HOST UNIVERSITY: Lund University

FACULTY: Faculty of Engineering

DEPARTMENT: Division of Fire Safety Engineering

Academic Year 2022-2023

Investigation on Enhancing Fire Threat Perception in Virtual Reality through Subject-Expectancy Effect

Hsuan-Ting Liu

Supervisor: Jonathan Wahlqvist, Lund University

Master thesis submitted in the Erasmus+ Study Programme

International Master of Science in Fire Safety Engineering

Investigation on Enhancing Fire Threat Perception in Virtual Reality through Subject-Expectancy Effect

HsuanTing Liu

Fire Safety Engineering
Lund University
Sweden

Report 5697, Lund 2023

Master Thesis in Fire Safety Engineering

Investigation on Enhancing Fire Threat Perception in Virtual Reality through Subject-Expectancy Effect

HsuanTing Liu

Report 5697
ISRN: LUTVDG/TVBB—5697--SE

Number of pages: 35
Illustrations:

Keywords
Virtual reality, safe distance, subject-expectancy effect, thermal radiation, placebo effect, fire scenario.

Abstract
This thesis examines the use of subject-expectancy effect on enhancing fire threat perception in virtual reality. The study involves a virtual fire scenario design and 33 participants who experience virtual fires of three different scales in the scenario using a head-mounted display as visual and auditory perception and adopting physical movement in real world as their way of locomotion. The experiment investigates the subject-expectancy effect on cognitive safe distance judgements from the virtual fires with the absence and presence of self-made thermal radiation device as the primary manipulated variable. The collected data is evaluated statistically with boxplots assisted to facilitate the identification. The study found that the application of the subject-expectancy effect has only slight benefit on the realism of the fire scenario in virtual reality.

© Copyright: Fire Safety Engineering, Lund University
Lund 2023.

Fire Safety Engineering
Lund University
P.O. Box 118
SE-221 00 Lund
Sweden

DISCLAIMER

This thesis is submitted in partial fulfilment of the requirements for the degree of *The International Master of Science in Fire Safety Engineering (IMFSE)*. This thesis has never been submitted for any degree or examination to any other University/programme. The author(s) declare(s) that this thesis is original work except where stated. This declaration constitutes an assertion that full and accurate references and citations have been included for all material, directly included and indirectly contributing to the thesis. The author(s) gives (give) permission to make this master thesis available for consultation and to copy parts of this master thesis for personal use. In the case of any other use, the limitations of the copyright have to be respected, in particular with regard to the obligation to state expressly the source when quoting results from this master thesis. The thesis supervisor must be informed when data or results are used.

Read and approved,

HsuanTing Liu

11th, May, 2023

List of figures and tables

List of abbreviation

VR – Virtual Reality
VE – Virtual Environment

Table of Contents

Abstract

This thesis examines the use of subject-expectancy effect on enhancing fire threat perception in virtual reality. The study involves a virtual fire scenario design and 33 participants who experience virtual fires of three different scales in the scenario using a head-mounted display as visual and auditory perception and adopting physical movement in real world as their way of locomotion. The experiment investigates the subject-expectancy effect on cognitive safe distance judgements from virtual fires with the absence and presence of self-made thermal radiation device as the primary manipulated variable. The collected data is evaluated statistically with boxplots assisted to facilitate the identification. The study found that the application of the subject-expectancy effect has only slight benefit on the realism of the fire scenario in virtual reality.

本論文檢驗受試者期望效應在增強虛擬現實中火災威脅感知中的效果。 此研究涉及一個虛擬火災場景設計，33 名參與者使用頭戴式顯示器作為視覺與聽覺感知接收，並在指定空間中直接行走於場景中體驗三種不同規模的虛擬火災。 實驗以自製熱輻射裝置的存在與否作為主要操縱變量，研究受試者期望效應對安全距離判斷的影響。 數據通過統計檢驗進行評估與箱型圖繪製助於識別。研究發現應用受試者期望效應對虛擬現實中火災場景的真實性有些微增強。

1. Introduction and Objectives

1.1. Introduction and Background

Virtual environments (VE) are ideal for conducting experiments in fire safety field as they offer a high degree of control, are simple to reproduce giving it strength in internal validity, and provide a relatively realistic representation of real-world scenarios while ensuring the safety of the occupants [1].

However, the VR application for fire threat perception scenario has certain limitations that need to be considered. One of the major shortcomings is that fires in VR lack two essential threat perception factors: thermal change and olfactory perception from flame and smoke. While equipment that simulates thermal[1] and olfactory[2] [1]senses in VR is under development [2], the amount of research studying on the effectiveness of these enhancements for virtual fire scenarios is still limited. Not to mention that these sensory simulations are generally constrained by ethical restrictions, which restrains the ability to provide similar intensity within reality, and the lack of consequences and risks poses challenges to the enhancement of VR experiment realism as well, even though this is usually the reason why VR was adopted [1].

The other major drawback of VR is its validation weaknesses especially for ecological validity, referring to how well the realistic could be represented and examined in the simulated environment, and external validity, how well the findings obtained in VR could be generalized and applied into wider situation and population [3,4]. Due to the technical limitations from hardware and software used, VR experiments implement more simplifications of models, processes, behaviors, movements, and surrounding to reduce the complexity of human behaviors and minimize extraneous variables and unexpected feedback from them. However, this trade-off can result in issues with ecological validity and ergonomic aspects, any feedback that does not reflect real-life situations may lead to unrealistic behaviors, which can significantly reduce the reliability and validity of the result obtained in VR [5].

In order to improve the validity and reliability of fire experiment in VR, a straightforward approach is to enhance the realism of the simulation. This can be accomplished by increasing the level of detail in the VR model, the complexity of the environment, and the movement of characters, and for fire scenario, providing additional sensations to the participants through

[1] TEGWAY. http://tegway.co.kr/?ckattempt=1 (accessed April 24, 2023).
[2] OVR Technology - OVR Technology. https://ovrtechnology.com/ (accessed April 24, 2023)

changes in temperature and odor feedbacks. As for odor feedback, it must take into account both the concentration and dissipation rate, and real-time feedback devices should be portable and worn by participants to facilitate the VR experiment. However, the design of odor experiments is considerably more challenging than that of temperature change device experiments due to the multitude of variables involved [6]. In contrast, the thermal radiation device can be installed in a fixed location within the experimental site to simulate the fire source. Thus, considering time constraints, this thesis would focus on studying the influences of using the subject-expectancy effect involving thermal radiation.

In 2016, to improve a novel evacuation model, Bae et al.[7] conducted an experiment in which participants were blindfolded and guided towards an active radiator. Few participants in the experiment were reported to be exposed to a heat flux of over $15\ kW/m^2$, which exceeded the suggested threshold value ($2\ kW/m^2$ for long-term exposure to human skin without causing burns) reported in numerous literatures [8,9]. This resulted in ethical concerns, rendering the experiment impractical to be replicated in Sweden. Blomander's recent experiment [10] conducted at Lund University adopted a threshold value of $1.5\ kW/m^2$, which is ten times smaller than Bae's experiment. A similar VR multisensory experiments in the UK also used $2\ kW$ thermal radiation device and fans, with a distance of over 1 meter in the experimental design only [11]. Hence, the feasibility of reconstructing Bae's experiment in VR to validate and verify the correlation of results is subject to debate.

However, the results of Blomander's experiment revealed an interesting phenomenon in which participants in the control group reported experiencing thermal radiation despite not being expected to do so. Martin's research found that human perception of temperature in VR has high plasticity and could be influenced by environmental colour and scenario design visual factors [12]. Since it is improbable for the forthcoming experiment to provide thermal radiation of comparable intensity as in Bae's experiment, creating an illusionary heat source in subjects' minds with a inactivated heat radiation device, as the subject-expectancy effect in the title indicating, could be a viable and unexplored alternative to enhance fire threat perception in VR.

The subject expectancy effect, also known as the placebo effect in pharmacology [13], is a cognitive bias in behavioral psychology that has been extensively studied in clinical trials involving human subjects. The phenomenon arises due to the subjects' preconceived expectations oriented to a particular outcome, leading to a discrepancy between the actual experimental results and the theoretical expectation. The placebo effect has been observed in many clinical scenarios, wherein patients have reported experiencing symptom relief despite receiving a placebo which is confirmed to have no help with the symptom; this is a classic example of the placebo effect and has been confirmed owning significant implications for the design and interpretation of studies involving humans as subjects.

1.2. Purpose

The purpose of this dissertation is to identify and evaluate the interaction of subject-expectancy effect on fire threat perception, resulting from the presence of thermal radiation device in a VR fire scenario.

To achieve the goal, the following tasks would be implemented.

- To identify potential factors that may affect the subject-expectancy effect in this VR experiment as much as possible, determining the interested independent and dependent variables, and reducing the effects of extraneous variables that are not interested in the experiment.
- To design and create a realistic fire scenario in VR that includes one or more simple tasks for participants to perform, enabling researchers to observe participants' behavior and to record participants' cognitive safe distance data for subsequent analysis of results.
- To design a questionnaire to help with measuring the unobservable variables, such as the level of the VR scenario realism that participants perceived, collecting the results to support and the numerical results of cognitive safe distance and to help with justifying the interpretations.
- To investigate the effectiveness of the subject expectancy effect for fire threat perception in the VR fire scenario and discuss the potential work for future research and development.

2. Methodology

As stated in the research objective, the experiment would use VR technology to create a scenario as the purpose is to investigate the effectiveness of the subject-expectancy effect on fire threat perception in the VE, with safe distance perception as the main dependent variable, and questionnaire survey results as the second dependent variable for evaluation of fire threat perception influenced by the presence of heat radiation device, as the main independent variable.

To observe and quantify the influence of the subject-expectancy effect (placebo effect) on the two dependent variables, the experiment adopted between-subject design, the participants would be separated into two groups: a control group and a treatment group [14]. In order to observe the interaction between the subject-expectancy effect and fire threat perception in the VR experiment, manipulated variables will be utilized in the study design, including the presence or absence of a thermal radiation device and pre-experimental introduction provided by the researcher to the subjects. The control group would not be exposed to the thermal radiation device and would be informed that the thermal radiation is not involved in the VR experiment, while the treatment group would receive the opposite treatment. This allows for maximum variation in the independent variable. Blinding of the radiant heat application information was performed during the experiment. To avoid unexpected feedback that may introduce errors in the results, participants in both groups were not informed of the detailed experimental procedures prior to the start of the experiment. After data collection, the test results would be organized and analyzed using appropriate statistical methods to examine the efficacy and reliability of the results and attempt to identify any significant differences caused by the subject-expectancy effect. Subsequently, the following section provides a detail of the origin of the experimental design, the considered factors during the design process, and their intricacies based on related literature reviews.

Since no previous experiment regarding the application of the subject-expectancy effect on heat radiation in fire safety field could be found, the literature search for introduction was conducted in the following steps. Firstly, using combinations of keywords "virtual reality" and "fire safety", after manually filtering, 11 representative reviews published within the past 10 years from databases including Elsevier, Lund University Libraries search engine, and Google Scholar were selected. A search for reviews and experiments related to the placebo effect in VR was performed on the National Library of Medicine and Google Scholar, resulting in 3 articles. Next, the search for experiment design was conducted using combinations of keywords "virtual reality," "fire," and "experiment" to identify 5 recent articles within the fire safety field that did not employ sensory enhancement in VR, and another search using additional keywords "heat flux" and "heat radiation" was performed to identify 3 articles that specifically focused on using thermal radiation as a sensory enhancement in VR experiments. The experimental methods and design were referred to similar experiments within the literature and by conducting additional searches on Google Scholar using corresponding keywords.

2.1. Virtual reality

In the context of this thesis, VR here specifically refers to immersive VE operated on computers and experienced through head-mounted displays, which allow users to interact with simulated environment as if they were physically present there, rather than laboratory simulations for field cases or non-immersive VE presented on desktop screens. The concept of immersive VR can be traced back to the 1960s [15], while the use of VR to refer to this head-mounted simulation technology was pioneered by VPL Research in the 1980s and started being developed for commercial and research purposes [16]. Since then, immersive VR has been used for simulating environments in medical, automotive, aviation, and space training. By the time, many studies have adopted this technology to develop fire scenarios for fire safety education [17], firefighting training [18,19], and evacuation drill [20], and fire research purposes [21,22].

As stated in the introduction, VR offers a relatively safe and controlled environment for conducting experiments, allowing researchers to simulate scenarios such as firefighting or evacuation in smoke-filled environments. However, regardless of how realistic the simulation is, participants are always aware that they are in a VE, which poses challenges for result validation [4]. Furthermore, not only for real experiments, but the psychological concern is also a critical ethical consideration for VR experiments, as realistic or dangerous simulations in VR may still trigger psychological trauma in some participants [23]. Although the lack of consequence from the nature of VR experiments diminishes most of the trigger cues compared with real experiments. To avoid the probability VR scenarios must be designed to enable participants to clearly distinguish between virtuality and reality, while also achieving a sensory realism that does not compromise their ability to discern reality. This inherent trade-off between sensory realism and participant discernment makes it impossible for VR experiments to replace laboratory experiments.

