Assessment of People's Perception of Fire Growth: A Virtual Reality Study

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Abstract

One important aspect that is considered when designing safer buildings is human behavior. A comprehensive assessment of how people react during a fire, provides engineers valuable information, which will allow them to develop effective solutions to help people reach a safe place under tenable conditions. When evacuating a building, a key factor is pre-evacuation time, this is the lapse of time that starts when the person is alerted of a fire cue and ends once they evaluate the situation, before reacting and starting the purposive movement towards a safe place.
Pre-evacuation times are associated with fire risk perception. The purpose of this thesis is to evaluate how people perceive fire growth risk in a fire scenario represented in virtual reality when compared to other methods, such as educational videos. The experiments included fifty-five test participants who were immersed in a virtual environment, where they had to predict the evolution of a fire and estimate if they could extinguish it with the help of a portable fire extinguisher. The results obtained showed that 97% of participants could not accurately estimate fire growth. Only 3% of people estimated a time difference that corresponded to the real time difference. In addition, there was a significant variation on the results (under/overestimation). A slightly higher number of responses underestimated the fire growth, this was observed in 56 out of the 104 incorrect responses. Finally, it was possible to derive that at later stages of fires people will not try to use a portable fire extinguisher.

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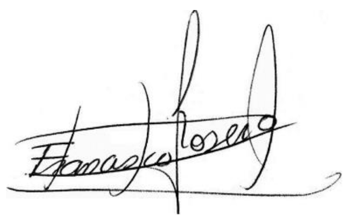

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Read and Approved

Abstract

One important aspect that is considered when designing safer buildings is human behavior. A comprehensive assessment of how people react during a fire, provides engineers valuable information, which will allow them to develop effective solutions to help people reach a safe place under tenable conditions. When evacuating a building, a key factor is pre-evacuation time, this is the lapse of time that starts when the person is alerted of a fire cue and ends once they evaluate the situation, before reacting and starting the purposive movement towards a safe place.

Pre-evacuation times are associated with fire risk perception. The purpose of this thesis is to evaluate how people perceive fire growth risk in a fire scenario represented in virtual reality when compared to other methods, such as educational videos. The experiments included fifty-five test participants who were immersed in a virtual environment, where they had to predict the evolution of a fire and estimate if they could extinguish it with the help of a portable fire extinguisher. The results obtained showed that 97% of participants could not accurately estimate fire growth. Only 3% of people estimated a time difference that corresponded to the real time difference. In addition, there was a significant variation on the results (under/overestimation). A slightly higher number of responses underestimated the fire growth, this was observed in 56 out of the 104 incorrect responses. Finally, it was possible to derive that at later stages of fires people will not try to use a portable fire extinguisher.

Abstract (Español)

Un aspecto importante que se considera al diseñar edificios más seguros es el comportamiento humano. Una evaluación exhaustiva de cómo reaccionan las personas durante un incendio, proporciona a los ingenieros información valiosa, que les permitirá desarrollar soluciones eficaces para ayudar a las personas a llegar a un lugar seguro bajo condiciones seguras. Al evacuar un edificio, un factor clave es el tiempo previo a la evacuación, este es el lapso de tiempo que comienza cuando la persona es alertada de una señal de incendio y termina una vez que evalúan la situación, antes de reaccionar y comenzar a trasladarse hacia un lugar seguro.

Los tiempos previos a la evacuación están asociados con la percepción del riesgo en incendios. El objetivo de esta tesis es evaluar cómo las personas perciben el riesgo de crecimiento del fuego en un escenario de fuego representado en realidad virtual en comparación con otros métodos, como los videos educativos. Los experimentos incluyeron cincuenta y cinco participantes que estaban inmersos en un entorno virtual, donde tenían que predecir la evolución de un incendio y estimar si podían extinguirlo con la ayuda de un extintor portátil. Los resultados obtenidos mostraron que el 97% de los participantes no pudo estimar con precisión el crecimiento del fuego. Sólo el 3% de las personas estimó una diferencia de tiempo que correspondía a la diferencia de tiempo real. Además, hubo una variación significativa en los resultados (bajo/sobreestimación). Un número ligeramente mayor de respuestas subestimó el crecimiento del fuego, esto se observó en 56 de las 104 respuestas incorrectas. Finalmente, fue posible deducir que en etapas posteriores de incendios es probable que la gente no intentará usar un extintor portátil.

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1. Introduction

There are different behaviors that people may experience when they are facing a fire emergency. For instance, once an occupant receives the first cue, they may try to help other occupants evacuate, extinguish the fire or warn the rest of people (Hurley, 2016). Human behavior in fires varies significantly between individuals. These differences in behavior during fire may be due to several factors such as gender, age, cultural background, previous experiences and even media may have an important impact on how people perceive the environment (Fahy, Proulx, & Aiman, 2009).

Experiments have shown that people may not perform an accurate assessment of fire growth at early stages and for most cases, the fire is not truly estimated because people are not aware of the severity of it and evacuation takes some time in order to start (Fridolf, 2010). In evacuation, an important parameter which must be taken in consideration is pre-evacuation time. Pre-evacuation time includes two phases; recognition time and response time, which are the times when people recognized alarm cues and begin to respond before traveling to a safe location (Ronchi & Nilsson, 2016). Evacuation research studies have been performed in order to improve the egress response during an emergency scenario, different research methods have been applied such as: evacuation drills, case studies, experiments, hypothetical studies and others; each one with different strengths, opportunities, threats and weakness (Kinateder, Ronchi, & Nilsson, 2014). There are some studies (Fridolf & Nilsson, 2011) and (Canter, Powell, & Booker, 1987) where fire growth estimation was studied. On the experiment carried out by Canter, Powell and Booker (1987) participants were shown pictures of fire at different stages. It was found people overestimated the time between distinct stages of fire however, on this experiment (Canter et al., 1987) only 40 people participated which might be a small sample of participants. Fridolf and Nilsson (2011) experiment was conducted using a different technology to evaluate people's perception regarding fire growth and to evaluate their ability to estimate whether or not they could extinguish a specific fire with the help of a fire extinguisher. Occupants in a building will not evacuate unless a dangerous or risky situation is perceived (Kinateder, Kuligowsky, & Reneke, 2014). Evaluating how people perceive and evaluate the situation when they are looking directly to the fire will provide a better understanding of human behavior during fires.

1.1. Background

On December 31, 1986, there was a fire in Puerto Rico at Dupont Plaza Hotel, as a result of this event 97 people died and 146 were injured. The majority of the fatalities were located in the casino or at the main lobby (NFPA, 1987). During this incident, it was observed that in the casino, people did not immediately evacuate after seeing the fire or receiving indications to do so, even though flames were already present at the time. The following extract was taken from the NFPA report from a guest at the hotel who was present at the moment of the incident:

"He looked in the direction of the ballroom, through the glass partition within the east wall, and observed "White smoke" on the exterior of the building. The gambler continued to play blackjack and moments later began to observe light black smoke coming from the casino´s air conditioning vents. Shortly thereafter, a woman entered the west door of the casino and began yelling, "Fire, Fire". The gambler stop playing, collected his money, and began to walk toward the west exit door of the casino. From this position, he could see the fire in the lobby area. The gambler then tried to break one of the glass partitions along the casino´s west wall. After some difficulty, he broke the window. Just as he was about to jump, he turned to see a flame front moving toward him from the east, and a friend ignited from the waist up."

From this description, it can be concluded that the witness underestimated the incident from the moment he received the first cue of a fire. The witness was playing blackjack and kept gambling until another person alerted him about the dangerous event. Before evacuating, the witness proceeded to first collect his money and then tried to evacuate. A comparable situation occurred on April 14,2017, at the Bellagio casino and resort fire on Las Vegas. One witness said that he and his friends initially thought the fire was part of the iconic fountain show that the casino usually had until the smoke started to smell like burnt plastic ("Las Vegas Review-Journal," 2017). There are several other fire cases in which people had smelled smoke or watched the fire without realizing the potential consequences of this risk. Sometimes evacuation does not take place immediately after the occupants received the first cue; it has been recorded that several times, occupants went to collect their belongings or kept on with the activity they were performing before evacuating because they assumed the fire would take longer to develop, as noted on the testimony above. Similar findings have been observed with other fires, such as the fire in The Bradford Football Stadium. This fire is one of the worst disasters in the history of football; according to the City of Bradford website (2017), the fire killed 56 people and injured more than 260. Video footage from the event, shows that people kept watching the soccer match during the initial stages of the fire, even though the flames had a significant size, and did not start to evacuate until the fire was spreading very rapidly. A similar behavior was observed during The Fire at the Stardust Club, which suggested that people encountered some difficulty perceiving the severity of the fire specially at early stages of the fire (Fridolf & Nilsson, 2011).

In 2005, an experiment was conducted by Fridolf & Nilsson (2011), in which participants were shown two pictures of a fire at different stages. They were required to estimate the time difference between the pictures and if they thought they could extinguish it with a fire extinguisher. The conclusion was that people tend to overestimate the time between the pictures, therefore underestimate the fire growth (Fridolf & Nilsson, 2011). In 2010, similar experiments were executed but this time, technology allowed the researchers to use looped videos played on monitors, instead of pictures, to test if the participants could determine how severe the fire was and also to test their awareness of the usage of fire extinguishers. During these tests, people were told to assume they arrived on the exact moment the sequence was played. It was observed people were not aware of the seriousness of the fire (Fridolf, 2010).

New methods with more advanced technology and a higher level of realism have been developed to perform laboratory experiments e.g. Virtual Reality (VR). Virtual Reality is a relatively new approach used to investigate human behavior in fires using Virtual Environments (VE) to recreate situations where people have to act according to the scenario they are placed in, without being exposed to be injured this behavior is called, “Presence”. Presence is behaving and feeling as if the person is inside the virtual environment created by the displays of the simulators. In the last decade, virtual reality (VR) has gained a lot of interest in research and some studies have been carried on simulating emergency situations (Kinateder, 2012). Virtual Reality can be a valuable tool as it can be used to represent environments that will be difficult or expensive to study in reality. The virtual environment has to be designed in a way that people who are being tested can experience a realistic setting; providing data which can be taken as if they were the results from real world study scenarios (Kobes, Helsloot, de Vries, & Jos, 2010).

This project will try to recreate in VR the experiment done by Fridolf and Nilsson (2011) where participants were shown videos and were required to estimate the time difference between them, participants were indirectly estimating fire growth. The current thesis project was conducted using virtual reality with a head mounted display (Oculus Rift) to place participants in a virtual situation where their fire growth estimation was assessed. The results allow to better understand the capabilities of VR as a research tool for fire safety engineering. The data obtained was compared to previous results obtained with different methodologies (Fridolf & Nilsson, 2011) and (Canter et al., 1980). The second part of this project studied if people are able to estimate their ability to extinguish distinct fires with the help of a portable fire extinguisher.

