to the Vive system and how the controllers work. Another simple VR application will initially be used to get the test person comfortable with VR. Thereafter the test person will run through the VR-prototype twice and for each level their performance and time will be collected.	Computer with the HTC Vive System installed. Time measuring device (iPhone) and a laptop to enter the result	5-10 min per person
Operating a real fire extinguisher	The test person will be taken to a conference room and before entering the imaginary fire scenario will be explained. The test person must thereafter use the real fire extinguisher as they would in a real scenario. Their performance will be recorded with a video camera and they will be instructed to speak out loudly what they are doing and thinking.	Fire extinguisher that has been emptied, conference room, and a video camera	5-10 min per person
Questionnaire	Both before and after completing both steps above the test person will be asked to answer a digital questionnaire	Laptop or similar	5 min per person

A.6 Data collection

The following comparative data should be collected for the test subjects training in VR. For training with the real fire extinguisher video is used in order to evaluate differences in performance between the test subjects and groups. Each participant will be entered into lists following the template in table A.3 and A.4

- **Group 1:** Starts with training in VR and then with a real fire extinguisher
- **Group 2:** Starts with a real fire extinguisher and then trains in VR
  - *All test subjects with previous experience of using the VR-prototype will be in group 1*
  - *Foam left was added after 10 persons had already tried*

Table A.3: Test subjects:

ID number:	Group:	Name:	Tried VR -prototype before:
01	1/2	Example	✓/×

Table A.4: Recorded performance for the first and second test with VR-prototype

ID number:	Test round:	Time - Intro Level:	Time - Level 1:	Time - Level 2:	Total Time:	Extinguished Fires:	Alarm Activated:	Foam left:
01	1/2	00:00:00	00:00:00	00:00:00	00:00:00	2/2	✓/×	0%

A.7 Questionnaire

- Part 1: *(Personal Information)*
  - Q. Enter your age:
  - Q. Enter your gender:
  - Q. Between 0-5, what is your experience with VR? *(5 being the most experienced)*
  - Q. Between 0-5, what is your experience with computer- and video games? *(5 being the most experienced)*
- Part 2: *(Submitted before the test begins)*
  - Q. Do you have a fire extinguisher at home? *(Yes/No)*
  - Q. Have you ever used a fire extinguisher before? *(Yes/No)*
  - Q. Between 1-10, how important do you think training with a fire extinguisher is? *(10 being the most important)*
  - Q. Between 1-10, how secure do you feel about operating a fire extinguisher in a critical situation at home or at work? *(10 being the most secure)*
- Part 3: *(Submitted after the tests)*
  - Q. Between 1-10, how secure do you feel now about operating a fire extinguisher in a critical situation at home or at work? *(10 being the most secure)*
  - Q. Do you feel more interested in fire safety after training in VR? *(Yes/No/Maybe)*
  - Q. Other feedback:

APPENDIX B

Expert Evaluation

B.1 Interview 1

Date: 2017-12-11
Location: The VR Lab at IKDC, Lund University
Number of test persons: 1

Q. Do you think VR could have a positive effect on people's interest in fire safety?
A. *Yes.*

Q. What do you see as the main advantages of using VR compared to traditional training methods for fire extinguishers?
A. *Environmental, ease of access, repetition.*

Q. What do you see as the main disadvantages of using VR compared to traditional training methods for fire extinguishers?
A. *You do not get the same level of feedback from the extinguisher, e.g. resistance in pulling the sprint or pressing the handle.*

Q. How well do you think the VR prototype prepares for situations in the real world where a fire extinguisher is needed?
A. *With additional instructions of general usage, repeated VR attempts and perhaps a real dummy to get the feel of the weight I would equal or better than a person that gets real life training once or twice.*

Q. In VR most people will have a lowered perception of threat, how do you think that affects the training?
A. *It does have a negative impact for sure, but by setting a serious tone in the lead up (when the instructions and information is given) I think this can be lessened.*

Q. Do you think the possibility to easily repeat exercises in VR could weigh up its technical limitations compared to traditional training in the real world?
A. *Absolutely to some degree, people who used a real fire extinguisher once are likely less capable than someone who has done it several times in VR, especially repeated with time in between.*

Q. Are there elements from real fire situations you think are missing in the VR prototype. And in that case, which ones?
A. *Physical feedback (heat, weight etc.), 1:1 feedback of how the fire reacts with extinguishing agent.*