2.2. Experiment design and setup

This section introduces the VR experimental design based on the manipulation of the subject-expectancy effect and the involved variables for two test groups.

In this VR experiment, visual cues (presence of equipment) and auditory cues (instructions and the thermal radiation device's activation sound) would be introduced as inducing factors to elicit the expected experience of heat radiation among the treatment group. The visual and auditory cues are to enhance the sense of immersion and presence in the VE, and to manipulate the participants' expectations regarding the experiences. Specifically, the treatment group would be led to anticipate the sensation of heat radiation, while the control group should not be exposed to any such expectation. These experimental manipulations were designed to evaluate the impact of expectations on the subjective experience of heat radiation and related physiological responses.

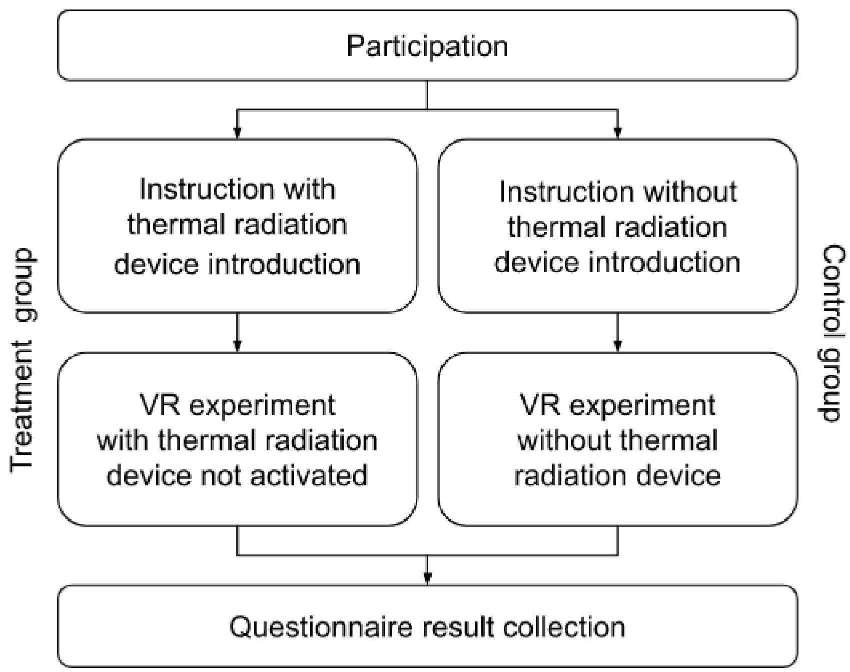

Figure 1 - Experiment process between two test groups

Figure 1 simply describes the difference in the experiment process between the treatment group and the control group. The experiment design is centered on two manipulated variables, namely visual cues (presence of equipment) and auditory cues (instructions and thermal radiation device's activation sound), with the aim of investigating their potential impact on fire threat perception. The hypothesis was tested by examining the cognitive safe distance from virtual fire and the answers to the questionnaire survey provided by the subjects.

The decision to focus on cognitive safe distance from virtual fires was inspired by Bae's experiment. This variable is regarded as the primary variable of interest because it is a crucial determinant in processing environmental danger information and making judgments in a fire scenario. The hypothesis posits that if threat perception is increased, the perceived safe distance should also correspondingly increase due to humans' innate instincts to avoid danger[24]. Additionally, distance measurement does not require additional instruments and arise no ethical concerns that could reveal sensitive personal data as collection of biometric data such as measuring heart rate [25].

The experiment was designed to allow participants to walk directly in VE, as the laboratory space is sufficient for this mode of locomotion. Compared to indirect inputs such as joysticks, this mode of control can provide a more intuitive way of movement, enhancing the connection between the virtual and physical spaces, thus enhancing the sense of realism and presence. However, a drawback is that it may increase the likelihood of motion sickness and discomfort [26].

Figure 2 provides a simplified depiction of the coordination between the VR environment and the laboratory space, as well as the relative positions of the various elements within the experiment. It should be noted that this figure is not drawn to scale.

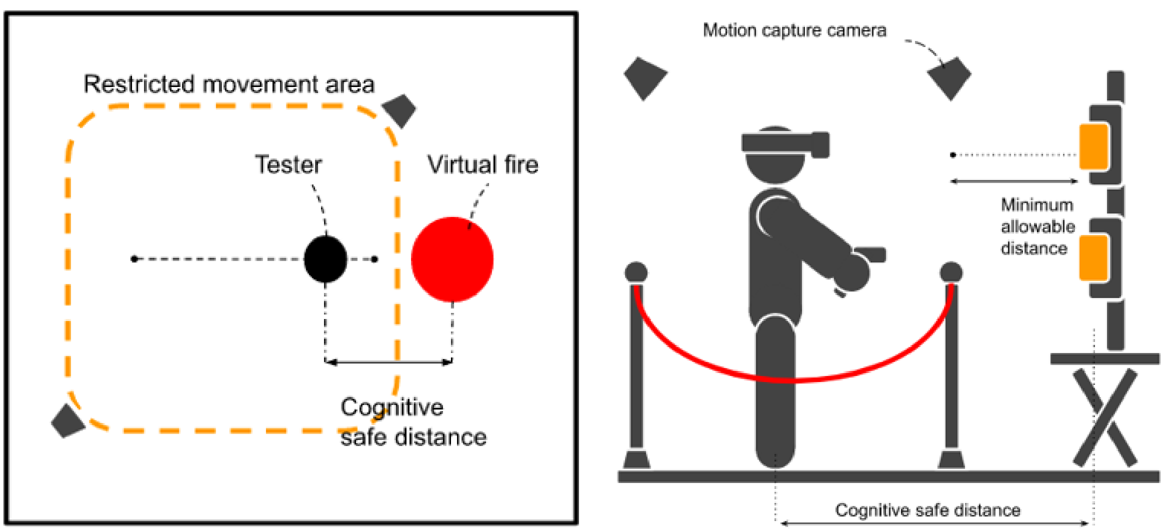

Figure 2 - Schematic diagram of the VE and the laboratory space

2.2.1. Participant recruitment

If possible, this VR experiment is expected to recruit at least sixty participants, with thirty participants in each group, and no restrictions on age or educational and occupational backgrounds, the participant amount is based on Gay and Diehl's suggestion for experimental design [27]. Power analysis for sample size is not adopted for the information of $P(X > Y)$, the probability of sample difference, is unknown before the experiment is conducted and is biased to assume a certain number since the result is sensitive, the suggested sample size varies from 1 to infinity with the P being assumed as 1 (Sample X is generally higher than Sample Y) to .5 (Samples show equivalence) [28].

The study only accepted adult participants, and the informed consent document explicitly stated that individuals with epilepsy or any anxiety and stress disorders would be declined for participation in case of safety concerns. The recruitment process involved spreading recruitment information in student group chat in mobile communication software, social media, distributing flyers on Lund University campus and posting announcements on bulletin boards in nearby faculties and student accommodations, with the intention of achieving random sampling to avoid introducing bias and increase the representativeness to population.

Convenience sampling and snowball sampling were utilized as alternatives for the time and financial constraints reason, as no budget and only one month for experiment conduction and data collection, a portion of the participants were recruited from the researcher and participants' network. These sampling methods are commonly employed in research studies when it is not possible to randomly select a representative sample from the target population. Convenience sampling involves selecting individuals who are easily accessible, and snowball sampling involves identifying initial participants and then requesting that they recruit additional participants from their social network [29].

With all sampling methods used, all recruited participants were required to register through an online form and reserve a time slot in the registration system. The online form provided digital consent information in advance to ensure that participants understand their rights. In addition, a hard-copy consent form was provided on site for participants to confirm their understanding and sign before proceeding with the experiment.

2.2.2. Experimental space

Since the experiment did not involve the activation of actual thermal radiation device it was able to be conducted in a well-sealed space. Specifically, the experiment was carried out in the VR laboratory located on the basement floor of Lund University V-Building, where a space of approximately 3×5 square meters was used, pictured in Figure 3. This setup not only minimized external interference, such as noise, but also provided the researchers with a completely controlled laboratory environment. The movable range of the VR space and actual space was adjusted and coordinated to ensure that participants remained within the designated area during the experiment, while avoiding any obstacles that could potentially pose a risk of collision, stumble or falling. To prevent participants from crossing the designated area and coming into contact with any equipment accidentally, the researcher's observation position and computer equipment were strategically placed near the thermal radiation device. This allowed for prompt intervention from the researcher if necessary to ensure participants' safety during the experiment.

Figure 3 - Picture of the laboratory space

2.2.3. HTC Vive

The HTC Vive is a VR device set co-developed by HTC and Valve Corporation[3], which includes a head-mounted display, two hand controllers, and two base stations, shown in Figure 4. The head-mounted display features AMOLED screens with a resolution of 1080P and a refresh rate of 90Hz, making it suitable for use with the HDRP template project in Unity 3D, providing a highly detailed visual experience that enhances the immersion of the VR experiment. The hand controllers designed for VR use allow for direct interaction with the VE and provide users with a straightforward means of measuring distances, while the two base stations enable users to move freely in a specific area without the need for indirect input, such as joystick or keyboard. These components work together aiming to create a highly immersive experience, providing participants with a high degree of realism in the experiment.

Figure 4 - HTC Vive set[3]

[3] VIVE European Union | Discover Virtual Reality Beyond Imagination. https://www.vive.com/eu/ (accessed April 24, 2023).

2.2.4. Unity 3D

Unity 3D[4] is a multi-platform supported game engine developed by Unity Technologies that can be used to develop 2D and 3D content. Apart from applying for game development, Unity 3D can also be adopted in architectural visualization, training simulation, educational content, and even film and animation production fields. The primary scripting language utilized in Unity 3D is C#, enabling researchers to develop custom scripts and modify existing code to tailor their projects to their specific research needs, such as recording execution time and movement trajectories for data collection in experiments. For this study, Unity 3D was employed to import Sketchup models and integrate them into an interactable virtual fire scenario, with the HTC Vive devices activated through SteamVR[5] serving as the experimental platform.

Figure 5 showcases the interior design and overview of the scene. To enhance the correlation of the fire experiment and to facilitate association for the participants, a few fire equipment such as fire extinguishers, emergency light, fire alarm pull station and smoke hood have been added to the scene. The blue square area on the floor corresponds to the restricted movement area for the participants in the real world. These additions aim to increase the immersion of the participants in the VR experiment. The decision to place the virtual fire source on the ground within a fuel plate was based on feedback from prototype participants, who suggested that this would increase the perceived level of danger compared to placing the fire source in a barrel container. Additionally, to avoid the unrealistic feeling of no smoke accumulation in the space, the virtual fire source was placed under an extraction hood in order to create a more realistic buildups in the scenario.

Figure 5 - The VR scenario designed for the experiment

[4] Unity Real-Time Development Platform | 3D, 2D, VR & AR Engine, Unity. https://unity.com (accessed April 24, 2023).
[5] SteamVR on Steam. https://store.steampowered.com/app/250820/SteamVR/ (accessed April 24, 2023).

Figure 6 portrays the three red buttons which could be interacted with hand controller to initiate the virtual fire scenario. The buttons are configured to be single-use and change colour to green after activation. To avoid any potential learning effect, the scale of the virtual fire ignited is randomized by the computer. The buttons' purpose is to heighten immersion by enabling the participants to activate the scenario independently and to facilitate their return to the starting position for distance measurement.

Figure 6 - The three interactable red buttons in the VR scenario

Figure 7 depicts the virtual fire scenario activated by the participants through the button. The scale of the virtual fire is determined to allow for easy visual differentiation, with three levels based on flame height. Specifically, the large scale of virtual fire is set at a height of approximately 1.5 meters, the medium scale at 1 meter, and the small scale at 0.5 meters high. The determination of the heights was based solely on enabling participants to visually differentiate among the fire scales with the naked eye and to maintain a realistic fire scales within the scene. Other fire visual effects were proportionally scaled up accordingly.