1.2. Aim and Objective

The purpose of this thesis is to evaluate how people perceive risk in a fire scenario represented in virtual reality when compared to other training methods (e.g. educational videos). Test participants were immersed in a virtual environment where they had to predict the evolution of the fire and estimate their ability to extinguish a fire with the help of a fire extinguisher. Taking this into account, the aim was accomplished with the following objectives:

- To review literature available of the previous experiments in order to reproduce the previous study accurately.
- To test people using Virtual Reality to assess their estimation of fire growth at initial stages and their ability to extinguish a fire with the help of a fire extinguisher in a virtual environment.
- To develop the understanding of human behavior in fire, comparing the results obtained between different methods (VR vs educational videos).

1.3. Methodology

The present research study can be divided into three main phases. The first phase was a literature review to have a better understanding of the previous experiment. The second phase was the execution of the experiments and the third phase was the analysis of the results.

1.3.1. Literature Review

The first phase of the project was to collect information regarding evacuation and human behavior in fires. In this phase, a review of how people perceived risk and how risk perception changes in relation to gender was reviewed. The second part of the literature review briefly describes the Alpha t-squared model which is used by fire engineers to represent the growing rate of a fire as developed by Karlsson and Quintiere (2000). The third part of the literature review covers virtual reality. The different strengths, opportunities, threats, weakness and limitations of using it as a research tool are explained. The last part describes the previous experiment which was done by Fridolf and Nilsson (2011). This chapter will provide readers a better understanding of the project and background information prior to the experiments section.

1.3.2. Experiments

To achieve the purpose of the project, the laboratory environment used by Fridolf and Nilsson (2011), was recreated in Virtual Reality. The experiment setup was modelled in a 3D modelling software attempting to achieve an elevated level of realism to allow participants to be immersed in the experiments. The game engine software Unity 3D ("Unity," 2017) was used to program the game and the logic of the virtual environment.

For the experiments, a group of 56 people were tested. The questionnaire included two sections. The first section is related to the participant's background. Section two is related to the assessment of risk awareness and the fidelity of the scenario. This will make it possible to evaluate their risk perception using a Virtual Reality head mounted display (in comparison to other methods).

1.3.3. Data Analysis

The final phase of the thesis is the analysis of the date collected during the experiments. The information required for this experiment was obtained by questionnaires which were filled in during each test to see how participants estimated the fire and to assess their ability to extinguish a fire. All the participants that took part in the experiments signed an informed consent form which gives the permission to take photographs, record the experiments and use the data collected on this study. A background questionnaire was filled out by the participants to analyze if the answers given are related with previous experiences of the participants.

Figures and tables are used to show the descriptive statistics found on the experiments. Box Plots were used to observe the statistical distribution of the responses obtained on this study. The results are shown in a similar manner to the results obtained by Fridolf and Nilsson (2011) in order to allow for easier comparison. There were six distinct types of questionnaires, each one had two questions about estimation of fire growth and three questions about fire extinguishing. The analysis was done by comparing the time difference participants estimated with the real time difference. The values under or over the real time difference show if people over or underestimate the fire growth on the first part of the experiment.

1.4. Limitations

There are some variables which limit the present study. Some of the limitations of this project were due to the use of Virtual Reality; one of them was associated with ecological validity. Ecological validity could not be fully achieved due to some unrealism on the VR model; even though it led to a great sense of immersion, human behavior in fires is the result of different factors which put the subject under stress conditions before the person reacts to the situation; in this case, participants were aware it was a simulation. Additionally, due to the limited time, some features could not be added to the scenario such as sound or radiator panels to recreate the impact of heat plus the smell of something burning. The objectives of this project as well as the number of participants in the experiment were delimited due to the time constraint. More studies of comparison should be performed in order to assess to which extent the behaviors observed using virtual environments are comparable to real situations (Kinateder, Ronchi, et al., 2014a).

2. Literature Review

A review of literature concerning evacuation and human behavior in fires with virtual reality as a research tool is presented.

2.1. Human Behavior and Risk Perception

There are distinct aspects which must be taken into consideration when designing a building regarding fire safety. The building needs to have tenable conditions long enough to assure occupants safety. There are two concepts in fire engineering which help us meet some life safety standards when designing a building, they are: Available Safe Egress Time (ASET) and Required Safe Egress Time (RSET). The ASET is the available time that the occupants have to evacuate safely before the conditions are not tenable anymore. The RSET is the minimum time that is required for occupants to reach a safe place. To consider a building safe, the ASET has to be bigger than the RSET. To determine these times, it is important to focus on evacuation which is an action that consists of several behaviors. The time-line model which has been included in the Society of Fire Protection Engineering Handbook (Proulx,2002) and norms such as ISO TR16738 (International Standard Organization, 2009) or the British Standard BS PD 7974-6 (British Standard, 2004) calculates evacuation time by adding the distinct phases which are involved during evacuation (Ronchi & Nilsson, 2016). It is also important to take into account that some phases may not be included in evacuation models, e.g. detection and warning time. Most of the evacuation models are based on a time-line model which is illustrated on Figure 1.

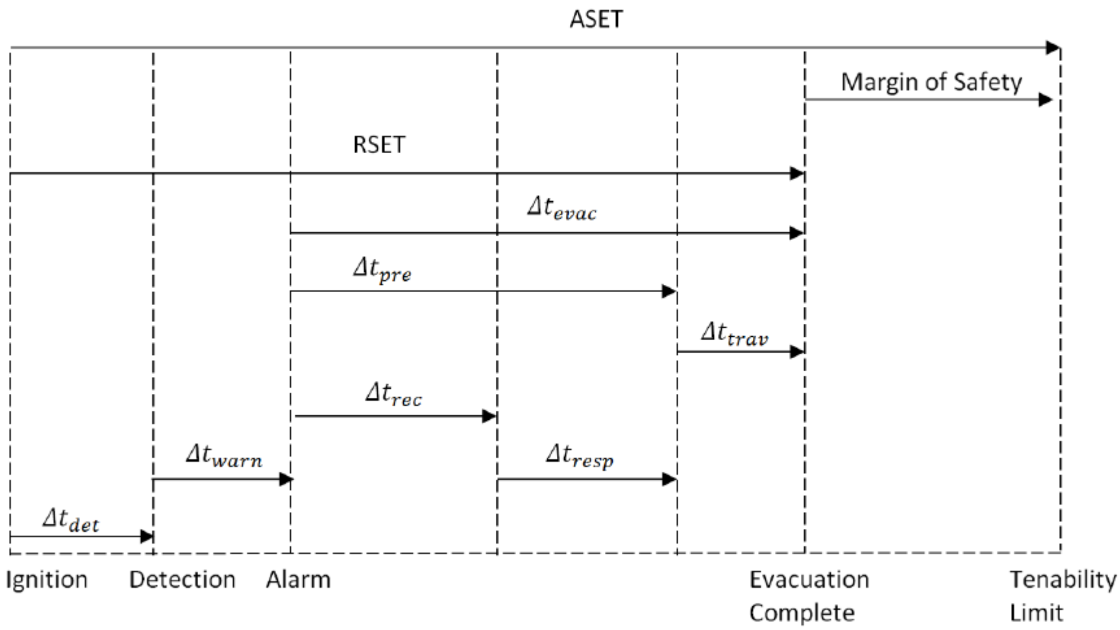

Figure 1 Time-Line Model

The RSET can be calculated with the following equation (Ronchi & Nilsson, 2016)

$$\boldsymbol{RSET} = \Delta t_{det} + \Delta t_{warn} + \Delta t_{pre} + \Delta t_{trav}$$

Where:

Δt_{det} is the detection time.

Δt_{warn} is the warning time which elapses from detection to the trigger of the alarm.

Δt_{pre} is the pre-evacuation time which is the time from the alarm until people start responding to the incident.

Δt_{trav} is the travel time which is the time needed for occupants to reach a safe place.

As it can be observed in Figure 1 to determine evacuation, four different times have to be considered: detection time, warning time, traveling time and pre-evacuation time. In a fire emergency, each of the occupants who is involved in evacuation may opt for different behaviors. It is important to focus the analysis on the pre-evacuation time, which is the time that elapses before people start traveling. There are several variables which influence this time. Researchers have developed a general model of human behavior in fires which was created by analyzing different patterns of human responses in fire (Canter et al., 1980).

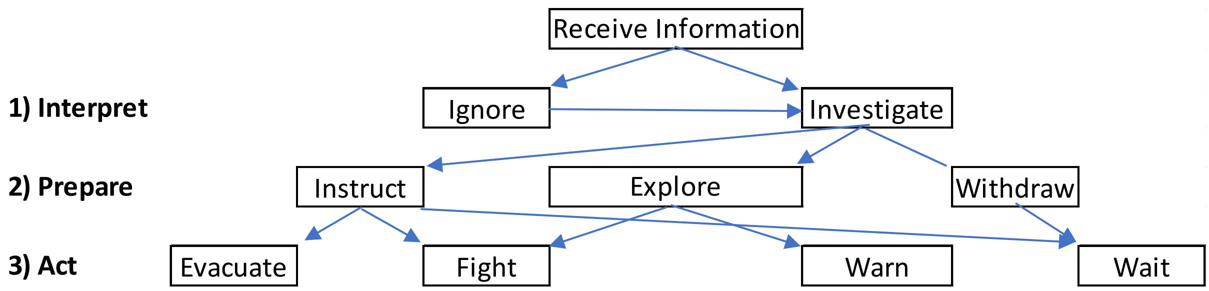

Figure 2 General Model Human Behavior. Figure Taken from (Canter et al., 1980)

Figure 2 represents a general model of human behavior in fire which categorizes the behavior into three potential sequences, once the person received the first piece of information. This sequence includes: interpret, prepare and act.

Once people receive the first signal of a fire, this signal must go through an interpretation process which can be reduced, if a clear alerting message is sent to the occupants, e.g. fire alarm. If there is not any other message, the uncertainty is high and the evacuation process depends on the subject itself with the information available during this stage. The behavioral process will start when the subject receives the first cue related to the fire, after the cue is perceived the subject will either prepare to act or have a response to the situation once it is aware of the risk that the situation represents (Kuligowsky, 2011).

An important stage on this behavioral sequence is interpretation, which consists of three phases: cue, situation and risk. They do not have an specific order but they are defined: before they react to the situation, they have to interpret the situation cue and the risk they are exposed to (Kuligowsky, 2008). The risk phase is very important since the evacuation will start as soon as the occupant defines the situation as risky (Fridolf & Nilsson, 2011).

2.2. Estimation of Fire Growth

During the first stage, a fire usually grows exponentially. In contrast, people might have different expectations (i.e. a linear growth). Fire has an accelerating growth which may not be foreseen by everyone. Fire engineers in order to determine this growing phase with a good approximation use a mathematical model to calculate the growing rate of a fire. The method previously mentioned is called, the Alpha t-squared model which was developed by Karlsson and Quintiere (2000). Fire engineers used this model when designing a building for detection systems and to determine the fire growth, when designing a fire. It is expressed by the following expression:

$$\dot{Q} = \alpha * t^2$$

Where

α is the growth factor (kW/s^2)

t is the time since ignition (s)

Q is the energy release rate (kW)

This model appears to fit well with the growing rates of different commodities (Quintiere & Karlsson, 2000).