Q. For future improvements, is there anything missing from the VR prototype?
A. *Gave you some feedback when we were there, but fixing some stuff like unintentional hand-swapping, consistent type of fire extinguisher.*

Q. One idea for further development is to extend the virtual environment with real object. For example, instead of using the Vive controllers a physical fire extinguisher could be used. How do you think that would affect the training?
A. *I think that would be a very worthwhile addition as people get used to the actual weight and handling.*

B.2 Interview 2

Date: 2017-12-17
Location: The fire station in central Malmö
Number of test persons: 7

Session 1: (2 test persons)
Q. Do you think VR could have a positive effect on people's interest in fire safety?
A. *Definitely an interesting approach that makes it easier to train with a fire extinguisher, especially the technique one should use.*

Q. Are people in general interested in fire safety?
A. *People with house are more often interested than people living in apartments generally. Also, people with kids are usually also interested since their kids like fire trucks etc.*

Q. How do you think VR compares to traditional training methods for fire extinguishers?
A. *Could definitely be an alternative but since it's not a real fire situation there is a limit on the degree you can learn. The fire situations during training at the fire situation is however not super accurate either. But it is a good complement for training on the technique one should use. And the potential to further de-*

velop the prototype is big.

Q. Do you see any disadvantages of using VR compared to traditional training methods?
A. *It is a good complement but it is not the same thing as learning in the real world. But for learning the techniques it is a good alternative since you do not have to burn stuff. It could also easily be adopted as a training alternative for fire fighters.*

Q. In VR most people will have a lowered perception of threat, how do you think that affects the training?
A. *There could be a risk that people get overly confident and thinks they can handle a real fire just because they managed to extinguish one in VR. Using VR is a good complement but people should still also train with real fire extinguishers on real fires.*

Q. For future improvements, is there anything missing from the VR prototype?
A. *Train with different fire extinguishers on different scenarios, like burning oil for example. And also the time aspect. For example, if it is burning in a frying pan, early on it would be sufficient just to put the lid on but if the flames have reached the kitchen fan one should instead use the fire extinguisher.*

Session 2: (3 test persons)
Q. Do you think VR could have a positive effect on people's interest in fire safety?
A. *Yes, since VR is something new. The classic answer for not being interested in fire safety is because people think it will not happen to them.*

Q. Do you think it is necessary to train with a fire extinguisher?
A. *Yes, you should preferable know how to operate a fire extinguisher. But it should also be important to learn what happens if you cannot extinguish the fire so can compare how it can be both easy and difficult to extinguish different fires depending on the circumstances.*

Q. What do you see as the main advantages of using VR compared to traditional training methods for fire extinguishers?
A. *You can repeat the exercise. Real fire extinguishers are expensive for training purposes. You can also train on different sizes of fires in VR more easily, both small and big ones.*

Q. What do you see as the main disadvantages of using VR compared to traditional training methods for fire extinguishers?
A. *People won't have the same respect for a virtual fire as a real one. People have more respect for a real fire.*

Q. Is there anything missing that would make the VR-prototype feel more re-

alistic?
A. *Louder sound effects, fires and fire extinguisher sound a lot. Also, make it possible to walk closer to the fire. The distance between the fire and where the fire extinguisher is operated should have an effect on the performance.*

Q. One idea for further development is to extend the virtual environment with real object. For example, instead of using the Vive controllers a physical fire extinguisher could be used. How do you think that would affect the training?
A. *It feels surprisingly realistic either way. And as mentioned before, adding a louder sound to the extinguisher is just as important.*

Session 3: (2 test persons)
Q. Do you think VR could have a positive effect on people's interest in fire safety?
A. *People are generally interested in fire safety but the problem is that they don't take the time and effort to learn about it. People that own a house a generally more interested in fire safety since they want to protect their property.*

Q. What do you see as the main advantages of using VR compared to traditional training methods for fire extinguishers?
A. *You can gamify the training where you continue through different levels depending on if you manage to extinguish a fire or not.*

Q. What do you see as the main disadvantages of using VR compared to traditional training methods for fire extinguishers?
A. *Fire extinguishers are heavy, so you should still hold and feel a real fire extinguisher to learn the weight and how the different parts like the handle and sprint works. But the extinguisher part in VR feels like it would in the real world. People are usually not prepared for how much a real fire extinguisher sounds, especially a C02-extinguisher. So perhaps somehow adding louder sound effects to the prototype*