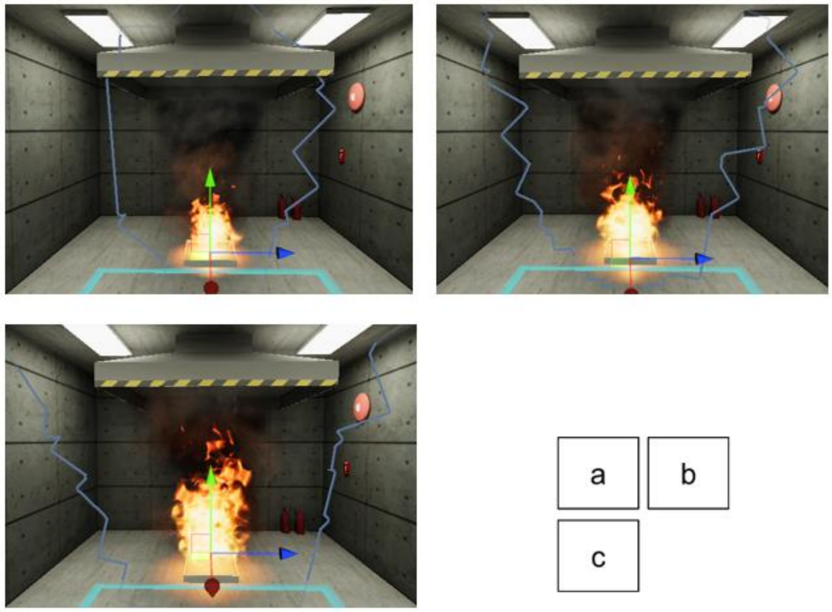

Figure 7 - The virtual fires in the VR scenario, a. small scale, b. medium scale, c. large scale.

2.2.5. Radiative heat device

The thermal radiation device consisted of two Arebos 2000W Infrared Radiator[6], which were vertically placed and anchored parallel to each other on two corner brackets that were placed on a stable and movable table, shown in Figure 9. The equipment has been tested to be resistant to slight shaking or mild collisions, with no risk of falling or injuring personnel. Depending on the test group, the equipment was either placed at the specific location of the virtual fire or removed and hidden. During the treatment group experiment, the equipment was positioned at the location of the virtual fire and facing towards the participants. Although the equipment was not activated during the experiment, the researcher would ensure that participants have no opportunity to come into contact with the equipment. There was approximately 60cm between the equipment and the closest allowable distance, which is right on the boundary of the virtual fire, in case the participant's hand with controller stretches to prevent accidental contact. As the

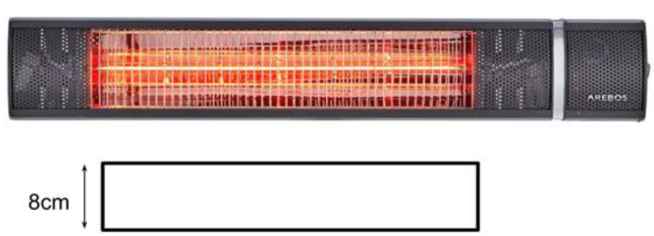

Figure 8 - Arebos Infrared Radiator[6]

[6] Infrarot Heizstrahler 2000W mit Fernbedienung. https://www.arebos.de/de_de/infrarot-heizstrahler-2000w-mit-fernbedienung.html (accessed April 24, 2023).

power of the two heating lamps were not plugged in and too large to be turned on simultaneously in the laboratory, there was no risk of accidental activation.

Figure 9 - The thermal radiation device

2.2.6. Procedure

Participants and the researcher met outside the laboratory at the agreed time during the experiment. Only one participant is accepted for each trial, and they were required to confirm consent information and potential risks provided in the online form at the time of registration. Upon arrival, the researcher provided a hard copy of the consent form, which the participants must sign before the experiment begins. The participants were informed that the experiment concerns a fire simulation and the addition of a thermal radiation device. However, they were not informed that the experiment utilizes the presence of the thermal radiation device to investigate the subject-expectancy effect.

After providing informed consent, participants were guided by the researcher to a designated position within the laboratory, where they were provided with a VR headset and two hand controllers. The researcher provided instructions on how to wear the VR headset and how to use the controller. Participants were given a brief period to adjust to the VE by moving their head, though their movements were limited.

Participants in the treatment group would hear the thermal radiation device being toggled on. Following this, the researcher provided task instructions to ensure that participants understood the experiment's procedures. Participants were then given permission to activate the fire scenario by touching one of three red buttons with hand controller. Throughout the experiment, researchers monitored participants' movements to ensure they did not move beyond the designated area.

When participants believed they had reached the closet safe distance from the virtual fire, the researcher confirmed their location and recorded the virtual fire source size, VR headset's position, and time values using a keyboard command. This process was repeated three times to complete the task in the scenario. After this, participants were then guided to the begin position to remove the VR headset.

The researcher gave only the designed instruction and no hint as much as possible to avoid the participants pleasing the researcher and deliberately meeting the researcher's expectations in result. In addition, the participants did not know beforehand that this is a between-subject experiment, the purpose of this blinding is to ensure that the participants only reflect their judgment based on what they can feel in the VR scenario, especially focusing on the threat perception from the virtual fires.

Following the experiment, participants were asked to complete a questionnaire. The researcher explained the experiment's purpose and engaged in an open discussion with participants to gather qualitative feedback. The entire experiment was designed to last no longer than 20 minutes.

2.2.7. Instruction design

Before starting the experiment, the researcher would provide verbal instructions to the participant wearing the VR headset, ensuring that they understand the task to be performed, thus facilitating data collection. The instructions should utilize simple and straightforward vocabulary to avoid misunderstandings and unnecessary information that may affect the experiment's outcome. The section would display all verbal instructions and their meanings for future experimental replication use.

a. Please stand at this designed position and do not move until the instruction is given.

This instruction is necessary to prevent the participant from moving out of the designed position, which might trigger the scenario accidentally without the complete instruction being given. In the prototype test, some participants were eager to explore the virtual space immediately after wearing the VR headset.

b. You may turn your head around to get familiar with the surroundings. If you feel any discomfort and you wish to stop continuing at any time, please say "Stop", the research will help you remove the VR equipment right away.

This instruction serves as a reminder of the participant's autonomy and enables the researcher to observe the participant's reaction after wearing the VR headset, ensuring their safety during the experiment.

c. If you didn't hear the instructions clearly, you can ask the instructor to repeat it again anytime.

The participant may encounter difficulty hearing instructions due to the VR headset's impact on audio clarity. This instruction confirms that the participant understands the instructions before proceeding with the tasks in the VE.

d. You will be placed in a room as an observer and a fire will start on a button press performed by you. You should be able to find three red buttons behind you. Only using controller to touch the red button is enough, and only interact with one button at a time.

As the VE is built in a game engine, some participants in the prototype test have provided feedback that they were unclear about their character in the VE. In response to this feedback, instructions will explicitly indicate the participant's role and explain how to activate the scenario by using hand controllers.

e. Your task is to slowly walk towards the fire and stop at a distance that you would consider safe in a real-life situation. Once done please notify the instructor, and you must walk back for the other two red buttons, and same process.

This instruction explains the task the participant needs to complete in the scenario. “Slowly walk” aims to reduce the risk of falls or collisions, also allowing participants to perceive and process risk information in the scenario, determining the safe distance they need to maintain from the virtual fire. Moreover, the instruction must avoid mentioning “the closest distance” to prevent participants from behaving contrary to real-life scenarios, as participant may walk into the virtual fire for no consequence feedback received. Participants were asked to inform the researcher when they reach a safe distance or answer the researcher's inquiry if they feel safe from the virtual fire for position recording.

f. After the procedure is done three times, you will be helped to remove the VR equipment.

This instruction aims to indicate to the participants the timing of the end of the scene, and the researcher would approach and help the participants remove the VR equipment to avoid the participants from taking off the equipment in an unintended way, which may cause damage to the equipment.

2.2.8. Questionnaire design

Due to ethical concerns, the questionnaire was unable to collect identifiable information such as names and ethnicity. Therefore, the personal information section of the questionnaire only investigated the biological gender and age of the participants. The questionnaire did not store any data that could be used to identify and target individual participants. Since the questionnaire was filled out after the experiment, the first question asked whether the participants experienced any discomfort to help the researcher understand the situation, and if necessary, the researcher would intervene to assist the participants.

The first half of the questionnaire (Question 2. to 5.) investigated the participants' educational background, experience with VR and video games, and experience with similar-sized flames, as the recruitment method could anticipate that some participants may come from a fire engineering background, which may affect the experimental results and therefore must be investigated in the questionnaire. The experience with VR and video games was also investigated because previous studies have found a negative correlation between the time spent playing games and the realism of VR scenes, suggesting that more experienced players are more likely to feel the unreality of the scenes due to the level of modeling detail. Investigating the participants' experience with similar flames aims to explore whether personal experience affects the evaluation of the safe distance.

After the background and experience data were collected, the questionnaire then asked questions (Question 6. To 8.) related to this VR experiment. Firstly, the participants were asked to rate the degree of realism of this VR scene, and whether they felt that approaching the virtual flames was dangerous. These two questions aimed to evaluate the participants' immersion level in the experiment, both directly and indirectly. The participants were then asked whether they felt any heat radiation during the experiment. Studies have shown that answers with 5-7 levels can clearly analyze degree-related questions [30], so the answers to these three questions were divided into six levels and excluded the neutral option to avoid researcher misinterpreting the participants' answers during subsequent analysis.

The factors that make participants feel threatened in the VE were also investigated in the questionnaire. Question 9. was designed as a multiple-choice item, inquiring whether the participants feel threatened visually, auditorily, or thermally by the virtual fire source. Specifically, the categories included the flame itself, burning sounds, smoke produced, and perceived heat. The question aims to identify which stimuli and elements in the VE contribute to the greatest sense of realism and immersion in relation to the virtual fire and whether there are any differences between groups. Lastly, participants were asked to provide reflections on the experiment, which would serve as a valuable source of qualitative data analysis. The researcher would also confirm and inquire about the reasons behind the participants' responses to the other questions.

The complete questionnaire used in this experiment can be found in Appendix A.

2.3. Data quantification and statistical analysis

After each participant completed the experiment, the system would automatically generate a comma separated values file record containing the timeline, the virtual fire scale, and the X, Y, and Z coordinates of the VR headset position in the VR space (with the virtual fire source as the origin). The record also included a highlight of the values when the researcher pressed a keyboard command. The recording started when the participant activated the scene by touching the red button and continued until the researcher stopped the scene. Three highlighted safe distances corresponding to three scales of the virtual fire in each comma separated values file were extracted for analysis. The questionnaire results were quantified by assigning numerical values to the answers. For example, a binary answer of "yes" or "no" would be assigned a value of 1 or 0, respectively, while the answers to questions about severity were quantified by assigning numerical values based on the level of severity.

The two test groups were small samples (both groups consist of less than 20 participants), and the two groups are independent, subjects in one group do not influence subjects in the other group. As the data is ranked and does not follow a normal distribution, the typical t-test is not applicable. Therefore, the Mann-Whitney U test was used instead [31], which does not rely on the assumption of normality and is suitable for analyzing non-parametric data. Since the result could be negative, indicating that the placebo effect might reduce realism, using a one-tailed assumption is not suitable for testing.

The two-tailed independent U test method would be used to calculate and compare the values against the alpha level. The null hypothesis assumes that the subject-expectancy effect has no influence on the fire threat perception in VR, meaning that the two groups are equal and there is no difference between the results from both groups. If the null hypothesis is rejected, the calculated p value is under the assumed alpha value, it indicates that difference is significant and less possible due to chance. According to this, the alpha value in this study is assumed as 0.05, which indicates under the assumption to show the significant difference between two groups, the U values must be smaller 81, at $p = .05$.

3. Results

This section presents the sorted recorded distance data, questionnaire answers from the experiment and statistical analysis. Convenience sampling and snowball sampling were the primary sampling methods used.

3.1. Subject categorization

A total of 33 participants were recruited for the VR experiment, all of whom were students and staff from Lund University. The participants consisted of 21 males and 13 females, with ages ranging from 20 to 38 years old. 16 participants were assigned to the treatment group, while 17 were assigned to the control group. Based on participant's fire background and prior experience with approaching a similar scale of fire in reality, participants could be further categorized into groups of 19 versus 14 individuals, and 24 versus 9 individuals, respectively.

Table 1 - Subject Categorization with simple binary classification.

Category	**Group 1 (Treatment/yes)**	**Group 2 (Control/no)**
Test	16	17
Fire background	19	14
Fire experience	24	9

In addition to the binary classification, participants could also be divided into the following groups based on their own VR usage experience and video gaming frequency.

Table 2 - Subject Categorization Based on VR and Video Gaming Experience.

Category	**First time Rarely play**	**1-3 times >1 hr/week**	**4-10 times 1~7hrs/week**	**>10 times and regular use >7hrs/week**
VR experience	11	13	7	2
Video gaming	11	7	9	6

The analysis focuses mainly on the comparison between the treatment and control groups, any significant differences found within other relationships were reported separately.

3.2. Safe distance results

The following figures show the distance distribution difference from three scales of virtual fire between the treatment and the control group, for the coordination, the X-axis represents the length of the movement space provided to participants in the laboratory, which is 4 meters, while the Y-axis represents the width of the movement space, which is 2.5 meters. The details of individual distance data are attached in Appendix D.