During a fire emergency occupants must estimate the risk they are exposed to; in this case how the fire will develop with time. An accurate estimation should be done to take a proper decision according to the situation they are facing. It was observed that people in real fires do not have a good estimation of fire growth and there are some factors which may influence people's perception for instance: if the fire can be seen, smelled or even heard, among others.

When an occupant is facing a fire or a risky situation, he/she must estimate and quantify the danger of the scenario that he/she is involved in. There are some factors that affect the behavioral process and change how people define or interpret the situation. These factors are present before the event happens such as: previous experience in fires, the current situation of the subject during the event (for instance: the proximity to the fire) and finally the cues perceived during the incident. The following table lists how these factors increase or decrease the risk perception of the subjects.

Table 1. An overview of influential factors for the behavioral process. Table taken from (Kuligowsky, 2009)

Factors	Phase 1	Phase 2: Interpretation	
	Perception	**2a: Definition of the situation as a fire**	**2b: Definition of the Risk to Self/Others**
Occupant-based pre-event factors			
Experience with fires (yes)	Increases	Increases	Increases
Has knowledge of fire/training (yes)	Increases	Increases	Increases
Habituation of environment (yes)	Decreases	---	---
Knowledge of routes (yes)	---	---	Decreases
Frequent False Alarms (yes)	---	Decreases	---
Feeling of security on the building (yes)	---	Decreases	---
Has a perceptual disability (yes)	Decreases	---	---
Age (older adults)	Decreases	---	Increases
Gender (woman)	Increases	---	Increases
Speaks the same language as others (yes)	Increases	---	---
Frequent interaction with family	Increases	---	---
Occupant-based event factors			
A higher stress/anxiety level	Decreases	---	Increases
Perceives a time pressure (yes)	Decreases	Decreases	Increases
Presence of others (yes)	Decreases	---	Increases
Proximity to fire/visual access (yes)	Increases	---	---
Sleeping (yes)	Decreases	---	---
A high number of behavioral process (>1)	---	Increases	---
Defines situation as fire (yes)	---	N/A	Increases
Cue-based Factors			
A higher number of cues	Mixed	Increases	Increases
Consistent cues (yes)	---	Increases	Increases
Unambiguos cues (yes)	---	Increases	---
Social Cues (others actions) that are consistent with a fire situation (yes)	---	Increases	Increases
Official source (yes)	Increases	Increases	---
Familiar source (yes)	---	Increases	---
A higher dose of toxic gases	---	Decreases	---
Extreme/dense cues (yes)	Decreases	---	Increases
Visual/audible cues (yes)	Increases	---	---
Risk information (yes)	---	Increases	---

2.3. Virtual Reality

Virtual reality (VR) is a technology which has been expanding since 1965 when it was first introduced by Ivan Sutherland, who stated that people want more than just to see an image through the monitor. Sutherland had the idea of creating a virtual world which looked real, sounded real and felt real (Mazuryk & Gervautz, 1996).

Over the last five decades, VR has advanced significantly and now there are three types of VR systems: Non-Immersive, Semi-Immersive and Fully Immersive head mounted display. Table 2 shows a qualitative comparison of the performance of the different systems.

Table 2. Qualitative Comparison VR performance. Table taken from (Costello, 1997)

	Qualitative Performance		
Main Features	**Non-Immersive VR (Desktop)**	**Semi-Immersive VR (Projection)**	**Full Immersive VR (Head-coupled)**
Resolution	High	High	Low-Medium
Scale (perception)	Low	Medium- High	High
Sense of situational awareness (navigation skills)	Low	Medium	High
Field of regard	Low	Medium	High
Lag	Low	Low	Medium- High
Sense of immersion	None - Low	Medium-High	Medium- High

Fully Immersive VR systems nowadays have high resolution typical 2160x1200 like the Oculus Rift (“Oculus,” 2017) or the HTC Vive (“Vive,” 2017) which allow the user to achieve a higher level of immersion. Head mounted display transfer images to the individual brain through usually LCD screens which are placed from 50-70 mm away from the eye. This technology tracks the position of the head in real time through sensors, allowing the user to see the Virtual Environment (VE) as it moves the head. There are different commercial brands of HMDs available on the market such as, HTC Vive (“Vive,” 2017), Google Daydream (“Daydream,” 2017.), Oculus (“Oculus,” 2017.), etc.

Oculus was the device used for this project. The development of Oculus Rift (“Oculus,” 2017) started in 2012 but it was not release until 2013 in a video conference E3 (Rubin, 2014). E3 is an annual electronic entertainment expo where several game developers and manufacturers of gaming systems and accessories present release new merchandise. The components of the first Oculus are shown on Figure 3.

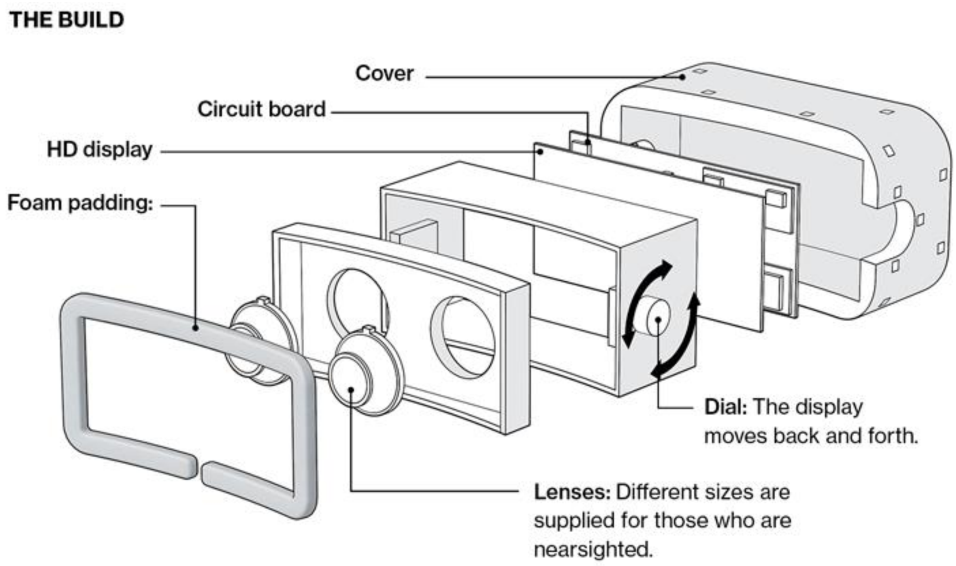

Figure 3 Components Oculus. Image taken from (Parkin, 2014)

The biggest challenge in Virtual Reality is to avoid any perceptible lag. The oculus rift uses a magnetometer, a gyroscope and an accelerometer to sense the user´s head in the real world. The advantage of this system is that it allows to predict the motion and render the images in advance, reducing the latency providing a more comfortable and immersive experience to the user (Oculus, 2016).

2.3.1. SWOT analysis of Virtual Reality

SWOT is a technique which is used to understand the strengths and weakness and to identify the threats and opportunities associated with a system, in this case with Virtual Reality. Kinateder et al. (2014) carried out a SWOT analysis of VR as a research tool in human behavior in fires and the summary of the results are shown in Table 3

One of the strengths of VR is that it is possible to recreate any environment and control the experiment as desired. It is easy to replicate an environment and it can allow participants to truly immerse on the Virtual Environment (VE) without any risk.

On the other hand, one of the weaknesses encountered in VR is that even though an outstanding level of immersion can be achieved, there is still the need to increase the realism and interaction between the subject and the virtual environment. Another weak aspect is the side effects certain number of people experience when navigating on the VE, some of them include: motion sickness or nausea.

Further, the opportunities with VR as a technology that is changing rapidly, is that some of the current issues, such as technical aspects or immersion, will be reduced within the upcoming years. A natural interaction could be achieved with a high level of realism which will improve the ecological validity of the research.

The threats found on VR, are related to ecological validity and ethical aspects. In case of a high level of immersion, some people may experience side effects such as seizures or nausea which cannot be accepted (Kinateder, Ronchi, et al., 2014b).

Table 3. Summary of a SWOT for VR. Table taken from (Kinateder, Ronchi, et al., 2014b)

Summary of a SWOT Analysis for VR in Fire Evacuation Research

Strengths	Weaknesses	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 challenges
•Ecological validity	•Inter-individual differences in ease of interaction with VR	•Multi-modal simulation 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	•Efforts		
•Precise measurements			
•Psychophysiological monitoring			
•Low costs			
•Repeated measurements			
•Flexibility			
•Control of confounding variables			
•Independent of imagination abilities/willingness of participants			
•Participant recruitment			

2.4. Original Experiment (Fridolf and Nilsson, 2011)

The experiment performed by Fridolf and Nilsson (2011) consisted of three parts. The First part was an example question were a video of a moving bus was shown and participants had to estimate the time that elapses between the last frame on the first video and the second video. A screenshot of the first part can be seen on Figure 4

Figure 4 Screenshot of the first part of Fridolf and Nilsson's experiment. Picture taken from (Fridolf & Nilsson, 2011)

On the second part of the experiment the participants had to estimate the time difference between two fires. At the beginning of the second part a growing fire which consisted of a pile of popcorn boxes was shown to the participants. Then a looped video of the same fire after some time was reproduced and the participants had to estimate the time difference between the two videos, thus indirectly estimating the fire growth. Figure 5 shows how the fire of the popcorn was display to the participants on the monitor.

Figure 5 Scenario for the estimation of Fire Growth in Fridolf and Nilsson' experiments. Pictures taken from (Fridolf & Nilsson, 2011)

The last part of the experiment participants were shown a looped video of a fire with a picture of a fire extinguisher and the question was, "Would you be able to extinguish the fire on the left-hand side using the fire extinguisher?" Figure 6 shows the fire extinguisher which was used on the questionnaire and one fire case that was presented to the participants.

Figure 6 Part 3 of the Experiment in Fridolf and Nilsson experiment. Pictures taken from (Fridolf & Nilsson, 2011)

2.4.1. Questionnaire

Fridolf and Nilsson (2011) developed a questionnaire with six different variants. Table 4 shows the six variants of the questionnaire that were used during the first part of the experiment. In this part, each participant had to estimate the fire growth of two different fires. For example: in variant 1 of the questionnaire, participants were shown a video sequence that consisted of a growing fire from 0 to 30 seconds. Then, a second video of the same fire at a different stage (47s) was shown. Participants were required to estimate the time it takes for the first fire to reach a stage as a second fire. Afterwards, another scenario was presented with a growing fire from 0 to 30 seconds and the same fire at 80s.