Q. How well do you think the VR prototype prepares for situations in the real world where a fire extinguisher is needed?
A. *You would know the different steps of how to operate a fire extinguisher but it also important to get the feeling of a real fire extinguisher, how much they weigh and sound for example.*

Q. Since people usually associate VR with entertainment they might not take training in VR as serious as in the real world. How do you think this affects using VR for training on fire safety?
A. *It depends on where and how the training is introduced. As long as it with a serious tone I think people will take it serious.*

APPENDIX C

Test results

Group 1: Starts with training in VR and then with a real fire extinguisher
Group 2: Starts with using a real fire extinguisher and then trains in VR

Table C.1: Test subjects, part 1

ID number:	Group:	Name:	Tried VR-prototype before:
01	1	S**** L*******	✓
02	1	M**** I*******	-
03	1	E**** A*******	✓
04	1	E**** M*******	✓
05	1	O**** H*******	✓
06	1	A**** L*******	✓
07	1	H**** K*******	✓
08	1	H**** R*******	×
09	1	J**** Å*******	✓
10	1	P**** D*******	×
11	1	A**** A*******	×
12	1	M**** R*******	×
13	1	R**** H*******	×
14	1	V**** H*******	✓
15	1	P**** B*******	×
16	1	S**** A*******	×
17	1	N**** L*******	✓
18	1	L**** A*******	✓
19	1	J**** B*******	✓
20	1	J**** N*******	✓

Table C.2: Test subjects, part 2

ID number:	Group:	Name:	Tried VR-prototype before:
21	2	M**** M*******	×
22	2	G**** N*******	×
23	2	C**** J*******	×
24	2	W**** P*******	×
25	2	M**** S*******	×
26	2	E**** H*******	×
27	2	K**** S*******	×
28	2	K**** L*******	×
29	2	A**** L*******	×
30	2	H**** S*******	×
31	2	A**** B*******	×
32	2	H**** L*******	×
33	2	C**** P*******	×
34	2	R**** A*******	×
35	2	A**** A*******	×
36	2	A**** O*******	×
37	2	L**** Å*******	×
38	2	R**** T*******	×
39	2	A**** E*******	×
40	2	H**** A*******	×
41	2	P**** S*******	×
42	1	C**** A*******	×

Table C.3: Group 1 with VR-prototype

ID number:	**Test round:**	**Time - Intro Level:**	**Time - Level 1:**	**Time - Level 2:**	**Total Time:**	**Extinguished Fires:**	**Alarm Activated:**	**Foam left (%):**
01	1/2	00:36,10	00:40,48	00:38,09	01:54,67	2/2	×	-
01	2/2	00:16,33	00:22,66	00:28,98	01:07,97	2/2	×	-
02	1/2	00:55,03	00:32,85	00:34,32	02:02,20	2/2	×	-
02	2/2	00:16,43	00:34,67	00:45,97	01:37,07	2/2	✓	-
03	1/2	00:19,85	00:27,62	00:39,75	01:27,22	2/2	✓	-
03	2/2	00:12,26	00:22,87	00:24,44	00:59,57	2/2	✓	-
04	1/2	00:30,73	00:49,16	00:48,33	02:08,22	1/2	✓	-
04	2/2	00:13,64	00:28,29	00:27,98	01:09,91	2/2	×	-
05	1/2	00:17,60	00:27,86	00:32,56	01:18,02	2/2	×	-
05	2/2	00:08,82	00:19,52	00:24,73	00:53,07	2/2	✓	-
06	1/2	00:47,55	00:41,92	00:34,03	02:03,50	2/2	✓	-
06	2/2	00:11,38	00:34,95	00:37,55	01:23,88	2/2	✓	-
07	1/2	00:32,82	00:31,99	00:37,66	01:42,47	2/2	✓	-
07	2/2	00:18,99	00:25,12	00:30,54	01:14,65	2/2	✓	-
08	1/2	00:58,06	00:27,22	00:28,81	01:54,09	2/2	×	-
08	2/2	00:17,29	00:23,72	00:23,11	01:04,12	2/2	×	-
09	1/2	00:24,06	00:32,79	00:32,45	01:29,30	2/2	×	0%
09	2/2	00:13,95	00:19,34	00:30,38	01:03,67	2/2	×	23%
10	1/2	01:02,89	00:47,70	00:31,79	02:22,38	2/2	×	8%
10	2/2	01:17,28	00:30,94	00:47,13	02:35,35	2/2	×	30%
11	1/2	00:13,89	00:33,95	00:40,46	01:28,30	2/2	×	9%
11	2/2	00:14,94	00:26,76	00:33,92	01:15,62	2/2	×	19%
12	1/2	00:57,89	00:34,59	00:30,32	02:02,80	2/2	×	0%
12	2/2	00:23,34	00:25,52	00:29,56	01:18,42	2/2	×	34%
13	1/2	00:28,69	00:28,52	00:28,08	01:25,29	2/2	×	16%
13	2/2	00:09,62	00:20,17	00:23,34	00:53,13	2/2	✓	32%
14	1/2	00:54,60	00:37,48	00:34,61	02:06,69	2/2	×	8%
14	2/2	00:11,25	00:25,48	00:24,88	01:01,61	2/2	×	40%
15	1/2	01:01,12	00:30,23	00:28,91	02:00,26	2/2	×	6%
15	2/2	00:23,13	00:28,01	00:29,58	01:20,72	2/2	✓	18%
16	1/2	01:43,57	00:33,90	00:37,76	02:55,23	2/2	×	38%
16	2/2	00:24,19	00:30,61	00:37,78	01:32,58	2/2	×	31%
17	1/2	00:32,49	00:27,61	00:34,92	01:35,02	2/2	×	15%
17	2/2	00:12,75	00:21,36	00:28,52	01:02,63	2/2	×	18%
18	1/2	00:27,07	00:46,10	01:14,23	02:27,40	1/2	✓	0%
18	2/2	00:09,29	00:26,79	00:35,10	01:11,18	2/2	×	2%
19	1/2	00:13,68	00:38,04	00:31,44	01:23,16	2/2	×	0%
19	2/2	00:10,75	00:21,93	00:23,62	00:56,30	2/2	×	25%
20	1/2	00:12,29	00:33,02	00:28,25	01:13,56	2/2	×	3%
20	2/2	00:11,01	00:21,19	00:25,63	00:57,82	2/2	✓	20%
42	1/2	02:56,61	02:01,40	0:00:00	04:58,01	0/2	×	0%
42	2/2	01:00,58	00:56,60	01:25,66	03:22,84	1/2	×	0%