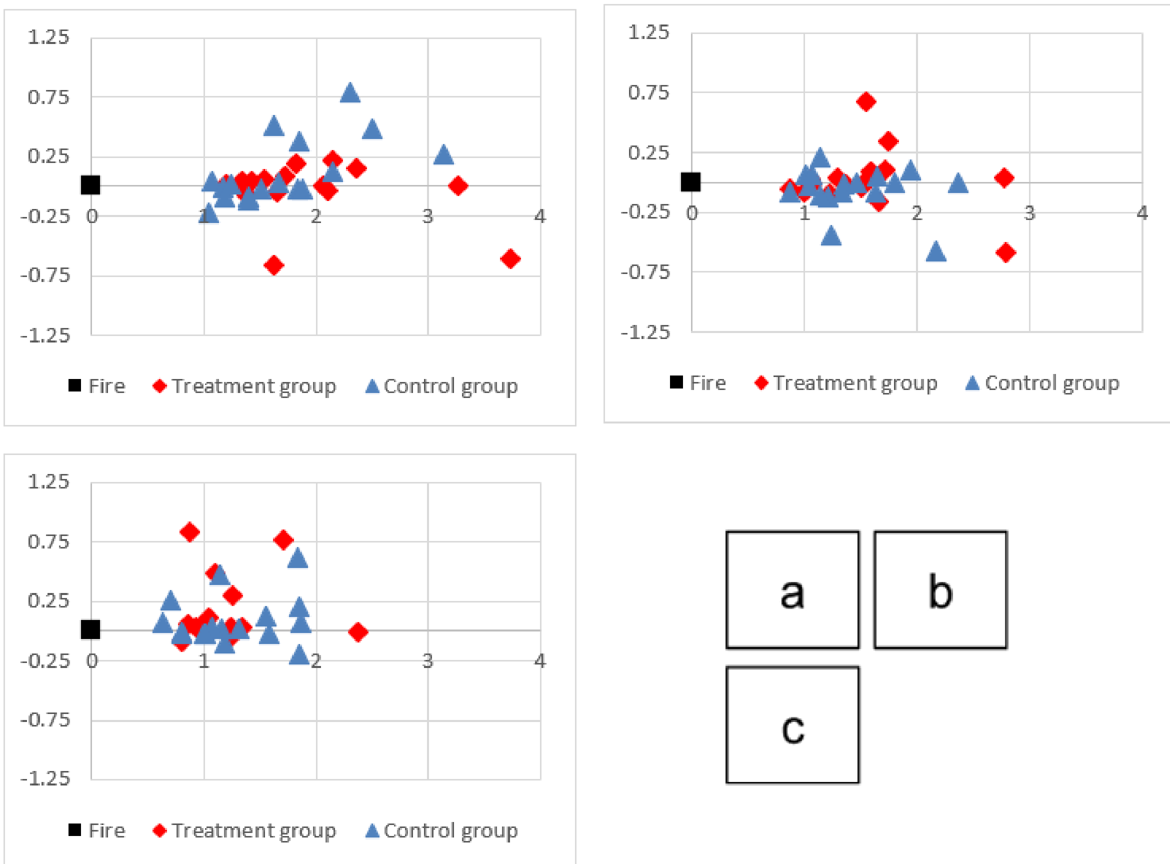

Figure 10 - Distribution of the safe distance position from the virtual fire,

a. large scale, b. medium scale, c. small scale.

Figure 10 reveals that as the virtual fire scale become larger, the overall safe distance data distributes further from the virtual fire point at (0, 0), including the closest distances and the extreme outliners, for large scale case, the closest distance is at around 1 meter, whereas the small case is at around 0.5 meter around. However, in the two-dimensional graphs, it is difficult to show an obvious difference in the coordinate distribution characteristics of the three virtual fire scales between the two groups. Therefore, the distribution of coordinates was transformed into one-dimensional data to facilitate the subsequent statistical analysis. To transform the coordination position data into one dimension value, the following formular is applied.

$$D_i^2 = [X_i^2] + [Y_i^2]$$

The symbol D represents the one-dimensional distance from the fire, while X denotes the position on the length scale and Y denotes the position on the width scale of the space. These values can be found in the data sheet presented in Appendix C, corresponding to the [X] and [Y] columns, respectively. The calculation result was listed in the same sheet with title “Distance”, unit in meter.

3.3. Questionnaire answer result

The first question of the questionnaire asked whether the participants felt any discomfort during the experiment. Only one participant from the control group answered "Yes", but still completed the experiment, and reported experiencing slight dizziness from the VR scene, which he could tolerate. Question 2 to 5 inquired about the participants' background and experience, and the results are detailed in section 3.1. Subject categorization. The following table presents the number of participants who selected each level for Question 6 to 8 in the questionnaire between the two test groups.

Table 3 - Number of Participants Selecting Each Response for Questions 6 to 8.

Question No.	Group	1 Strongly disagree	2 Disagree	3 Slightly disagree	4 Slightly agree	5 Agree	6 Strongly agree
6. Realism	Treatment	0	2	2	2	7	3
	Control	1	2	2	8	4	1
7. Unsafe	Treatment	2	4	1	3	4	2
	Control	4	2	1	7	3	0
8. Heat	Treatment	1	6	2	7	0	0
	Control	8	5	1	0	3	0

The results were also visualized using line graphs to show the mode and distribution differences between two groups, the X-axis in the following graphs corresponds to the agreement levels ranging from 1 to 6, and the Y-axis represents the number of participants who chose each option, as shown in Table 3.

Figure 11 presents the trend line of agreement level regarding the realism of the VR experiment between two test groups. The mode of the control group is "4- Slightly agree" with 8 participants choosing this option, while the mode of the treatment group is "5- Agree" with 7 participants selecting it. The trend lines show that the distributions between two groups are similar, with the treatment group's trend line seems to shift upward by one level compared to the control group.

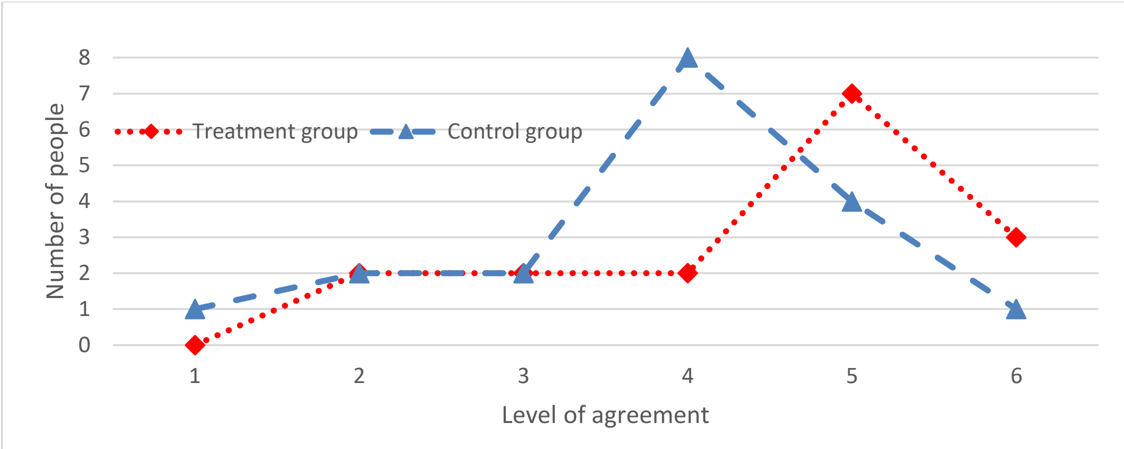

Figure 11 - Participants' ratings of the realism of the VR experiment.

Figure 12 displays the distribution of the agreement level between the two test groups regarding the unsafe feeling from being too close to the virtual fire in VR. The control group has a mode at "4-Slightly agree" with 7 participants, while the distribution line of the treatment group is relatively flat without significant peaks, with no option exceeding 4 participants. The trend lines between the two groups are not similar. It is worth noting that compared to the control group where no participants chose "6- Strongly agree," the treatment group had 2 participants selecting this option.

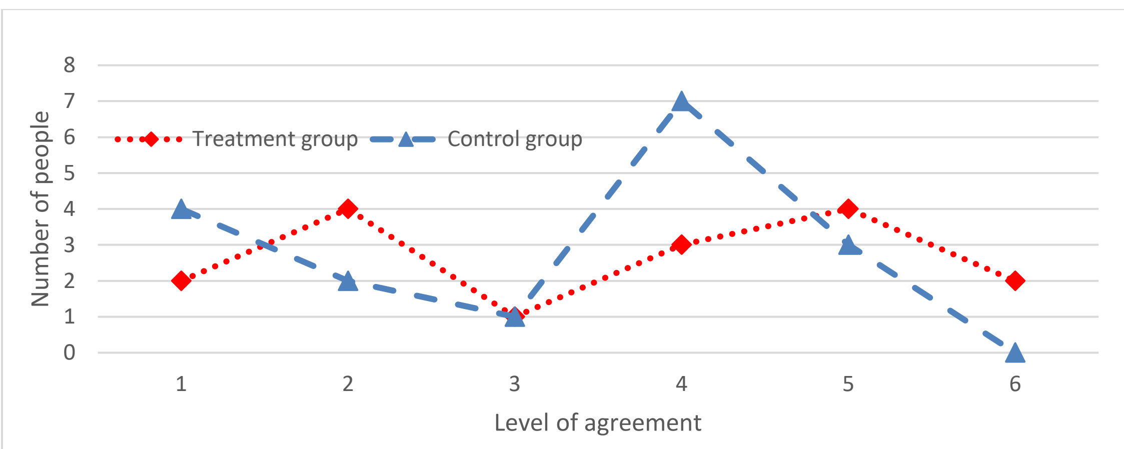

Figure 12 - Participants' ratings of the unsafe feeling of being too close to the virtual fire.

Figure 13 illustrates the distribution of agreement levels between the two test groups regarding the heat perception from the virtual fire. The control group had a mode of "1-Strongly disagree," with 8 participants selecting this option. The treatment group showed a bimodal distribution with a mode of "4-Slightly agree" with 7 participants selecting this option and a second peak at "2-Disagree" with 6 participants selecting this option. The trend lines suggest that the distributions between the two groups are highly dissimilar. None of the participants in the treatment group selected higher than "5- Agree" option, most of the qualitative feedback indicated that the heat experienced was weaker than expected. In contrast, 3 participants in the control group explicitly stated that they felt the heat during the experiment and selected "5-Agree." The reasons for this phenomenon was discussed in the next chapter.

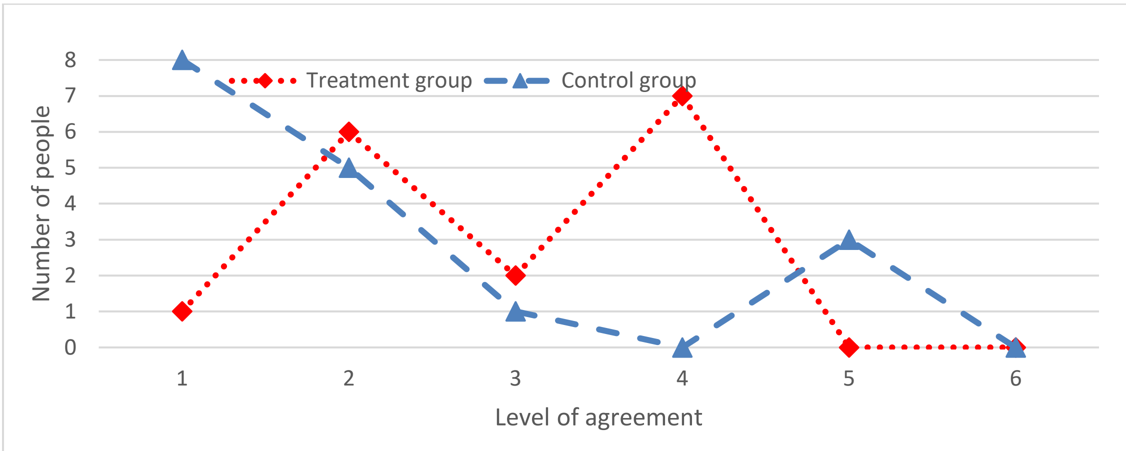

Figure 13 - Participants' ratings of the heat perception during the VR experiment

Based on the distribution differences of the three indicators between the two groups, the mode positions of the treatment group were consistently higher than those of the control group. This could be interpreted as a slight positive effect of using subject-expectancy bias on participants' perceived realism and immersion in the VR experiment.