Table 4. Six Variants of the questionnaire concerning the estimation of fire growth (time expressed in seconds)

Variant	Video Sequence	First Looped Video (s)	Second Looped Video (s)
1	0-30	47	80
2	0-30	60	100
3	0-60	80	100
4	0-30	80	47
5	0-30	100	60
6	0-60	100	80

On the second part of the experiment participants had to answer if they could extinguish a fire with a portable fire extinguisher. Three different fires were asked to each participant. The six different variants for this part of the experiment are illustrated on Table 5

Table 5. Six Variants of the questionnaire concerning fire extinguishment (time expressed in seconds)

Variant	Fire time 1 (s)	Fire time 2 (s)	Fire time 3 (s)
1	30	47	80
2	30	60	100
3	60	80	100
4	30	80	47
5	30	100	60
6	60	100	80

2.4.2. Results from the original Experiment (2011)

A total of 141 participants took part in this experiment, 99 men and 42 women. The experiments consisted of two parts: estimation of time difference and estimation of ability to extinguish fire with a fire extinguisher. The quantity of variants answered can be observed on Table 6.

Table 6. Distribution of participants Fridolf and Nilsson (2011).

Variant	No. of Participants
1	23
2	27
3	24
4	22
5	22
6	23
Total	141

Part 1- Estimation of Time Difference

Fridolf and Nilsson (2011) showed two different fires for estimating fire growth during their experiments. One of them was with a popcorn fire and the other one a kitchen fire. The results of both experiments can be observed on Table 7.

Table 7. Answer of Participant Experiments Fridolf & Nilsson (2011)

Answers	No. Popcorn Fire	%	No. Kitchen Fire	%
Correct	7	3 %	6	7 %
Underestimate Fire	61	22 %	59	62 %
Overestimate Fire	214	75 %	29	31 %
Σ	282	100 %	94	100 %

The results of the popcorn fire can be appreciated in Table 7. A total of 282 estimations were done, 7 estimations were answered correctly which means that the estimated time corresponded to the real time. From the incorrect answers, 75% responses overestimate the fire which implies the time was underestimated. The rest of participants 22% underestimate the fire meaning they overestimated the time.

The estimated time of the participants on the different fires are shown on Figure 7. It can be seen on the plot for the popcorn fire, the median is below the real time line which means the time was underestimated. Fridolf and Nilsson (2011) found that the variation at time 100s between the percentile 5th and 95th was of 112 seconds for the popcorn fire.

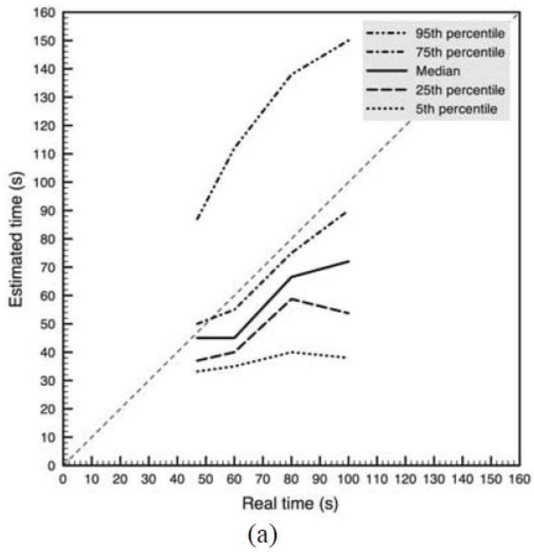

Figure 7 Estimated time at different real times for (a) the popcorn fire. Taken from (Fridolf & Nilsson, 2011)

Part 2- Estimation of ability to extinguish fire with a fire extinguisher

For the second part of the experiment, participants were asked if they could extinguish a fire with the help of a fire extinguisher which has foam as an extinguish agent on the inside with a capacity of 9 liters. This fire extinguisher was certified according to the European norm EN-3 which specifies the requirements for portable fire extinguishers that will be used with the European Union. The portable extinguisher was Type A which is meant for paper, wood, cardboard and most plastics ("Safety Marine," 2017). This extinguisher to comply with the norm should be tested on a fully developed wood crib fire 0.5 m width, 2.1m length and 0.56m height. The heat release rate produce by the wood crib fire is greater than the fire produced by the popcorn fire at any stage therefore it is sufficient to extinguish this fire (Fridolf & Nilsson, 2011). For this part of the experiment, 3 questions were asked and the results found by Fridolf and Nilsson (2011), are presented on Table 8.

Table 8. The total number of answers for each stage of the fire taken from (Fridolf & Nilsson, 2011)

Fire Time (s)	HRR (kW)	Yes	No	Do not know	Σ
30	20	86 (91%)	1 (1%)	7 (7%)	94 (100%)
47	55	43 (80%)	2 (4%)	9 (17%)	54 (100%)
60	80	55 (74%)	7 (9%)	12 (16%)	74 (100%)
80	175	63 (55%)	27 (24%)	24 (21%)	114 (100%)
100	220	30 (34%)	31 (36%)	26 (30%)	87 (100%)

Table 8 presents the results obtained in the second part of the experiments. When the fire is small 91% of the responses show, participants think the fire can be extinguished. As the fire increases the tendency to extinguish the fire decreases. In the last scenario at time 100 seconds only 34% of participants believed the fire could be extinguished it. While on the first scenario at time 30 seconds 91% of responses stated that with the help of a portable fire extinguisher the fire could be extinguished.

3. Experiments

The experiments were conducted from the 22th to the 29th of March 2017 at Lund University in the Department of Combustion, building Fysiska Institutionen. The experiment recreated Fridolf and Nilsson (2011) experiment, but this time in a virtual environment which was display on a head mounted display (Oculus).

3.1. Participants

The participants who took part in this experiment were between 20 years old and 37 years old. All the participants were students at Lund University, with different degree levels which included: master program students, bachelor program students and PhD students.

The participants in this project also participated in another research project: “Flashing lights at road tunnel emergency exit portals: A VR study with head mounted displays” done by David Mayorga. For this thesis 55 participants were part of the experiments and they were students at Lund University; 73% of the participants did not have any experience or knowledge regarding fire engineering.

The recruitment process consisted of a contact information form which gathered the potential participants contact information in order to generate a more consistent final list of participants. The complete contact information form can be seen in Annex A. Once the participants fill out the contact information form, an email was sent with information participants needed to know before the experiment such as location, selected schedule and an informed consent with a short summary of the activities, safety procedure stating the experiment will not be dangerous and the participants will be able to terminate the experiment at any time if they fell nausea or dizziness. The information of the email is shown below:

> “The present email contains information regarding the experimental sessions for two Master Thesis developed at Lund University by IMFSE students. Francisco Rosero and David Mayorga will perform a series of experiments with Virtual Reality during Fire. Together, both experiments will last between 45 minutes and 1 hour and will take place from March 22-29 in Fysiska Institutionen at Lund University near LTH.
> Google Maps location:
> https://www.google.com/maps?q=55.710531,13.205177&hl=en&gl=us&shorturl=1
> Please click the following Link to choose a Time Slot with your availability.
> http://doodle.com/poll/3962yeq3z4y4brvf
> N.B.: Attached to this email there is a document with more detailed information which you will be required to sign the day of the experiment.
> Thanking you in advance for your time and collaboration.”

The informed consent can be found on the Appendixes section at the end of this document in Annex B

3.2. Experiment using Virtual Reality

The experiment consisted of three parts. During Part 1, participants watched two videos of a moving bus on a screen which was inside the virtual room. The participants had to estimate how much time elapsed between the last frame they saw on the first video and the looped video shown after that one. This example question was asked to ensure that everyone understood the method of the study. On the training scenario participants needed to avoid wood boxes and reach the final destination which was a room after entering a green door. A screenshot of the training scenario can be observed on Figure 8.

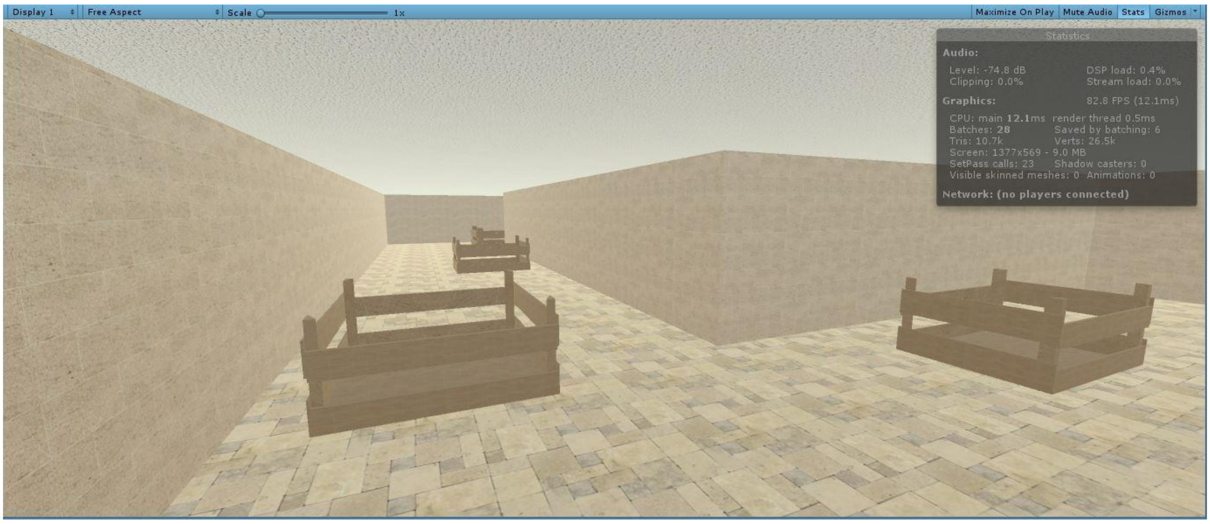

Figure 8 Training Scenario Screenshot.

The difference with the experiment done by Fridolf and Nilsson (2011), is that participants were immersed in a Virtual Environment where they could see the Popcorn Fire through a head mounted display (Oculus). On the current project the scene shown on Figure 9 was recreated, similar objects were place in a virtual room that was created using a 3D modeling software.

Figure 9 Configuration of Objects in the Popcorn Fire in Fridolf and Nilsson experiment. Pictures taken from (Fridolf & Nilsson, 2011)

To recreate the experiment on virtual reality different tools such as SketchUp ("SketchUp," 2017), Unity ("Unity," 2017) and Blender ("Blender.org," 2017) were used and will be explained in detail below.

3.2.1. Google Sketchup PRO

The first stage was to build the geometry of the room where the participants were placed in VR. For this Sketchup PRO ("SketchUp," 2017) was used. The size and geometry of the room can be seen in Figure 10.