Table C.4: Group 2 with VR-prototype

ID number:	Test round:	Time – Intro Level:	Time – Level 1:	Time – Level 2:	Total Time:	Extinguished Fires:	Alarm Activated:	Foam left (%):
21	1/2	00:35,42	00:33,82	01:03,37	02:12,61	1/2	×	-
21	2/2	00:11,07	00:32,89	00:34,62	01:18,58	2/2	×	-
22	1/2	00:42,45	00:32,90	00:33,55	01:48,90	2/2	×	-
22	2/2	00:10,28	00:21,44	00:31,88	01:03,60	2/2	✓	35%
23	1/2	00:34,40	00:53,90	01:36,06	03:04,35	1/2	×	0%
23	2/2	00:21,63	00:33,85	00:48,26	01:43,74	1/2	×	0%
24	1/2	00:21,36	00:42,45	01:23,96	02:47,55	1/2	×	0%
24	2/2	00:12,69	00:26,09	00:39,27	01:18,05	2/2	×	26%
25	1/2	00:29,32	00:37,77	00:36,51	01:43,60	2/2	×	2%
25	2/2	00:17,89	00:25,04	00:26,38	01:09,31	2/2	×	26%
26	1/2	00:36,17	00:31,94	00:30,31	01:38,42	2/2	×	0%
26	2/2	00:08,91	00:26,67	01:15,20	01:50,78	1/2	✓	0%
27	1/2	00:30,10	00:33,53	00:31,22	01:34,85	2/2	×	6%
27	2/2	00:13,54	00:22,35	00:27,37	01:03,26	2/2	×	18%
28	1/2	00:26,17	00:28,07	00:27,33	01:21,57	2/2	×	22%
28	2/2	00:16,56	00:22,45	00:29,25	01:08,26	2/2	×	14%
29	1/2	00:28,02	00:27,48	00:36,96	01:32,46	2/2	×	33%
29	2/2	00:17,27	00:20,66	00:21,90	00:59,83	2/2	×	44%
30	1/2	00:39,62	00:25,72	00:39,62	01:44,96	1/2	✓	0%
30	2/2	00:14,45	00:26,72	00:30,22	01:11,39	2/2	×	19%
31	1/2	00:30,13	00:39,62	00:32,41	01:42,16	2/2	×	0%
31	2/2	00:20,00	00:22,47	00:31,15	01:13,62	2/2	×	17%
32	1/2	00:16,34	00:29,14	00:28,72	01:14,20	2/2	×	2%
32	2/2	00:08,92	00:31,38	00:55,28	01:35,58	1/2	✓	0%
33	1/2	00:46,75	00:45,01	00:23,91	01:55,67	2/2	×	7%
33	2/2	00:11,37	00:24,27	00:34,37	01:10,01	2/2	✓	27%
34	1/2	00:37,77	00:29,08	00:26,20	01:33,05	2/2	×	30%
34	2/2	00:14,25	00:18,27	00:23,71	00:56,23	2/2	×	34%
35	1/2	00:15,73	00:27,20	00:51,02	01:33,95	1/2	✓	0%
35	2/2	00:07,05	00:32,68	00:27,26	01:06,99	1/2	✓	0%
36	1/2	00:21,13	00:34,22	00:54,79	01:50,14	1/2	×	0%
36	2/2	00:26,12	00:31,24	00:37,41	01:34,77	1/2	×	0%
37	1/2	00:34,57	00:23,52	00:23,23	01:21,32	2/2	×	34%
37	2/2	00:08,63	00:20,03	00:23,37	00:52,03	2/2	×	32%
38	1/2	00:29,24	00:28,64	00:26,64	01:24,52	2/2	×	23%
38	2/2	00:14,95	00:21,05	00:30,07	01:06,07	2/2	×	28%
39	1/2	00:41,02	00:50,10	00:26,86	01:57,98	2/2	×	0%
39	2/2	00:14,97	00:23,10	00:22,74	01:00,81	2/2	×	24%
40	1/2	00:21,74	00:31,91	00:35,20	01:28,85	2/2	×	7%
40	2/2	00:18,03	00:23,33	00:27,66	01:09,02	2/2	×	37%
41	1/2	01:50,34	00:43,24	01:25,90	03:59,48	1/2	×	0%
41	2/2	01:03,61	00:30,80	00:56,95	02:31,36	1/2	×	0%