Table 4 presents the question 9 result in the questionnaire, where participants were asked to identify the factors in the virtual fire that made them reluctant to approach closer, including flame, sound, smoke, and heat elements. The value is the ratio of the amount of participant who selected the factor within the group to the total amount of participants in the group. The results showed that the treatment group data has a higher ratio for “Flame”, “Sound” and “Smoke” compared to the control group. However, the ratio of participants who perceived the temperature change as a risk was similarly low in both groups. Notably, participant no.31 indicated that the special effect of "distortion" was the primary contributor to her perception of danger in the virtual fire scenario.

Table 4 - Factor Selection Ratio between The Two Test Group for Question 9

Group	Flames	Sound	Smoke	Heat
Treatment	1	0.56	0.43	0.19
Control	0.82	0.41	0.35	0.18

A correlation analysis was conducted on the VR experiences and video gaming frequency of the participants, based on their test groups and responses to Question 6. And 7. Table 5 presents the correlation coefficients for individual categories among all participants, the treatment group, and the control group. In Table 5, "VR" refers to VR experiences, while "Game" refers to video gaming frequency, and "Realism" and "Unsafe" are the same as in the previous table. Although all values show only weak correlations, it was observed that in the control group, gaming experience was negatively correlated with perceived realism, consistent with the trend identified in "The Gamer group" in Arias's review [1]. However, such negative correlation was not observed in the treatment group, which showed slightly increased correlation in the category related to VR experience and perceived unsafe feeling. This suggests that the subject-expectancy effect may have potentially improved the perceived realism and immersion for those with VR experience or high video gaming frequency.

Table 5 - Correlations with VR Experience and Video Gaming Frequency for Perceived Realism and Unsafe feeling

Total	**Correlation coefficient**	**Realism**	**Unsafe**
	VR	0.0394	0.2268
	Game	-0.1512	-0.0629
Treatment	**Correlation coefficient**	**Realism**	**Unsafe**
	VR	0.0817	0.3465
	Game	0.0158	-0.0768
Control	**Correlation coefficient**	**Realism**	**Unsafe**
	VR	-0.0525	0.0828
	Game	-0.3693	-0.0647

3.4. Statistical result

The following statistical analysis is based on the collected safe distance data transformed into one-dimensional distance, and the results of the questionnaire survey are quantified as numbers according to different degrees for ease of calculation. With the obtained data, six Mann-Whitney U tests were performed to evaluate the subject-expectancy effect's influence on fire threat perception in VR. Thus, four null hypotheses have been stated, with three distance cases sharing the same null hypotheses.

- H_0 = The use of the subject-expectancy effect has no influence on the perceived realism in the VR scenario.
- H_0 = The use of the subject-expectancy effect has no influence on the unsafe feeling perceived as approaching too close to the virtual fire.

- H_0 = The use of the subject-expectancy effect has no influence on the heat perception from the virtual fire.

- H_0 = The use of the subject-expectancy effect has no influence on the judgment of safe distance maintaining from the virtual fire.

Table 6 presents the means, standard deviations, U-values, z-scores, and p-values of the three positions and quantitative questionnaire results between treatment group and control group. The three titles "Realism, Unsafe, and Heat" from the question 6, 7 and 8 in the questionnaire representing the immersive, presence and heat feeling of participants perceived in the VR experiment were to assist evaluating fire threat perception. The titles named "Large, Medium, and Small" refer to the scale of the virtual fire, and the values stand for participants' cognitive safe distance from the specific scale virtual fire.

Table 6 - Mean, Standard Deviation, and Results of Mann-Whitney U Test for Two Test Groups

Group		Realism	Unsafe	Heat	Large	Medium	Small
Treatment	**mean**	4.4375	3.5625	2.9375	1.935967	1.559338	1.20992
	std dev	1.314978	1.711481	1.062623	0.710878	0.561961	0.401625
Control	**mean**	3.823529	3.176471	2.117647	1.724855	1.447491	1.271715
	std dev	1.286239	1.509772	1.49509	0.581017	0.432201	0.430844
	U	95.5	144	80	111	122	126
	z	-1.44088	-0.77447	-1.99922	-0.88254	-0.4863	0.34221
	p	0.14986	0.4413	0.0455	0.37886	0.62414	0.72786

From the table, there was no significant difference observed for "realism" category, U= 95.5, p= .150, despite the ranking among treatment group (M = 4.438, SD = 1.315) attaining higher than control group (M = 3.824, SD = 1.286); and similar case with "unsafe" category, U= 144, p= 0.441. However, for "Heat" category heat perception, U= 80, the critical value of U at p< .05 is 81, the result is significant.

Figure 14 highlights the differences between the two test groups using boxplots. Notably, the treatment group exhibited distinct features in heat perception, as well as slightly higher data in the other two categories compared to the control group.

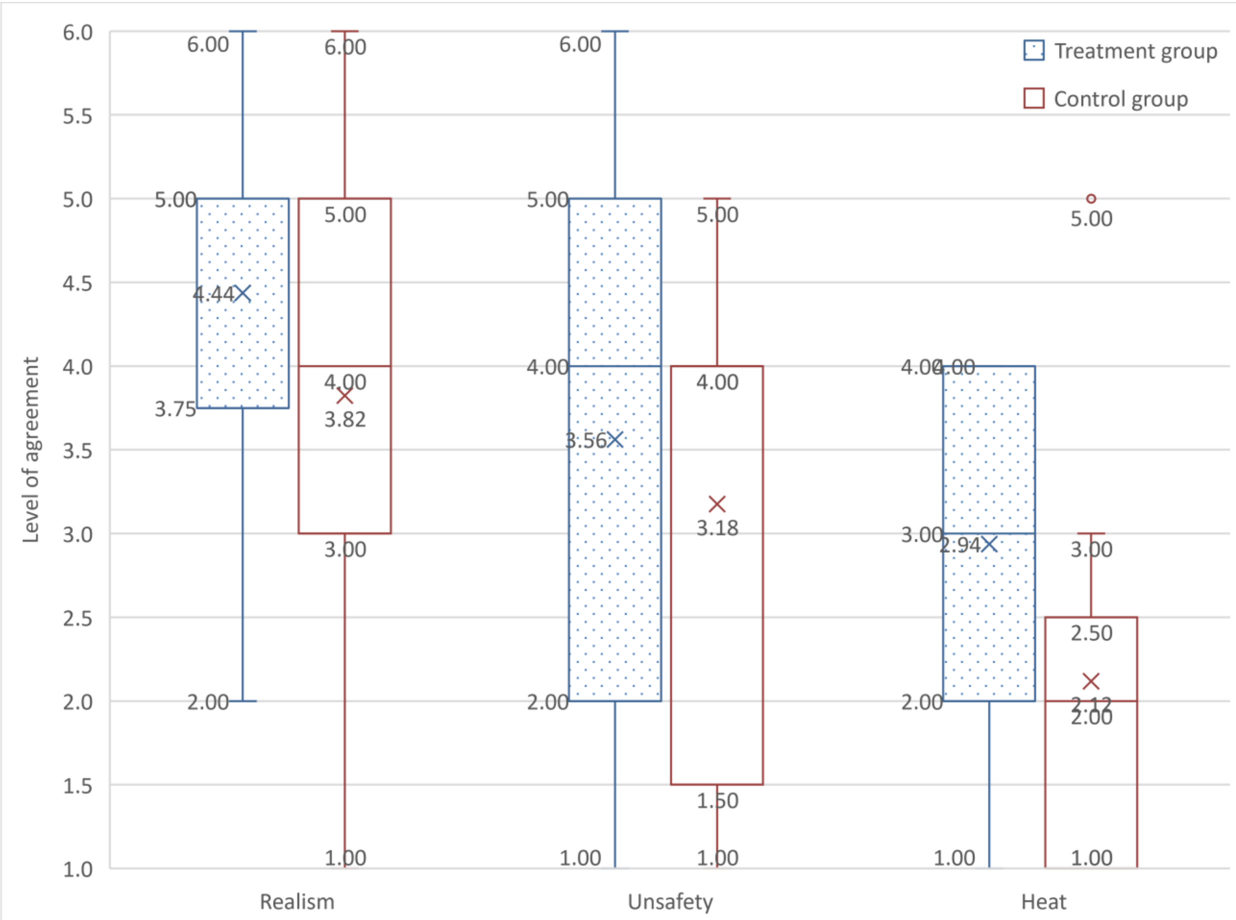

Figure 14 - Boxplot for the ranking data between the two test groups

In Table 4, the safe distances from the three scales of virtual fire categories were compared using the Mann-Whitney U Test. All U values exceeded the critical value of 81, indicating no significant difference among the three cases. However, the mean distance from large and medium scale virtual fires was higher in the treatment group than in the control group, although with a larger standard deviation. This difference may be attributed to the presence of a few extreme values in the treatment group. Boxplots depicted in Figure 15 revealed that the treatment group had slightly higher upper and lower outliers than the control group for all three virtual fire scales. It is noteworthy that the mean distance from small fires was lower in the treatment group than in the control group, indicating that the treatment group had most position data concentrated at a closer distance compared to the control group. This finding could suggest that the subject-expectancy effect may not have effectively enhanced the perception of small fires, as participants may have approached the flames at extremely close distances, leading to a breakdown of immersion.

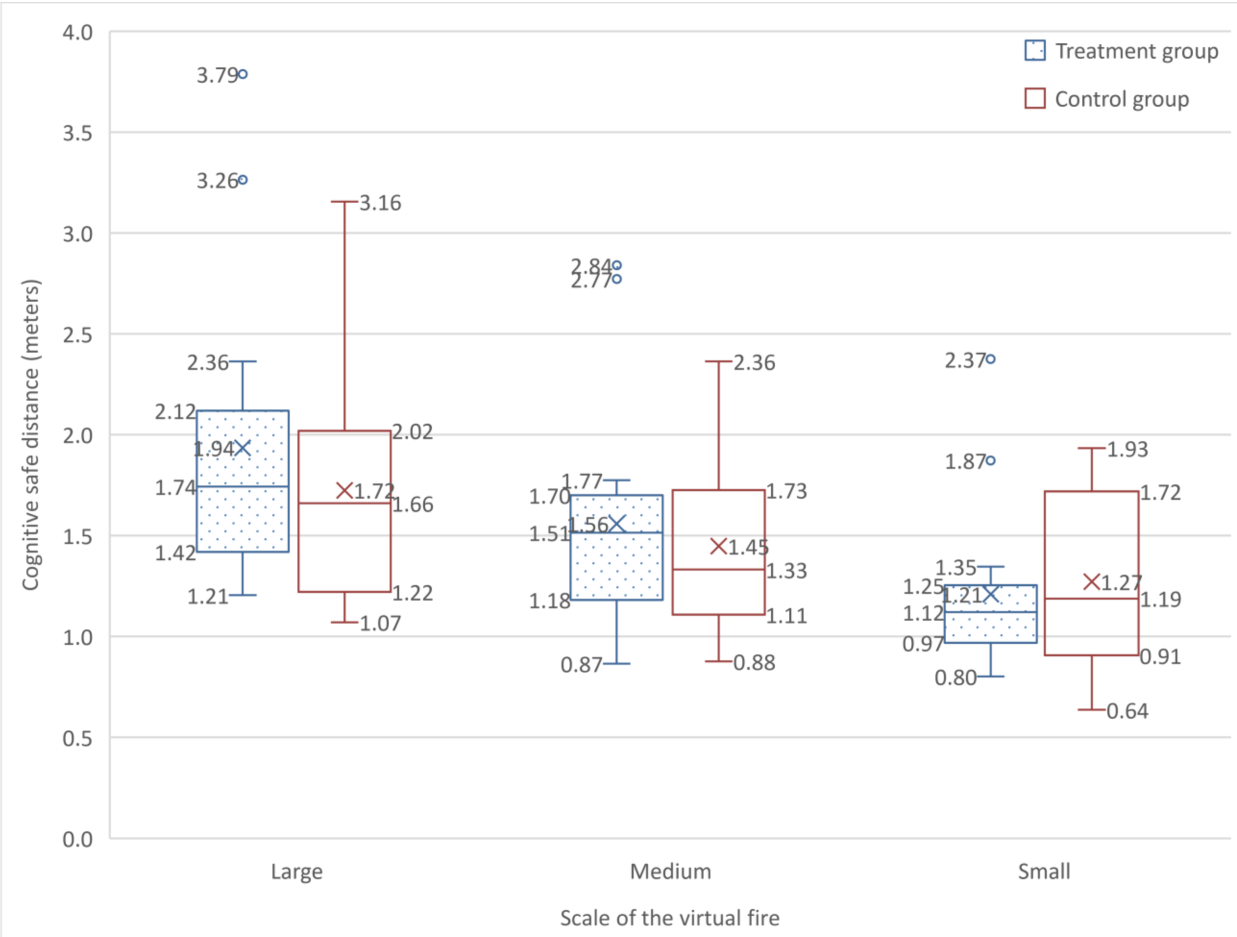

Figure 15 - Boxplot for the one-dimensional safe distance from three scales of virtual fire between the two test groups

3.5. Other relationships

Participants could also be classified with fire-related background owing or not, as shown in Table 1. Table 7 displays the results of the Mann-Whitney U tests performed based on this categorization, testing the following null hypothesis:

- H_0 = With fire related background in education or occupation has no influence on the perceived realism in the VR scenario.
- H_0 = With fire related background in education or occupation has no influence on the unsafe feeling perceived as approaching too close to the virtual fire.
- H_0 = With fire related background in education or occupation has no influence on the heat perception form the virtual fire.