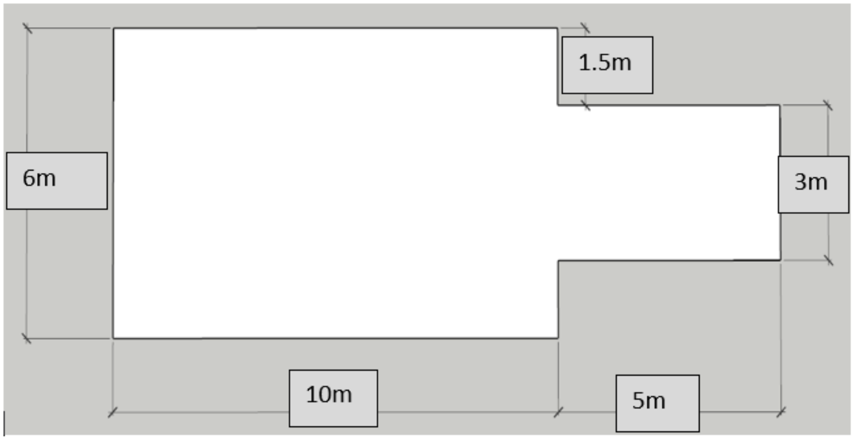

Figure 10 Size and Geometry of the Room

Several objects were built like the shelf, the extraction hood and the lamps while other elements such us the fire extinguisher, the popcorn and the barrel were imported from 3D WareHouse, a library from Sketchup that contains several objects. The process with Sketchup finished when textures were added to the different objects as depicted on Figure 11.

Figure 11 Room Setup in Sketchup.

3.2.2. Unity 3D

Unity is a game engine which is used to develop virtual scenarios mainly for video games that can be exported to different platforms such as Xbox, PlayStation and computers (Mac & Windows). The geometry was imported from a SKB file (Sketchup file) and it was developed from the scene that is shown on Figure 9. The experiment consisted of 13 scenes which were used to recreate the 6 questionnaires that were used on the experiment done by Fridolf and Nilsson, (2011). Figure 12 shows the room after adding lighting, 3D textures, and a complete built environment.

Figure 12 Room of the Virtual Reality experiments in Unity 3D.

One important aspect was recreating the fire in Unity based on the fire in the original videos. This was done with the particles system tool in Unity which is a component that models fluids such as flames, clouds or liquids ("Unity - Manual: Particle System," 2017). The fire on the experiment started once the participants entered a collider and then several particle systems of fire started to activate in time until a similar representation with virtual reality was achieved. Figure 13 displays the fire after 80 seconds. The image on the left is the virtual fire and a snapshot of the footage from the Fridolf and Nilsson (2011) experiment is shown on the right side.

Figure 13 Comparison between the fire as represented in VR and a screenshot from the original video of the fire in Fridolf and Nilsson's experiments.

3.2.3. Questionnaire

There were six variants of the questionnaire where participants should estimate the fire growth with two different stages of the fire and also estimate if they could extinguish the fire shown with the help of a fire extinguisher, three cases were shown to them. The six questionnaires were evenly distributed among the participants to reduce the effect of questionnaire design. The times of the different scenarios for the experiment were taken from Fridolf and Nilsson experiment (2011).

3.3. Procedure

The procedure that was followed for the experiments was conducted as it is explained on Figure 14.

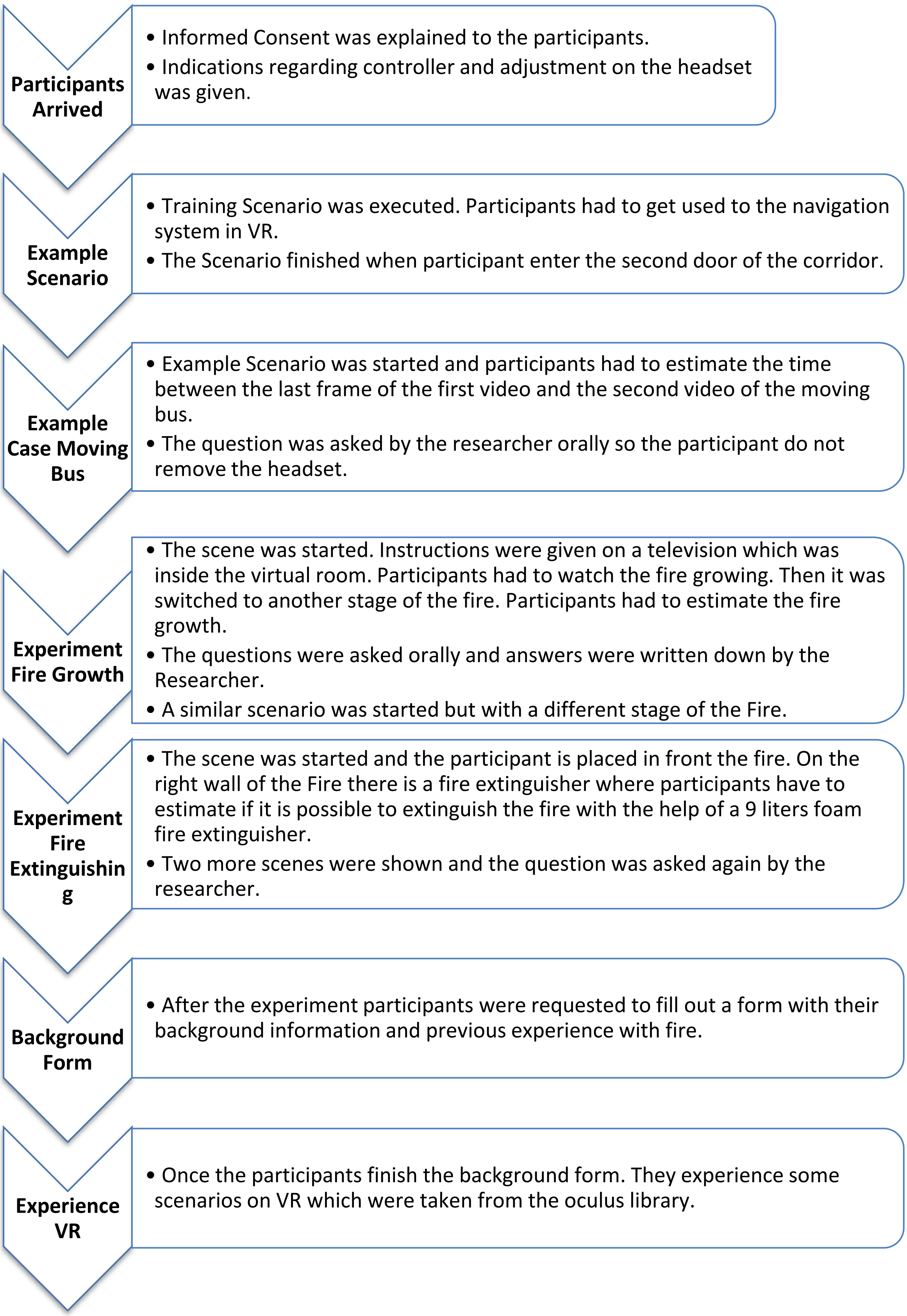

Figure 14. Experimental procedure

3.4. Ethical Aspects

A set of precautions were taken to avoid psychological and physical injury during the experiments. Some physical side effects that may occur in virtual reality experiments are dizziness or nausea during the navigation on the virtual reality environment. If any of these symptoms appeared, the participants had the right to tell the researcher to stop the experiment immediately. They would receive help to counteract the symptoms, and a first aid kit and water were available during the experiments. Participants were also asked if they agreed to being photographed and were informed of the purpose of the experiment through an informed consent form which can be found on Appendix B.

4. Results

4.1. Results Experiment using VR

A total of 55 participants took part of the experiments, 29 women and 26 men. Six different questionnaires (variants) were distributed among the participants, the order of the variants was randomized among the participants. The quantity of variants answered can be observed on Table 9.

Table 9 Distribution of Participants

Variant	No. of Participants
1	10
2	9
3	9
4	9
5	9
6	9
Total	55

Part 1- Estimation of Time Difference

Each variant of the questionnaires contained 6 questions. The first question was an example question to see if the participants understood the method, the results are not shown because they are not relevant for this study. The second and third questions were regarding fire estimation. Participants experienced two scenarios where a popcorn fire was shown at distinct stages. The time difference between the growing phase and the fire at a later stage is shown on the table as Δt i.e. if the participant saw the first 30 seconds of the growing fire and then a fire at 47 seconds was shown, the Δt of that case is 17 seconds where the exact correct estimation will also be 17 seconds. A total of 110 estimations of fire growth were done, 6 exact correct estimations were obtained which means the estimated time equals the real time in the fires as Table 10 illustrates.

Table 10 No. of Correct Estimations

Growing Phase (s)	Later Stage (s)	Δt	Number of estimations	Number of exact correct estimations	%
0-30	47	17	19	0	0
0-60	80	20	18	4	22
0-30	60	30	18	1	6
0-60	100	40	18	1	6
0-30	80	50	19	0	0
0-30	100	70	18	0	0
		Σ	110	6	

The number of incorrect estimations were 104, the number of participants which under or overestimate the fire can be seen on Table 11.

Table 11 Answers of participants

Answers	Number	%
Correct	6	6 %
Underestimate Fire	56	51 %
Overestimate Fire	48	43 %
Σ	100	100 %

The incorrect estimations were 104, where 51% of them underestimate the fire which means the time given by the participants was overestimated and the rest of the estimations underestimated the time. Figure 15 illustrates by how much the responses underestimate and overestimate the time with respect to the real time difference i.e. If the real time difference was 17 seconds and the participant estimated 15 seconds the percentage that this answer underestimates the time from the real time difference is 11.76%. It can be observed that a vast number of estimations which underestimate the fire, underestimate by a significant amount.