Table C.5: Group 1 with real fire extinguisher

ID:	**Pull:**	**Aim:**	**Squeeze:**	**Sweep:**	**Distance:**	**Grade:**
01	✓	✓	✓	-	✓	4
02	✓	✓	✓	✓	✓	5
03	✓	✓	✓	✓	✓	5
04	✓	✓	✓	✓	✓	5
05	✓	✓	✓	-	-	3
06	✓	✓	✓	✓	✓	5
07	✓	✓	✓	✓	✓	5
08	✓	✓	✓	-	-	3
09	✓	✓	✓	✓	✓	5
10	✓	-	✓	-	-	2
11	✓	-	✓	-	✓	3
12	✓	✓	✓	✓	✓	5
13	✓	✓	✓	-	✓	4
14	✓	-	✓	-	✓	3
15	✓	✓	✓	✓	✓	5
16	✓	✓	✓	-	-	3
17	✓	✓	✓	-	✓	4
18	✓	✓	✓	✓	✓	5
19	✓	✓	✓	-	-	3
20	✓	✓	✓	✓	✓	5
42	✓	✓	✓	-	-	3
Average:	**100%**	**85,7%**	**100%**	**47,6%**	**71,4%**	**4,05**

Table C.6: Group 2 with real fire extinguisher

ID:	**Pull:**	**Aim:**	**Squeeze:**	**Sweep:**	**Distance:**	**Grade:**
21	✓	✓	✓	-	-	3
22	✓	✓	✓	✓	-	4
23	✓	✓	✓	-	-	3
24	✓	-	✓	-	-	2
25	✓	✓	✓	✓	✓	5
26	✓	-	✓	-	-	2
27	-	✓	✓	✓	-	3
28	✓	✓	✓	-	-	3
29	✓	✓	✓	-	✓	4
30	✓	✓	✓	-	-	3
31	✓	-	✓	-	✓	3
32	✓	✓	✓	-	-	3
33	✓	✓	✓	-	✓	4
34	-	✓	✓	✓	✓	4
35	✓	✓	✓	-	✓	4
36	✓	✓	✓	-	-	3
37	✓	✓	✓	-	-	3
38	✓	✓	✓	✓	-	4
39	✓	-	✓	-	✓	3
40	✓	✓	✓	✓	-	4
41	✓	✓	✓	-	-	3
Average:	**90,5%**	**81%**	**100%**	**28,6%**	**33,3%**	**3,33**