- H_0 = With fire related background in education or occupation has no influence on the judgment of safe distance maintain from the virtual fire.

The critical value of U at p< .05 is 78 for the six tests, and no significant statistical difference is confirmed, shown in Table 7.

Table 7 - Mean, Standard Deviation, and Results of Mann-Whitney U test between Participants with and without Fire-related Background

Background	N14Y19	Realism	Unsafe	Heat	Large	Medium	Small
Not fire related	**mean**	4.142857	3.571429	2.285714	2.04249	1.639054	1.329001
	std dev	1.231456	1.554858	1.382783	0.857923	0.639271	0.518383
Fire related	**mean**	4.105263	3.210526	2.684211	1.668587	1.400527	1.177466
	std dev	1.410072	1.652572	1.335525	0.383952	0.338097	0.311143
	U	132.5	113	108	107	108	116
	z	0	-0.71031	0.89243	-0.92886	-0.89243	-0.60103
	p	1	0.4777	0.37346	0.35238	0.37346	0.5485

Despite no statistical differences upon grouping the data based on participants' fire-related background, another examination revealed that those with a fire-related background exhibited a more concentrated data pattern with safe distance judgments from all three scales of the virtual fire. Boxplots depicting this data pattern are shown in Figure 16, illustrating that the second and third quartile lengths of the data for all three fire scales were obviously smaller for participants with a fire-related background than those without, and the mean of safe distances for all three fire scales were consistently smaller for the former group. Therefore, it could be inferred that the fire-related background has a slight influence for concentration on safe distance judgment, likely attributable to the experience gained from previous real-life experiments, resulting in more focused distance judgments.

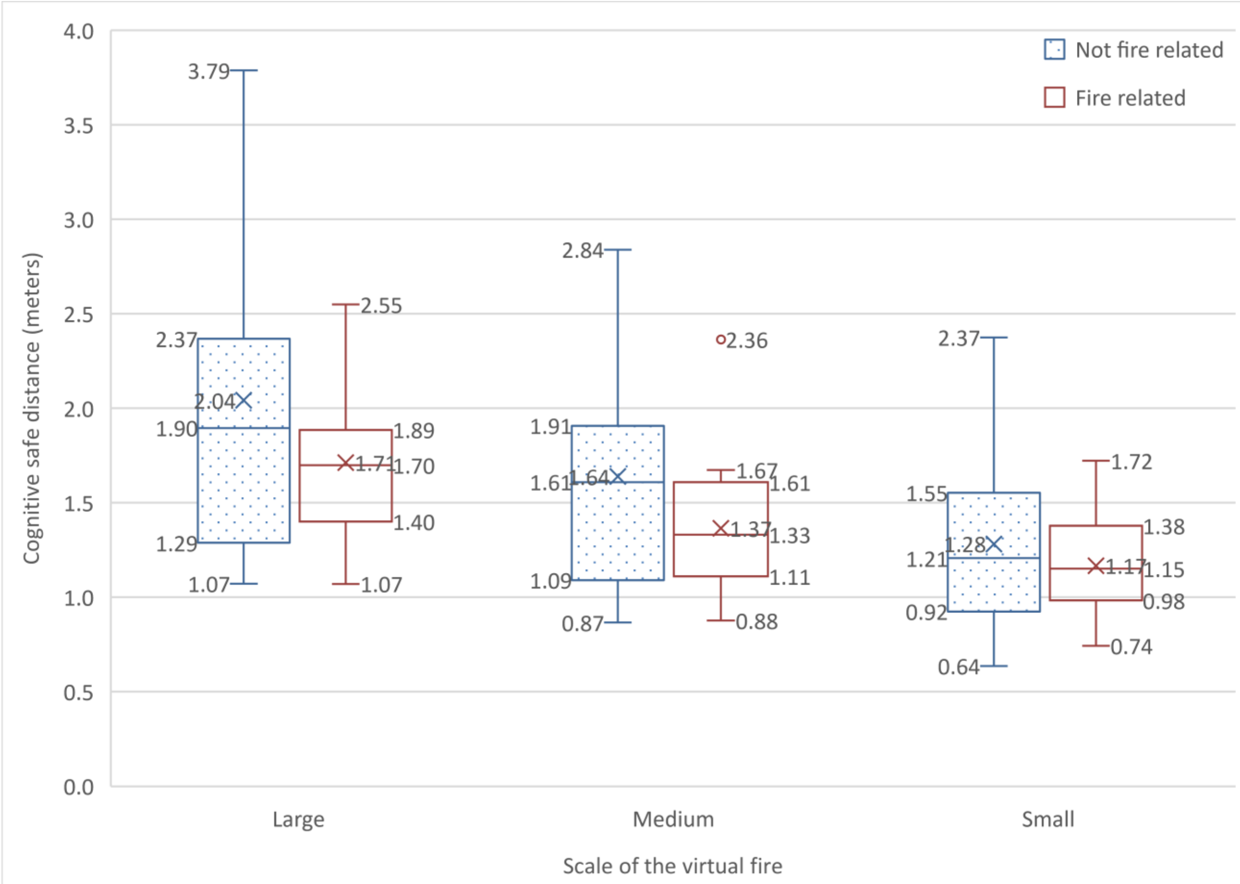

Figure 16 - Boxplot for the one-dimensional safe distance from three scales of virtual fire between Participants with and without Fire-related Background.

Participants could be classified based on their prior experience of approaching flames of similar size in real life. Table 8 reports the mean and standard deviation values for the different groups, which did not show significant differences between the groups. Hence, no further statistical tests, such as the Mann-Whitney U test, were deemed necessary.

Table 8 - Mean, Standard Deviation, and Results of Mann-Whitney U test between Participants with and without Similar Fire Approaching Experience.

Fire Experience	N9Y24	Realism	Unsafe	Heat	Large	Medium	Small
No	mean	4.222222	3.777778	2.222222	1.892066	1.439808	1.186795
	std dev	1.394433	1.394433	1.20185	0.679782	0.574221	0.464876
Yes	mean	4.083333	3.208333	2.625	1.802893	1.524937	1.262363
	std dev	1.316011	1.667572	1.408437	0.646057	0.4729	0.398627

3.6. Qualitative results

In addition to quantitative data, the participants in this experiment also provided qualitative feedback to the researcher. The following table represents the sorted reflections excerpted from the responses of the participants in the questionnaire.

Table 9 - Collected Reflections from The Questionnaire

Treatment group
1. The heat wasn't an issue, but visually felt like I was getting too close. – No. 4 2. I thought I wore too many clothes to feel the heat. – No. 10 3. The thermal radiation was not strong enough, I can feel a little bit but not too much. – No. 23
Control group
1. I feel a little heat at first when seeing the fire, but then realize it is illusionary, and the heat disappear. – No. 11 2. The instruction 'connecting to real life situation' made me think I should receive a bit radiant heat even 'no radiant heat device is involved' has been told. – No. 14 3. I stopped when I felt the heat. – No. 20 4. The intensity of the illusionary heat doesn't vary with the scale of fire. – No. 21 5. Approaching while standing or crouching made the willing and distance to approach the fire feel different. This is based on previous real-life experience. – No. 22 6. The lack of heat largely reduced the realism of the experiment. – No. 27

The results obtained from the treatment group's collection of qualitative feedback and quantitative data were consistent. Specifically, three participants from the treatment group provided qualitative feedback that was related to the low thermal radiation intensity during the experiment. Other participants in the treatment group were verbally asked and confirmed by the researcher about the reasons for their responses after completing the questionnaire. Linking back to the Table 3, those who selected "Slightly agree" on the heat perception mostly felt that the heat radiation intensity was insufficient, while those who chose "Slightly disagree" reported an inability to confirm the perception of thermal radiation. For those who chose "Disagree" and "Strongly disagree", they all agreed that they did not or hardly sense the heat radiation in the experiment.

In contrast, the control group's qualitative responses varied. The first comment described the process of triggering an illusionary heat sensation, which would be further explored in the subsequent chapter. The second comment, from participant No. 14, indicated a mild heat sensation, whereas three other participants No. 16, 20, 21, reported feeling thermal radiation without doubt. Feedback from participants No. 20 and 21 accounted for the third and fourth comments, respectively. However, the remaining participants either disagreed or strongly disagreed with the presence of thermal radiation. The fifth feedback was influenced by the participant's background in fire engineering, thereby reflecting his personal experiences. The sixth feedback suggested that the absence of thermal radiation feedback compromised the sense of presence during the experiment and consequently reduced the perceived realism of VE.

4. Discussion

This chapter would discuss the experimental methods used and interpret the results obtained in this study.

4.1. Experiment design

The experiment suffered from not being able to recruit a large number of participants. This resulted in a small sample size, which may have affected the overall reliability of the results and conclusion due to the potential impact of individual extreme samples. The issue is observed in Figure 10 and Table 6, where the mean safe distance and the standard deviation of the treatment group for the large and medium scale fire cases was higher due to the influence of few outlier samples. While this may be interpreted as the subject-expectancy effect was significant for minority (the outlier samples in the treatment group were identified as participants no. 0 and no. 8, both reporting feeling heat from the virtual flame during the experiment), it cannot determine that extreme deviations of cognitive safe distance from the virtual fire were caused by only the subject-expectancy effect. Drawing such a conclusion would be subjective.

The interpretation of the results is constrained by the homogeneity of the samples. All participants in the experiment were faculty members and students from Lund University. Since, it is debatable whether a similar result could be obtained if the participants were selected from the population in society with random sampling for more diverse background and ages range. Moreover, the recruitment methods used for the experiment, such as distributing flyers or posting announcements, tended to attracting participants who were interested in VR, which could further question the representativeness of the sample to the population, reducing the external validity [29]. The impact of the mentioned characteristics of the participants on the results remains to be investigated.

Apart from the participants, the essence of the experiment is to utilize the subject-expectancy effect as a manipulated variable to influence the experimental results. However, it is necessary to consider the potential influence of the observer-expectancy effect [32], a concept opposite to the subject-expectancy effect in behavioral psychology research. As the thesis has only one researcher, it is not possible to conduct a double-blind experiment design to reduce the potential impact of the researcher's behavior or language during the experiment on the participants' performance and feedback. This may lead to a strong deviation of the research results from the original values and misleading the following interpretation of the results, reducing the internal validity.

4.2. Result interpretation

In terms of the qualitative feedback, it was observed that not all participants who reported feeling heat were necessarily influenced by the manipulated variables. In Table 9, one participant in the control group explained that she felt heat due to visual cues, as she saw the fire appearing in the virtual scenario, which caused an automatic perception of heat on her skin. This phenomenon can be linked with Synesthesia in psychology [33], where stimulation of one sensory or cognitive pathway leads to involuntary experiences in a second sensory or cognitive pathway. The proportion of participants who reported experiencing this was reasonable, with 3 out of 33 participants reporting this phenomenon. Therefore, it is possible that some participants may have been slightly affected by Synesthesia during the experiment, and this should be taken into consideration when interpreting the results.

Observation from Figure 14 indicates that there is a slight positive influence of the subject-expectancy effect on the realism and presence of the VR fire scenario, but the influence is not statistically significant. The only statistically significant impact demonstrated among the six categories in Table 6 is the heat perception category.

The safety distance over three scales data in Table 6 suggests that subject-expectancy effects may have different effects on virtual fires of different scales. For small scale virtual fire, participants may walk closer with the expectation to experience the radiation heat, which could explain why the mean safe distance of the small-scale fire treatment group in Table 6 is slightly lower than that of the control group.

It is worth mentioning that Table 4 shows the ratio difference regarding the factors in the virtual fire between the two test groups, which could be explained as using subject-expectancy effect may potentially enhance other sensory perceptions through the illusionary heat in participants' mind. However, the claim lacks the analysis on the perception level, further research is required for the relationship being confirmed certainly. Question 9. should be designed as four ranking questions as Question 6. to 8., these may help with increasing the validity of the results.

The analysis of results also involved an examination of participants' backgrounds and experiences. Although Table 6 did not reveal any statistical differences, the results displayed in Figure 16 indicated that participants with a fire-related background tended to have a more concentrated distribution of safe distances. It is worth noting that the statistical tests employed in this study were limited to examining whether the means of the populations in two groups were equivalent; therefore, this effect could not be verified through the Mann-Whitney U test [31].