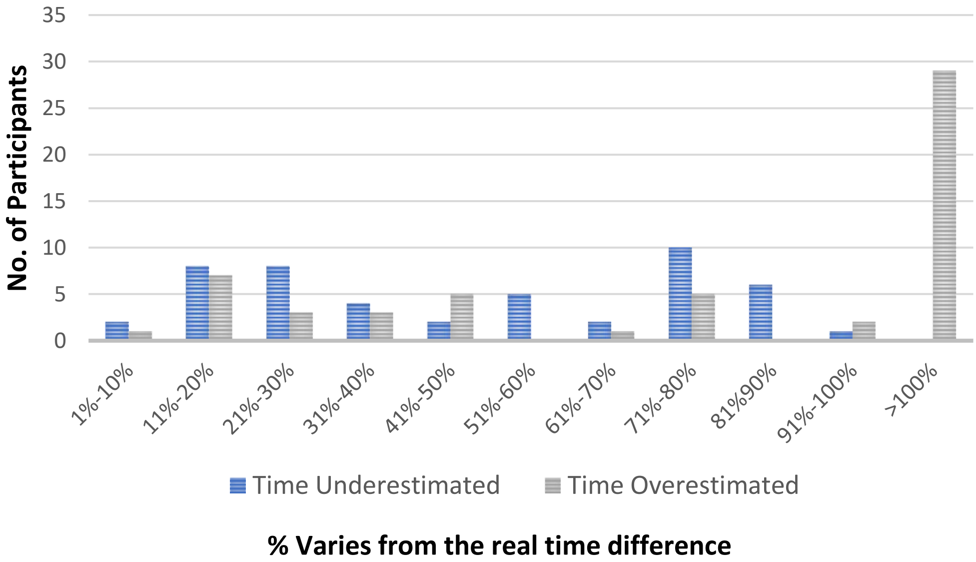

Figure 15 No. of Estimations with respect real time difference

There were 6 different possible scenarios during the experiments, each one of them with distinct stages of the fire where participants should estimate the time between stages. For example, in one scenario participants observed the fire from time 0s to time 30s, then a fire at 80 seconds was shown and the time difference was 50s. In another variant of the questionnaire, the participants saw the fire growing from time 0s to time 60s then a fire at

80s was shown, which means the time difference was 20s. Figure 16 displays the four different fires of the experiments. At time 80 the two possible scenarios are shown in the same box plot. The estimation time of the participants was added to the time of the growing phase i.e. 30 or 60 seconds to have both estimations under the same box plot. The black line inside the box represents the median where the lower and upper whistlers represent the maximum and minimum times consider for the analysis. The values shown with the stars or the circles were not considered on the data selection as these are outliers from the statistical distribution.

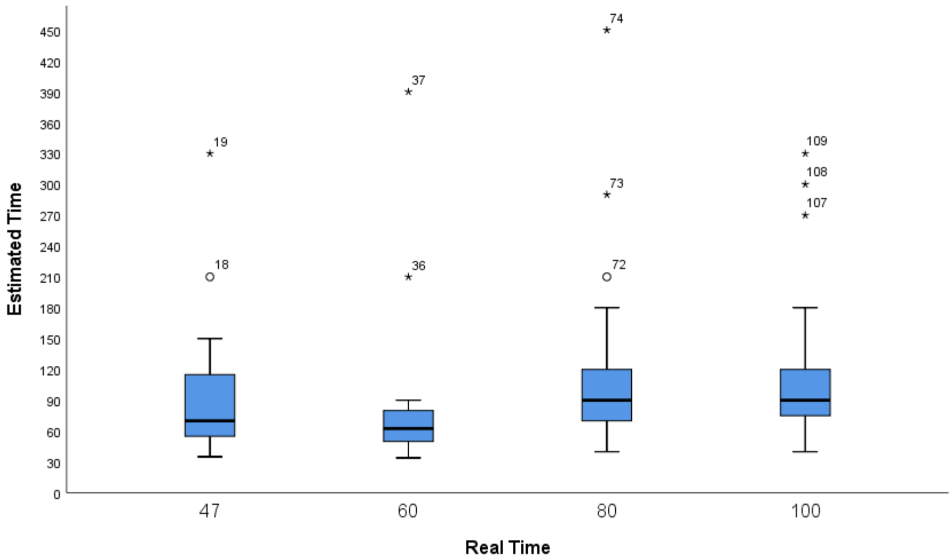

Figure 16 Box Plot Estimations

Figure 17 show the different responses of the participants in relation with the real time difference. As it can be seen on Fire 47 most of the responses overestimate the time difference. In a larger fire (Fire 100), there are more responses underneath the real time line which means people underestimate the time at this stage.

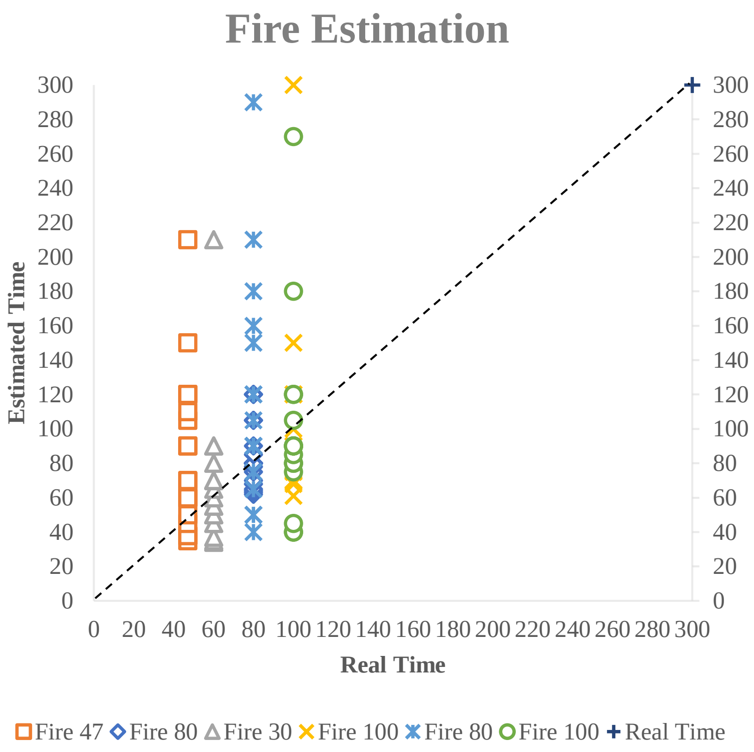

Figure 17 Responses of participants compared with the real time estimation

Figure 18 shows the results for the first part of the experiments, the figure illustrates the different response of the participants in different fires. The dash line on the figure represents the exact estimation of time, when the estimation time corresponds to the real time. On this figure, the different 5th, 25th, 50th (median), 75th and 95th percentile can be observed. The large variations on the results of this part of the experiments demonstrate the different perception people have with fire in Virtual Reality. The lines that are located above the Real Time line show the overestimation of time, when the estimated time was higher than the real time. The lines of the percentile 5th and 25th which are located underneath the Real time line show the underestimation of time, when the estimated time was lower than the real time, participants overestimated the fire growth. On this experiment, the variation between the 5th and the 95th percentile at time 100 is 110 seconds as it can be seen on Figure 18.

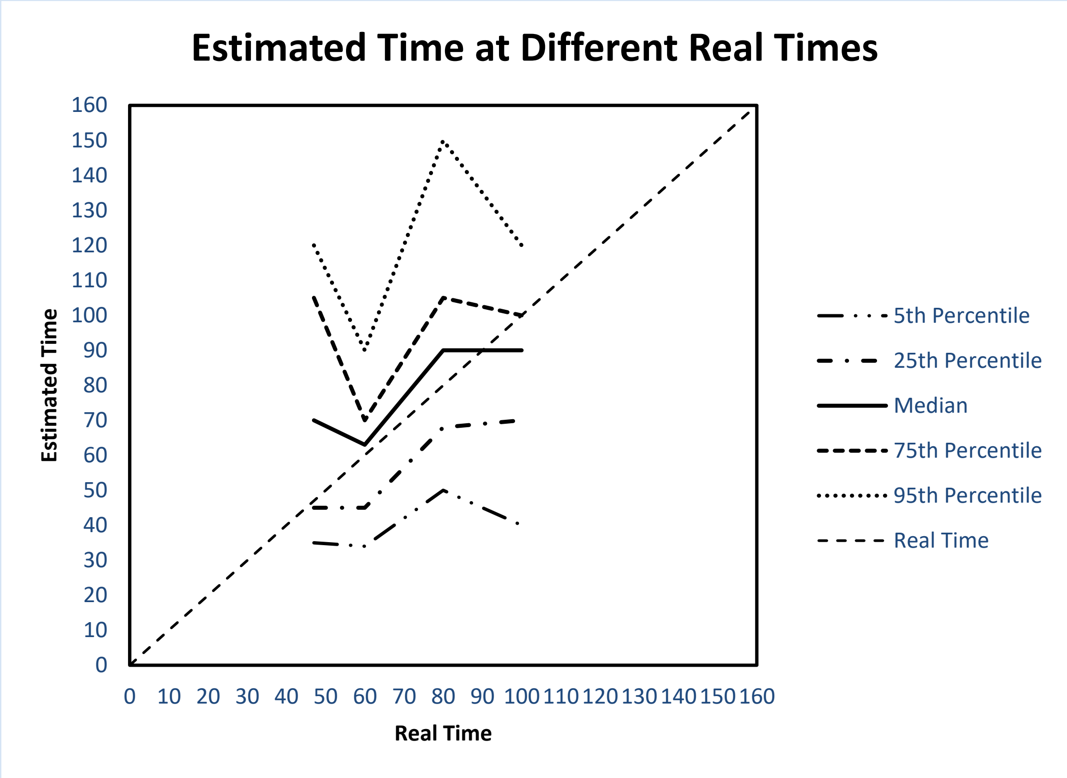

Figure 18. Estimated Time at Different Real Times

Part 2- Estimation of ability to extinguish fire with a fire extinguisher

The fire extinguisher which was used in the virtual environment had similar dimensions to the one shown by Fridolf and Nilsson (2011). The extinguisher had a different label from another commercial brand which was not possible to read from the position they were located on the room with the fire. The answers obtained during the experiments are presented in Table 12.

Table 12. The total number of answers for each stage of the fire

Fire Time	HRR	Yes	No	Do not know	Σ
30	20	37 (100%)	0 (0%)	0 (0%)	37 (100%)
47	55	18 (95%)	0 (0%)	1 (5%)	19 (100%)
60	80	32 (89%)	1 (3%)	3 (8%)	36 (100%)
80	175	21 (57%)	7 (19%)	9 (24%)	37 (100%)
100	220	12 (33%)	18 (50%)	6 (17%)	36 (100%)

The results obtained in the second part of the experiments indicates that when the fire is small, the majority (100% and 95%) think the fire can be extinguished with the portable extinguisher. As the fire increases in size the percentage of positive answers decreases to 33%. In the last scenario at time 100 seconds only 33% of participants believed the fire could be extinguished it. While on the first scenario at time 30 seconds 100% of responses stated that with the help of a portable fire extinguisher the fire could be extinguished.

The results on Table 13 are compared to consider if people who has received training or have used a fire extinguisher before, are more likely to try to extinguish a fire. The possible answers on this part of the experiment are: yes, no and I don't know. The positive responses of the participants with experience using portable fire extinguishers are narrowly higher than the participants without experience. However, the χ^2 test with a consistency of a 2x3 matrix, shows the difference is not enough to be considered statistically significant (χ^2=0,989, df=2, $p>0.05$).

Table 13 Experience using Fire Extinguishers

	Ability to Extinguish (165 Estimations)		
Exp. Fire Extinguisher	**Yes**	**No**	**I do not know**
Yes	33 (79%)	5 (12%)	4 (9%)
No	87 (71%)	21 (17%)	15 (12%)

4.2. Comparison of results

The results found by Fridolf and Nilsson (2012) for the popcorn fire comparing with the results found on this experiment demonstrate that people is not very good at predicting fire growth, however Fridolf and Nilsson (2012) results for the popcorn fire show that 75% of the participants overestimated the fire while on the current project 51% of the participants underestimate the fire growth.