With respect to the examination based on experiences with and without approaching similar scale fires in real life, no significant findings were observed between the two groups. However, in the open discussions with the participants, the researcher found that the experience sources could be fire engineering background with similar pool fire experiments for laboratory course; traditional bonfires during the Swedish festival Walpurgis Night in Lund, where the experiment was conducted; Chinese cultural background with burning joss paper as an ancestor worship tradition and so on. The diversity of experience sources in this grouping resulted in a low level of similarity within the group, making it difficult to detect any differences with the U test.

Overall, the result presented above cannot be objectively interpreted as evidence of the use of the subject-expectancy effect on enhancing the fire threat perception in VR, but it explicitly affects the heat sensation of the participants as the significant statistical difference confirmed in the heat sensation category within a such small sample size. It can be concluded that it might have a slight benefit in enhancing the realism of the VR scenario. Moreover, the experiment lacked comparison with data from a group that experienced real heat radiation, making it difficult to determine whether the application of the subject-expectancy effect in the scenario had a positive or negative impact on safe distance judgments. If the result of using real thermal radiation group were similar with the result of fire-related background group in Figure 16 obtaining a more concentrated distribution instead of showing a different mean, this could lead to applying the subject-expectancy effects in specific studies of VR scenarios that may yield results that are more in line with reality than using low-intensity thermal radiation device in experiments.

5. Conclusions

In conclusion, the study examined the effect of the subject-expectancy on enhancing fire threat perception in VR. While the qualitative feedback indicated that some participants reported feeling heat due to visual cues or synesthesia, the statistical analysis did not show a significant impact of the subject-expectancy effect on most categories, except for heat perception. The study also found that subject-expectancy effect may have different effects on virtual fires of different scales and that participants with a fire-related background tended to have a more concentrated distribution of safe distances. However, the study lacked comparison with data from a group that experienced real heat radiation, making it difficult to determine whether the application of the subject-expectancy effect in the scenario had a positive or negative impact on safe distance judgments. Therefore, the study's result cannot be objectively interpreted as evidence of the use of the subject-expectancy effect on enhancing the fire threat perception in VR, but it may have a slight benefit in enhancing the realism of the VR scenario.

However, the experiment suffered from several limitations that may have affected the reliability and validity of the results and the result interpretation. The small sample size has led to a great impact from individual extreme samples, which can influence the overall results. Moreover, the homogeneity of the sample, recruitment methods, and participants' characteristics raise questions about the representativeness of the results to the wider population. Additionally, the potential influence of the researcher-expectancy effect was not controlled, which can lead to a deviation from the original values and reduced internal validity. Therefore, the limitations of the experiment need to be acknowledged, and future studies should consider these factors to obtain more robust results. Further research is required to obtain more conclusive evidence on the subject-expectancy effect on enhancing fire threat perception in VR.

Acknowledgements

I would like to thank the following people for their help with this thesis. Without their help this thesis cannot be completed

First, I would like to thank my supervisor, Jonathan Wahlqvist, for his invaluable guidance and support throughout my thesis journey particularly with C# programming and experiment design.

I would also like to thank my friend Carlos, for being the first Guinea Pig in my experiment and for helping me to prepare for my job interviews, which gave me more time to focus on my thesis.

I am also grateful to my dormmates Daisy, Feiyu, Mio, and Xu for their inspiration and participation in my prototype experiment.

Furthermore, I would like to acknowledge my friend Jia Wei for his oversea support during times when I was feeling down. His encouragement and positive energy were always able to cheer me up.

Finally, I would like to express my great gratitude to my parents for their love and financial support, which enabled me to participate in the program without any worries. Thank you for encouraging me to pursue my dreams.

References

[1] S. Arias, J. Wahlqvist, D. Nilsson, E. Ronchi, H. Frantzich, Pursuing behavioral realism in Virtual Reality for fire evacuation research, Fire Mater. 45 (2021) 462–472. https://doi.org/10.1002/fam.2922.

[2] H. Khan, Fire Smell in Virtual Reality - Why Include It?, (2022).

[3] M. Gumaa, A. Khaireldin, A. Rehan Youssef, Validity and Reliability of Interactive Virtual Reality in Assessing the Musculoskeletal System: a Systematic Review, Curr. Rev. Musculoskelet. Med. 14 (2021) 130–144. https://doi.org/10.1007/s12178-021-09696-6.

[4] M. Kinateder, E. Ronchi, D. Nilsson, M. Kobes, M. Müller, P. Pauli, A. Mühlberger, Virtual Reality for Fire Evacuation Research, in: 2014: pp. 313–321. https://doi.org/10.15439/2014F94.

[5] S. Arias, E. Ronchi, J. Wahlqvist, J. Eriksson, D. Nilsson, ForensicVR: Investigating human behaviour in fire with Virtual Reality, LUTVDG/TVBB. 3218 (2018) 38.

[6] Olfaction for Virtual Reality, (1999). http://www.hitl.washington.edu/people/tfurness/courses/inde543/reports/3doc/ (accessed April 12, 2023).

[7] S. Bae, J.-H. Choi, C. Kim, W. Hong, H.S. Ryou, Development of new evacuation model (BR-radiation model) through an experiment, J. Mech. Sci. Technol. 30 (2016) 3379–3391. https://doi.org/10.1007/s12206-016-0647-y.

[8] S. Zhang, N. Zhu, S. Lu, Responses of human perception and skin temperature to directed thermal radiation in hot environments, Build. Environ. 197 (2021) 107857. https://doi.org/10.1016/j.buildenv.2021.107857.

[9] N. Arslanoglu, A. Yigit, Experimental and theoretical investigation of the effect of radiation heat flux on human thermal comfort, Energy Build. 113 (2016) 23–29. https://doi.org/10.1016/j.enbuild.2015.12.039.

[10] A. Blomander, Investigating the use of radiative heat panels to enhance perceived threat of fire in VR, (2020).

[11] G. Lawson, E. Shaw, T. Roper, T. Nilsson, L. Bajorunaite, A. Batool, Immersive virtual worlds: Multi-sensory virtual environments for health and safety training, (2019). https://doi.org/10.48550/arXiv.1910.04697.

[12] M. Kocur, L. Jackermeier, V. Schwind, N. Henze, The Effects of Avatar and Environment on Thermal Perception and Skin Temperature in Virtual Reality, in: Proc. 2023 CHI Conf. Hum. Factors Comput. Syst., ACM, Hamburg Germany, 2023: pp. 1–15. https://doi.org/10.1145/3544548.3580668.

[13] B. Horing, N.D. Newsome, P. Enck, S.V. Babu, E.R. Muth, A virtual experimenter to increase standardization for the investigation of placebo effects, BMC Med. Res. Methodol. 16 (2016) 84. https://doi.org/10.1186/s12874-016-0185-4.

[14] S. Bell, Experimental Design, in: R. Kitchin, N. Thrift (Eds.), Int. Encycl. Hum. Geogr., Elsevier, Oxford, 2009: pp. 672–675. https://doi.org/10.1016/B978-008044910-4.00431-4.

[15] O. Staadt, The Ultimate Display, (1965). http://worrydream.com/refs/Sutherland%20-%20The%20Ultimate%20Display.pdf (accessed April 12, 2023).

[16] N.C. Burbules, Rethinking the Virtual, in: J. Weiss, J. Nolan, J. Hunsinger, P. Trifonas (Eds.), Int. Handb. Virtual Learn. Environ., Springer Netherlands, Dordrecht, 2006: pp. 37–58. https://doi.org/10.1007/978-1-4020-3803-7_1.

[17] K. Tarkkanen, A. Lehto, D. Oliva, B. Somerkoski, T. Haavisto, M. Luimula, Research Study Design for Teaching and Testing Fire Safety Skills with AR and VR Games, in: 2020

11th IEEE Int. Conf. Cogn. Infocommunications CogInfoCom, 2020: pp. 000167–000172. https://doi.org/10.1109/CogInfoCom50765.2020.9237831.
[18] A. Moreno, S. Zlatanova, B. Bucher, J. Posada, C. Toro, Semantic Enhancement of a Virtual Reality Simulation System for Fire Fighting, in: 2011. https://shs.hal.science/halshs-02435333 (accessed April 24, 2023).
[19] M. Cha, S. Han, J. Lee, B. Choi, A virtual reality based fire training simulator integrated with fire dynamics data, Fire Saf. J. 50 (2012) 12–24. https://doi.org/10.1016/j.firesaf.2012.01.004.
[20] C. Lu, Y. Zhang, C. Liu, Y. Li, Design of the Fire Evacuation Training System for Underground Buildings Based on VR, in: 2021 4th Int. Conf. Adv. Electron. Mater. Comput. Softw. Eng. AEMCSE, 2021: pp. 921–924. https://doi.org/10.1109/AEMCSE51986.2021.00187.
[21] S. Arias, S. La Mendola, J. Wahlqvist, O. Rios, D. Nilsson, E. Ronchi, Virtual Reality Evacuation Experiments on Way-Finding Systems for the Future Circular Collider, Fire Technol. 55 (2019) 2319–2340. https://doi.org/10.1007/s10694-019-00868-y.
[22] S. Arias, A. Mossberg, D. Nilsson, J. Wahlqvist, A Study on Evacuation Behavior in Physical and Virtual Reality Experiments, Fire Technol. 58 (2022) 817–849. https://doi.org/10.1007/s10694-021-01172-4.
[23] B.K. Wiederhold, M.D. Wiederhold, Virtual reality treatment of posttraumatic stress disorder due to motor vehicle accident, Cyberpsychology Behav. Soc. Netw. 13 (2010) 21–27. https://doi.org/10.1089/cyber.2009.0394.
[24] D. Mobbs, C.C. Hagan, T. Dalgleish, B. Silston, C. Prévost, The ecology of human fear: survival optimization and the nervous system, Front. Neurosci. 9 (2015) 55. https://doi.org/10.3389/fnins.2015.00055.
[25] Ethical review | Staff Pages, (2023). https://www.staff.lu.se/research-and-education/research-support/research-ethics-and-animal-testing-ethics/ethical-review (accessed April 24, 2023).
[26] E. Chang, H.T. Kim, B. Yoo, Virtual Reality Sickness: A Review of Causes and Measurements, Int. J. Human–Computer Interact. 36 (2020) 1658–1682. https://doi.org/10.1080/10447318.2020.1778351.
[27] L.R. Gay, P.L. Diehl, Research Methods for Business and Management, Macmillan Publishing Company, 1992.
[28] G.E. Noether, Sample Size Determination for Some Common Nonparametric Tests, J. Am. Stat. Assoc. 82 (1987) 645–647. https://doi.org/10.2307/2289477.
[29] I. Etikan, Sampling and Sampling Methods, Biom. Biostat. Int. J. 5 (2017). https://doi.org/10.15406/bbij.2017.05.00149.
[30] P. Lietz, Research into Questionnaire Design: A Summary of the Literature, Int. J. Mark. Res. 52 (2010) 249–272. https://doi.org/10.2501/S147078530920120X.
[31] H.B. Mann, D.R. Whitney, On a Test of Whether one of Two Random Variables is Stochastically Larger than the Other, Ann. Math. Stat. 18 (1947) 50–60. https://doi.org/10.1214/aoms/1177730491.
[32] E.B. Goldstein, Cognitive psychology: connecting mind, research, and everyday experience, 3rd ed, Wadsworth Cengage Learning, Australia : Belmont, CA, 2011.
[33] K.S. Suslick, Synesthesia in science and technology: more than making the unseen visible, Curr. Opin. Chem. Biol. 16 (2012) 557–563. https://doi.org/10.1016/j.cbpa.2012.10.030.

Appendix A – Questionnaire

Age:

Gender:

Answer the following questions by ticking the most applicable option.

1. Did you feel discomfort during the experiment?

(If yes please specify what kind of discomfort, like nausea, dizziness, physical pain, trauma…etc)

☐No ☐ Yes, I felt ____________________

2. Is your education/career field related to fire safety?

☐Yes ☐No

3. Have you ever used Virtual Reality before?

☐ This is my first-time trying a scenario with VR equipment.

☐ I have tried VR 1-3 times before.

☐ I have tried VR 4-10 times before.

☐ I have tried VR more than 10 times.

☐ More than 10 times, and experience VR on a regular basis.

4. Do you play video games on any platforms (PC, consoles, mobile…etc.)?

☐ I don't/rarely play video games.

☐ I do, but usually less than 1 hour in a week.

☐ I do, and usually 1-7 hours in a week.

☐ I do, and usually more than 7 hours in a week.

5. Have you experienced a similar or larger fire from a similar distance as in the simulation in real life?

☐ Yes ☐ No/only a smaller fire/ a longer distance.