In the current experiment with VR and in the past experiment with educational video (Fridolf & Nilsson, 2011) there are large variations on the results. Figure 19 illustrates the large variation on the responses. For instance, at time 100 seconds the variations on the results between 5th and 95th percentile is 110 seconds for the current experiment and 112 seconds for the previous experiment (Fridolf and Nilsson, 2011).

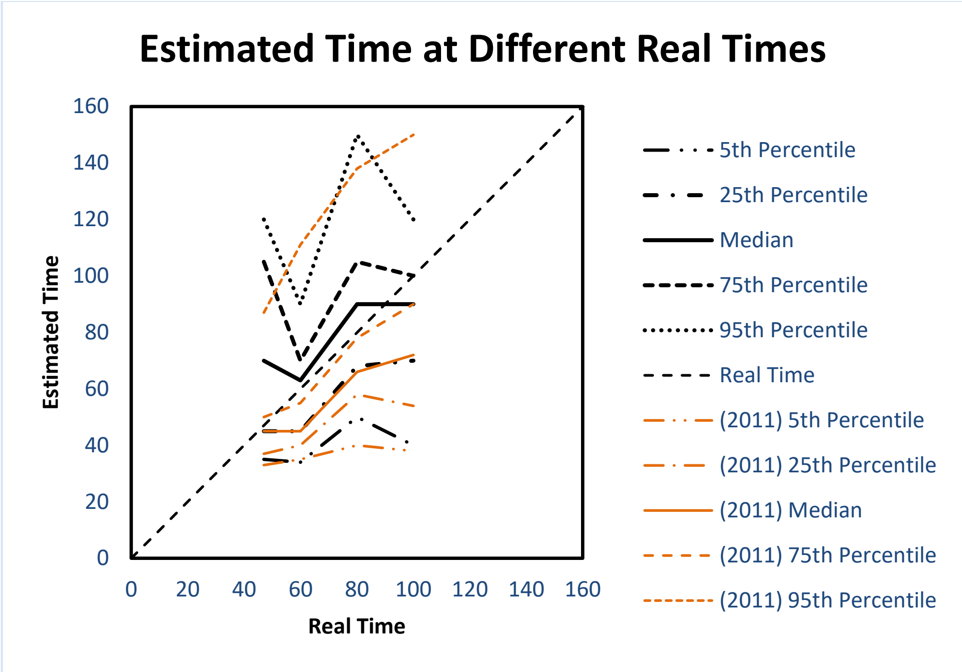

Figure 19 Comparison between current VR experiment vs previous educational videos method

Part 2- Estimation of ability to extinguish fire with a fire extinguisher

From the analysis of descriptive statistics, both experiments have comparable results regarding ability to extinguish fire with the help of a fire extinguisher. When the fire is on initial stage 30, 47 and 60 seconds, the percentage of responses that show it is possible to extinguish it with a fire extinguisher (yes) are from 74% to 91% on Fridolf and Nilsson (2011) experiment, and from 89% to 100% in the VR experiment. The percentage of "Yes" answers start to decrease as the fire increases on size. At 80 seconds, 55% of the responses in the experiment of 2011 and 57% in the VR experiment express it is possible to extinguish the fire with a portable fire extinguisher. On further stages of the fire, at 100 seconds the percentage of people that answered that the fire cannot be extinguish is of 50% in the VR experiment and 36% on the experiment carried out by Fridolf and Nilsson (2011). It can be seen that also the percentage of people who was not sure if they could extinguish the fire ("I do not know" answer) increased, 17% on the VR experiment and 30% on the Experiment done in 2011.

Table 14 Comparison of Part 2 of the experiments

	Experiment VR				Experiment (2011)		
Fire Time	Yes	No	Do not know	Fire Time	Yes	No	Do not know
30	37 (100%)	0 (0%)	0 (0%)	30	86 (91%)	1 (1%)	7 (7%)
47	18 (95%)	0 (0%)	1 (5%)	47	43 (80%)	2 (4%)	9 (17%)
60	32 (89%)	1 (3%)	3 (8%)	60	55 (74%)	7 (9%)	12 (16%)
80	21 (57%)	7 (19%)	9 (24%)	80	63 (55%)	27 (24%)	24 (21%)
100	12 (33%)	18 (50%)	6 (17%)	100	30 (34%)	31 (36%)	26 (30%)

5. Analysis and Discussion

Pre-evacuation time is a key factor when evacuating a building. During this time, the occupants have to evaluate the situation and react when they are aware of possible risks. Defining the seriousness of the situation will influence the behavior that is chosen by the occupant. A good estimation of the fire hazard can influence the outcome of the emergency, when an individual perceives a fire alarm it can over or underestimate this cue. The implications of these estimations can result in different human behaviors i.e. if the subject overestimate the situation it may over react going under unnecessary stress and it can also have an economic impact such as activating the suppression system in a building. Oppositely underestimating the seriousness of the situation (fire growth) can lead to long pre-evacuation times increasing the risk exposure of the person.

The present VR experiment is divided in two parts. Part 1- Estimation of Time Difference and Part 2- Estimation of ability to extinguish fire with a portable fire extinguisher. The information collected obtained during the experiments was arranged and only the values that lay on the statistical distribution were used. On the first part the results of the current project found the median percentile lies above the real time line which means the fire was underestimated by a slightly higher number of participants. The other experiment done Fridolf and Nilsson (2011) show the median of the responses tend to underestimate the time which means people were overestimating the fire. Even though they seem different results, both have large variations on the estimations when comparing the 5th and 95th percentile almost two minutes in some cases. Fridolf and Nilsson (2011) conclude the estimation on the fire growth seemed to be dependent on how rapidly the fire develops. In a fast-growing fire people tend to underestimate the time difference as it was shown with the data collected by Fridolf and Nilsson (2011). While in a slow growing fire people overestimate the fire. This might explain why there was this difference on the results on the first part of the experiments. For example, in a scenario where it was shown the first 30 seconds of fire growth. On the videos shown during their experiments it can be observed a person igniting the popcorn, no smoke or flames can be observed until second 10 where some smoke and flames started to appear. Even though there is no flames or smoke at the beginning, the individual is already aware that the fire started since the person on the video ignites the popcorn. On the experiments performed using virtual reality the participants do not see any flames or smoke until time 10s (on the original videos the first flames started to appear at 10s), the participant may think that the fire takes only 20 seconds to develop instead of 30 seconds where it was clear on the experiments carried out by Fridolf and Nilsson (2011). Another probable reason on the variation in this part of the experiment is that with this method people were more immerse on the fire situation, which implies they could have a different perception of the fire risk. Increasing the level of realism of the VR experiments could have resulted on different estimations. For instance adding sound the fire or adding heat to the experiments with radiation panels could have increased the level of realism on the experiments increasing the immersion on the virtual environment.

On the scenarios where participants observed a longer time of fire growth i.e. from 0s to 60 seconds the median tended to underestimate the time. As it was previously stated this behavior can be link to Fridolf and Nilsson conclusion, "the estimation of fire growth is dependent on how rapidly the fire develops" (Fridolf & Nilsson, 2011). It was found in various fires such us the Dupont fire in Puerto Rico or the Bradford Football Stadium fire on the United Kingdom people did not evacuate when they received the first cues of the fire, it was observed that people were underestimating the fire. On the current project, similar behavior was observed with 54% of the incorrect estimations during the first part of the experiment, people perceived the fire will take longer to grow than what it took in reality. On the second part of the experiments people had a similar response and follow the same trend in the current project and in the experiments carried out by Fridolf and Nilsson (2011). The participants said they could extinguish the fires at initial stages, when the fire started to increase the responses of people change and a greater percentage believed it was not possible to extinguish the fire at later stages. This project also examines if people with previous experience with portable extinguishers are more likely to extinguish the fires. The results showed people who had been trained are more inclined to extinguish the fires, however there was not difference shown on the statistical analysis of these results.

This project used a recent technology to study fire growth perception. The data obtained from this project showed comparable results to previous research (Fridolf & Nilsson, 2011) and (Canter et al., 1980) which was done with other methods. Fridolf and Nilsson (2011) found during their experiments in a slow growing fire (popcorn) people tend to overestimate the fire and in fast growing fires (kitchen fire), people tend to underestimate the fire. They conclude in general people do not have a good estimation of fire. On the experiments carried out by Canter et al., (1980), he concluded that in general people always underestimate fire growth. The results of the current thesis show that in this particular case people tended to underestimate the fire growth with some large variations on the data. It cannot be stated that people will always underestimate the fire growth. The experiment carried out by Fridolf and Nilsson (2011) had 141 participants which represent a bigger sample of data than the current experiment with VR (55 participants). On the previous experiment 37% of the participants belong to the Fire Safety Engineering program. On this experiment 26% of the participants were students of Fire Safety Engineering which, could have influenced the results due to the fact fire growth is usually taught on these programs. Further research has to be carried out considering a larger number of participants and also testing different scenarios or environments with different fire growth ranges and population types.

6. Conclusion

In this project, most of the participants performed a bad estimation of fire growth. Nevertheless, no significantly difference were found on the results to conclude that people tend to under/overestimate the fire growth, only a small percentage of the population which took part of the experiments estimated a time difference that corresponded to the real time difference. The results of this study may be used to argue that young adults (who represented the majority of the population) are not very good at predicting fire growth at various stages of the fire, which may explain why in real case scenarios some time elapses when people received the first cue, before starting to evacuate towards the emergency exits. This study suggest that virtual reality can be used as a research tool as an alternative method to study human behavior in fires, but high level of realism in the VR scenarios is required in order to use it for the evaluation of risk perception. Future validation studies will help increasing the understanding on its effectiveness in these types of scenarios. Even though people are aware they were on a simulated environment it would be important to study to which extent they feel immersed on the virtual world. Also, participants experienced a small level of dizziness which is not very frequent on other methods such as drills or educational videos. The results found on this project in part 2, are comparable to previous results which were taken using a different method of study however, the results from part 1 differed from the previous experiment. Accomplishing higher levels of realism could contribute to achieve behaviors similar than the ones people opt on real case scenarios. Further studies should be done adding extra cues to the virtual environment such as sound and a greater level of detail should be achieved on the different modelled objects to accomplish a higher immersion on the scenarios.

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Appendices

Appendix A Contact Information

Contact information

The present information is required in order to start a logistic process regarding experimental sessions for two Master Thesis developed at Lund University by IMFSE students. Francisco Rosero and David Mayorga will perform a series of experiments with Virtual Reality, Evacuation and Fire and it is important to receive this information in order to organize an schedule Doodle where participants can sign up and pick a preferred date and time to be tested. Both experiments will last between 30 minutes and one hour and will tentatively take place on March 20-24 at LTH. We kindly ask you to provide your Contact Information and any comments you have in order to have an initial idea of the number of participants, set these previously mentioned sessions and provide more information regarding the experiments to you.

Thanking you very in advance for your time and collaboration.

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+46 722038722

*Required

Name *

Your answer

Email *

Your answer

Study Program *

Your answer

Phone number

Your answer

Comments

Your answer

SUBMIT

Never submit passwords through Google Forms.

Appendix B Informed Consent

Lund University - IMFSE

Informed Consent Form for Experiments in Virtual Reality

This informed consent form is for students who are currently enrolled at Lund University and who are in invited to participate in research with Virtual Reality experiments.

Investigators: David Mayorga & Francisco Rosero
IMFSE- Lund University
Project 1: Flashing lights at road tunnel emergency exit portals: A VR study with head mounted displays
Project 2: Assessment of People's Perception of Fire Growth: A Virtual Reality Study

Information

The aim of these experiments is, perform a cross-validation between two different VR technologies using as method the replication of an experiment previously developed in an environment with flashing lights at emergency exit portals in road tunnels (Ronchi & Nilsson, 2015) and to evaluate how people perceived risk in a fire scenario represented in VR when compared with other training methods (e.g. educational videos).

The experiment set up was modelled in 3D software attempting to achieve a good level of realism to allow participants to be immersed in the experiments. The software Unity 3D was used to program the games and the logics of the virtual environments. As platforms "GEAR VR" and "Oculus Rift" will be used for the experiments. Participants will be immersed in virtual scenarios and navigate on them using an X-Box Controller. The research will take place in Lund University from March 22nd to March 29th , 2017 and will last approximately one hour. Your participation in this research is entirely voluntary. It is your choice whether to participate or not.

Procedure

The experiments will take place on the date previously schedule. Once the participant arrives to the VR lab they will be given a set of instructions regarding the experiment. First, a training session will take place followed by the two experiments of Virtual Reality. For each experiment, questionnaires will be used and at the end an additional one regarding participant's background information must be filled out.

Risks

A set of precautions were taken to avoid psychological and physical injury during the experiments. You may experience dizziness or nausea during the experiments. If you sense any of these tell the researcher to stop the experiment immediately if you think it is necessary. One of the researchers will help you sitting down and will provide a glass of water. It can also help to close your eyes while you sit down to counteract nausea. It is also important that you know that a first aid kit is available during the experiments.

I have accurately read out the informed consent and agree to participate on the experiments. The data obtained during my participation may be used for the purposes mentioned above.

Signature of Participant giving the consent:

____

Name ___________________________

Date ___________________________

DD/MM/YYYY

Appendix C Questionnaire Experiment

Assessment of People's Perception of Fire Growth

Part 1- Example Question

Try to estimate how much time elapsed between the last frame you see on the first video and the second video.

Your answer

NEXT

Assessment of People's Perception of Fire Growth

Assessment of People's Perception of Fire Growth

Part 2 Fire Growth Estimation

Try to estimate how much time it takes for the fire of the last frame you see to reach the stage of the fire that you will see now.

Your answer

Try to estimate how much time it takes for the fire of the last frame you see to reach the stage of the fire that you will see now.

Your answer

BACK NEXT

Assessment of People's Perception of Fire Growth

Assessment of People's Perception of Fire Growth

Part 3- Ability of extinguishing a fire with a portable extinguisher

Do you think you could put out the fire of the room using the fire extinguisher on the right.

- ◯ Yes
- ◯ No
- ◯ I dont know

Do you think you could put out the fire of the room using the fire extinguisher on the right.

- ◯ Yes
- ◯ No
- ◯ I dont know

Do you think you could put out the fire of the room using the fire extinguisher on the right.

- ◯ Yes
- ◯ No
- ◯ I dont know

BACK SUBMIT

Appendix D Responses of Participants

Time	Name	Scenario #	Estimation Bus	Fire 17 (s)	Fire 50 (s)	Extinguisher 1	Extinguisher 2	Extinguisher 3
2017/03/24 2:50:38 pm EET	Sawsan Kanaan	1	2	180	130	Yes	Yes	I dont know
2017/03/26 12:29:49 pm EET	Guangqi Qin	1	5	30	60	Yes	Yes	Yes
2017/03/27 11:40:33 am EET	Fiona de Heer	1	3	30	90	Yes	Yes	No
2017/03/27 7:23:57 pm EET	Juan Chaves	1	5	30	35	Yes	I dont know	No
2017/03/27 7:31:43 pm EET	Hicham Kouhkouh	1	7	20	60	Yes	Yes	Yes
2017/03/27 7:39:20 pm EET	Rohan Baptiste	1	2	75	260	Yes	Yes	Yes
2017/03/28 10:53:21 am EET	Saar Hoek	1	3	60	150	Yes	Yes	Yes
2017/03/29 4:29:07 pm EET	Israt Mukti	1	10	5	20	Yes	Yes	Yes
2017/03/29 4:32:07 pm EET	Murodilla Rikhsiboev	1	3	15	45	Yes	Yes	I dont know
2017/03/30 1:52:12 pm EET	Melchior Schepers	1	2	80	180	Yes	Yes	Yes

Time	Name	Scenario #	Estimation Bus	Fire 30 (s)	Fire 70 (s)	Extinguisher 1	Extinguisher 2	Extinguisher 3
2017/03/22 7:08:00 pm EET	Alejandra Velasco	2	3	40	75	Yes	Yes	Yes
2017/03/24 4:55:39 pm EET	Marius Herr	2	2	30	60	Yes	Yes	Yes
2017/03/26 12:31:49 pm EET	Yunan Zhou	2	3	60	90	Yes	Yes	No
2017/03/27 7:36:03 pm EET	Claudio Mandrioli	2	2	20	240	Yes	Yes	Yes
2017/03/27 7:38:04 pm EET	Monica Carpio	2	2	4	55	Yes	Yes	Yes
2017/03/28 11:50:25 am EET	Andy Lin	2	5	25	15	Yes	Yes	No
2017/03/29 10:16:32 am EET	Arjan Dexter	2	5	40	50	Yes	Yes	I dont know
2017/03/29 4:30:20 pm EET	Mathiew Verpaele	2	2	15	90	Yes	Yes	No
2017/03/29 7:09:45 pm EET	Darko Perovic	2	3	20	60	Yes	I dont know	No

Time	Name	Scenario #	Estimation Bus	Fire 20 (s)	Fire 40 (s)	Extinguisher 1	Extinguisher 2	Extinguisher 3
2017/03/23 12:50:19 pm EET	Nicolas Alvear	3	2	4	15	Yes	Yes	No
2017/03/23 9:58:44 pm EET	Christoffer Huynh	3	2	20	60	Yes	Yes	Yes
2017/03/24 4:56:21 pm EET	Martha Algard	3	3	5	8	Yes	I dont know	No
2017/03/26 7:48:49 pm EET	Maria Dimou	3	6	60	240	I dont know	No	No
2017/03/27 4:15:45 pm EET	Blaise Bayno	3	3	2	1	Yes	I dont know	No
2017/03/28 2:58:34 pm EET	Sylvia Platteau	3	4	3	10	Yes	No	No
2017/03/29 4:30:56 pm EET	Ye Qian	3	5	60	10	I dont know	No	No
2017/03/29 7:10:11 pm EET	Sanjin Bajramovic	3	2	45	90	Yes	Yes	I dont know
2017/03/30 5:14:34 pm EET	Khai Looi	3	3	20	40	Yes	Yes	I dont know

Time	Name	Scenario #	Estimation Bus	Fire 50 (s)	Fire 17 (s)	Extinguisher 1	Extinguisher 2	Extinguisher 3
2017/03/23 2:20:55 pm EET	Sandra Yousif	4	2	90	60	Yes	No	Yes
2017/03/23 10:00:06 pm EET	Nanami Zuzuki	4	5	75	40	Yes	Yes	Yes
2017/03/24 7:08:30 pm EET	Friday Chen	4	2	20	8	Yes	Yes	Yes
2017/03/26 7:51:15 pm EET	Joanna Asmokopolvo	4	1	60	120	Yes	I dont know	Yes
2017/03/27 4:54:14 pm EET	Katie Abbott	4	2	10	8	Yes	Yes	Yes
2017/03/28 6:08:43 pm EET	Habib Hamidy	4	2	60	40	Yes	I dont know	Yes
2017/03/29 4:29:41 pm EET	AKM Fahmidul Haque	4	4	120	90	Yes	Yes	Yes
2017/03/29 7:11:11 pm EET	Nina Nesterova	4	4	420	300	Yes	I dont know	Yes
2017/03/29 7:11:35 pm EET	Carlos Arellano	4	2	60	90	Yes	Yes	Yes

Time	Name	Scenario #	Estimation Bus	Fire 70 (s)	Fire 30 (s)	Extinguisher 1	Extinguisher 2	Extinguisher 3
2017/03/23 8:13:01 pm EET	Kanako Yasuoka	5	3	600	360	Yes	No	Yes
2017/03/24 9:23:12 pm EET	Sara Aitwassi	5	3	300	180	Yes	I dont know	Yes
2017/03/27 10:16:11 am EET	Julia Trojan	5	4	60	40	Yes	Yes	Yes
2017/03/27 6:09:09 pm EET	Ettore Carini	5	3	45	35	Yes	Yes	Yes
2017/03/27 7:24:48 pm EET	Ming-Cian Hong	5	7	10	5	Yes	I dont know	Yes
2017/03/27 7:27:14 pm EET	Martina Varisco	5	6	60	50	Yes	Yes	Yes
2017/03/28 1:43:17 pm EET	Evin Thana	5	5	50	25	Yes	Yes	Yes
2017/03/29 4:31:25 pm EET	Hu PingTing	5	4	10	7	Yes	Yes	Yes
2017/03/30 7:31:57 pm EET	Natacha Askovic	5	3	150	60	Yes	No	Yes

Time	Name	Scenario #	Estimation Bus	Fire 40 (s)	Fire 20 (s)	Extinguisher 1	Extinguisher 2	Extinguisher 3
2017/03/23 4:48:22 pm EET	Felix Hard	6	4	30	20	Yes	No	I dont know
2017/03/23 8:09:10 pm EET	Zulfiya Gafurova	6	5	25	18	Yes	No	I dont know
2017/03/25 7:28:41 pm EET	Kunsulu Bekish	6	4	20	15	Yes	No	Yes
2017/03/27 1:25:54 pm EET	Werner Nik	6	2	60	30	Yes	No	Yes
2017/03/27 6:57:12 pm EET	Banne Matutu	6	13	60	45	Yes	No	Yes
2017/03/27 7:28:36 pm EET	Sergio Vargas	6	1	9	8	Yes	Yes	Yes
2017/03/29 4:28:38 pm EET	Sasha Platonova	6	2	15	10	Yes	I dont know	Yes
2017/03/29 4:32:54 pm EET	Botir Eminjonos	6	20	30	25	Yes	Yes	Yes
2017/03/30 7:32:50 pm EET	Cynthia Chauvet	6	3	30	20	No	No	No