6. Overall, the realism of the simulation was high.

☐Strongly disagree ☐Disagree ☐Slightly disagree ☐Slightly agree ☐Agree ☐Strongly agree

7. I felt getting too close to the fire might be unsafe during the experiment.

☐Strongly disagree ☐Disagree ☐Slightly disagree ☐Slightly agree ☐Agree ☐Strongly agree

8. I felt the heat from the fire during the experiment.

☐Strongly disagree ☐Disagree ☐Slightly disagree ☐Slightly agree ☐Agree ☐Strongly agree

9. Select any factor that made you less willing to approach the fire during the experiment:

☐The flames

☐The sound from the fire

☐The smoke

☐The heat from the fire

☐Other: _______

10. Other reflections if you have:

Appendix B – Consent information

This document contains information about an experiment using Virtual Reality to be conducted as part of a thesis written at LTH, Lund University, Sweden.

1. Background and purpose

Virtual Reality (VR) has been broadly used for entertainment, gaming and even educational and training purposes. In recent years VR have been applied as a research method of human behavior.

In this experiment participant will be exposed to a realistic scenario in VR. The purpose of the experiment is to investigate peoples experience and behavior in this virtual environment. The full scenario, purpose and objective will not be revealed beforehand, as this might affect the outcome of the experiment.

2. Call for participants

You have been selected to participate in the experiment because you volunteered to take part in it. Your participation is completely voluntary, i.e. you only participate if you want to, and you can withdraw your participation at any point.

3. How does it work?

You will be equipped with a VR helmet (head mounted display), which consists of two screens, one for each eye. When different images are shown on those screens, a slight offset between the images allows you to have a 3D view of the virtual surroundings. You will be able to move around in the virtual environment. This would allow you to experience the VR environment as if you were physically there. You will use hand controllers to interact with the environment. During the experiment, you are expected to interact, make decisions and behave as you would do in the real world.
A researcher will be with you during the whole experiment. You can stop the experiment immediately and at any point by signal the researcher if you would like to do so. The researcher will help you to remove the equipment right away.

After the experiment, you will fill in a questionnaire with background questions and questions about the experiment.

4. What are the risks?

Since this experiment is about natural behavior, for experimental reasons it is not possible to disclose fully each aspect of the experiment until after you have participated. However, it is our duty to provide information about all reasonable risks you must be aware of before you decide to participate or not:

Some volunteers might feel anxious or stressed out for not knowing what exactly we are looking into. If you have any sort of mental disorder or physical condition that might be triggered by being anxious or affect you in some way during the experiment, you must notify the researcher about it before taking part in the experiment. The researcher might then refuse to take you as a participant. Examples of these disorders and conditions include, but are not restricted to: epilepsy, heart conditions, asthma, anxiety disorders, stress-related disorders and phobias.

The experiment will involve variations in the physical environment. These variations of the physical environment may not be the same for every participant. Variations can include differences in temperature, such as heating or cooling, or other physical stimuli such as wind or smell. In these cases, safety measures have been taken to make sure that these variations do not cause discomfort or risk of injury. There is a small risk of malfunction, for example technical issues with a heat source, which in this case could cause participants to be exposed to more heat than intended. The researcher in the room will interrupt the experiment if any malfunction is noticed. If you feel uncomfortable or threatened before or during the experiment, you will have the right to interrupt it at any point without giving any reasons, and you can also withdraw your participation after finishing it.

You will not be in contact with the heat source, but you could experience low levels of thermal radiation. These low levels can be similar to exposure to sunlight on a warm summer day. It is unlikely that exposure to these thermal radiation levels could lead to irritation of the skin or first-degree burns, especially since the exposure to them will not be longer than 10 minutes. If you feel uncomfortable or threatened before or during the experiment, you will have the right to interrupt it at any point without giving any reasons, and you can also withdraw your participation after finishing it.

There is a risk of feeling motion sickness or dizziness when you are in the virtual environment. If you feel dizzy, there is always a risk of losing balance and falling. Therefore, you should tell the researcher when you start feeling motion sickness or dizziness. The researcher will help you to remove the equipment and to get some water for you to drink if you would like some. Sometimes participants feel better when they close their eyes when sitting down to counteract the nausea.

The experimental room will have a designated area in which the experiment will be performed. You will be instructed stay in the designated area, but you are allowed to wave your hands, crouch, or turn around as you please. However, even though the experiment will be performed stationary there is a risk of losing balance and fall. As you will be standing on the floor, the fall cannot be especially dangerous.

5. Are there any benefits?

Benefits relate to the possibility to experience Virtual Reality technology and understand the interaction that we can have with virtual environments.

6. Handling the data

The data presented in the final report will be encoded, and it will not be possible to identify you in it. Your contact information will be saved for up to 6 months, but it will not be connected to the collected data in any way. The contact information is saved in case we need to contact you after the experiment to check on you if you experienced discomfort.

7. How do I get information about the experiment results?

The result of the experiment will later be found at the final report of the thesis which the experiment is part of. Theses written at Lund's University are published at: https://lup.lub.lu.se/student-papers/search.

8. Voluntary participation

Participation in the experiment is fully voluntary. You can stop the participation at any point of the experiment. If you want to stop, you can remove the equipment by yourself or let the researcher know. You can also withdraw your participation after concluding the experiment. You do not need to give any reasons to do so, although you can help the researchers to avoiding uncomfortable experiments if you explain why.

9. Who is responsible for the experiment?

The experiment is performed by researchers at the Department of Fire safety Engineering from Lund University. The responsible researcher is Jonathan Wahlqvist. You can reach Jonathan by phone +46 46 222 15 58). You are welcome to contact Jonathan if you have questions about the experiment.

Appendix C – Individual test result

Table of the cognitive safe distance data

No	Group	time	[X]	[Z]	[Y]	Scale	Distance
0	1	112.7436	3.264746	1.73244	0.006224	Large	3.264752
1	1	37.17506	1.354834	1.59937	-0.02536	Large	1.355071
2	1	133.8495	1.204879	1.580761	0.022344	Large	1.205086
3	1	69.47638	1.659268	1.610474	-0.04317	Large	1.65983
4	1	31.89677	1.823102	1.682547	0.192509	Large	1.833238
5	1	260.4853	2.3592	1.53648	0.149274	Large	2.363918
6	1	174.373	1.385504	1.66252	-0.0803	Large	1.387829
7	1	84.46161	1.428964	1.644678	0.050609	Large	1.42986
8	1	110.2109	3.737326	1.845118	-0.61325	Large	3.787305
9	1	139.7592	2.154939	1.540626	0.21316	Large	2.165456
10	1	67.15472	2.059769	1.612333	0.007601	Large	2.059783
11	2	202.655	1.398388	1.629201	-0.1088	Large	1.402614
12	2	121.397	1.394278	1.713262	-0.09039	Large	1.397205
13	2	92.90399	2.301346	1.493494	0.797131	Large	2.43549
14	2	74.11969	1.830299	1.450569	-0.02499	Large	1.83047
15	2	24.50842	1.070796	1.527926	0.040768	Large	1.071572

16	2	48.36506	1.511552	1.43698	-0.02573	Large	1.511771
17	2	59.76619	1.620237	1.535795	0.507502	Large	1.697859
18	2	96.91412	1.048072	1.462914	-0.21967	Large	1.070846
19	2	61.87751	1.881968	1.725158	-0.01665	Large	1.882042
20	2	70.10956	1.85016	1.484772	0.384163	Large	1.889622
21	2	143.5583	2.146262	1.564214	0.125729	Large	2.149941
22	2	64.62201	2.501874	1.532996	0.490119	Large	2.549429
23	1	74.11969	1.627314	1.58403	-0.65661	Large	1.754789
24	2	213.2079	1.176529	1.466395	-0.01193	Large	1.17659
25	1	117.3869	1.72893	1.64662	0.084451	Large	1.730991
26	1	47.73166	2.10332	1.628841	-0.03646	Large	2.103636
27	2	24.71952	1.660592	1.713148	0.0327	Large	1.660914
28	2	16.48678	1.191125	1.56487	-0.09421	Large	1.194845
29	1	40.97543	1.535606	1.587211	0.062864	Large	1.536892
30	2	226.5047	1.245981	1.670786	0.016303	Large	1.246088
31	2	126.8846	3.14284	1.683969	0.279466	Large	3.155241
32	1	59.76619	1.336412	1.539132	0.041044	Large	1.337042
0	1	91.00446	2.771625	1.727448	0.042254	Medium	2.771947
1	1	56.59921	1.067311	1.608521	-0.01553	Medium	1.067424
2	1	184.926	0.86422	1.594627	-0.05459	Medium	0.865942
3	1	96.492	1.35741	1.61884	-0.00832	Medium	1.357435
4	1	49.63185	1.664523	1.737948	-0.16598	Medium	1.672778
5	1	166.5638	1.583195	1.451315	0.087909	Medium	1.585634
6	1	151.1564	0.993251	1.520035	-0.07998	Medium	0.996465
7	1	69.26532	1.053612	1.618977	0.032297	Medium	1.054107
8	1	72.22015	2.779804	1.85657	-0.58004	Medium	2.839676
9	1	174.584	1.551387	1.533925	0.678428	Medium	1.693241
10	1	26.61938	1.524953	1.579857	0.004649	Medium	1.52496
11	2	118.8643	0.874058	1.575335	-0.07808	Medium	0.877539
12	2	100.2911	1.213107	1.698969	-0.11694	Medium	1.218731
13	2	125.6182	1.801228	1.516052	-0.00199	Medium	1.801229
14	2	88.89386	1.630454	1.464474	-0.07402	Medium	1.632133
15	2	59.97732	1.044308	1.556364	-0.03317	Medium	1.044835
16	2	71.37592	1.34829	1.42047	-0.01884	Medium	1.348422
17	2	96.492	1.238124	1.512421	-0.44557	Medium	1.31586
18	2	68.63214	1.134593	1.464887	0.216872	Medium	1.155134
19	2	40.13091	1.329474	1.706802	-0.07598	Medium	1.331643
20	2	83.82843	1.649463	1.4725	0.054062	Medium	1.650349
21	2	184.5038	1.94033	1.555415	0.108513	Medium	1.943362
22	2	162.1315	2.363572	1.519183	0.004545	Medium	2.363576
23	1	92.05975	1.503948	1.550583	-0.04612	Medium	1.504655
24	2	292.7774	1.014947	1.441211	0.062667	Medium	1.01688
25	1	72.43121	1.741245	1.61682	0.342164	Medium	1.774545

26	1	31.89677	1.718865	1.60861	0.107495	Medium	1.722223
27	2	69.05426	1.070588	1.684549	0.066457	Medium	1.072649
28	2	64.62201	1.137965	1.671316	-0.10428	Medium	1.142733
29	1	26.83047	1.217115	1.601286	-0.09071	Medium	1.220491
30	2	175.4283	1.458011	1.684926	-0.00114	Medium	1.458011
31	2	146.091	2.161174	1.692695	-0.56682	Medium	2.23427
32	1	36.1194	1.297152	1.542455	0.043628	Medium	1.297885
0	1	67.99896	2.374884	1.734727	-0.00278	Small	2.374886
1	1	69.47638	0.997444	1.58901	-0.00153	Small	0.997445
2	1	164.4532	0.923675	1.591614	0.031615	Small	0.924215
3	1	111.2662	0.968334	1.583483	0.037068	Small	0.969043
4	1	62.93317	1.251855	1.671671	0.29376	Small	1.28586
5	1	223.5499	1.03601	1.446198	0.112172	Small	1.042065
6	1	105.5676	0.79654	1.535934	-0.09083	Small	0.801702
7	1	98.18048	0.853861	1.613744	0.062965	Small	0.856179
8	1	29.78582	1.707423	1.826138	0.768911	Small	1.87257
9	1	107.8892	0.874283	1.51986	0.831432	Small	1.206504
10	1	50.26524	1.242381	1.575828	0.03605	Small	1.242904
11	2	176.2725	1.151148	1.687947	0.01852	Small	1.151297
12	2	62.29977	1.184055	1.696173	-0.1036	Small	1.188579
13	2	109.3666	1.846835	1.5085	0.209992	Small	1.858735
14	2	57.44373	1.580695	1.438714	-0.02354	Small	1.58087
15	2	42.45336	0.805975	1.493881	-0.01889	Small	0.806196
16	2	87.20538	1.006802	1.431749	-0.01784	Small	1.00696
17	2	78.55194	1.135661	1.475929	0.467951	Small	1.228293
18	2	119.7086	0.698315	1.427977	0.253292	Small	0.742832
19	2	79.8183	1.010859	1.709573	-0.02192	Small	1.011097
20	2	48.78732	1.858707	1.462514	0.070639	Small	1.860049
21	2	218.2734	1.548726	1.543302	0.123274	Small	1.553624
22	2	126.0403	1.849851	1.442099	-0.20157	Small	1.860801
23	1	53.43222	1.095827	1.535155	0.487363	Small	1.199316
24	2	261.7516	0.805318	1.435664	-0.00177	Small	0.80532
25	1	96.06989	1.346174	1.687217	0.035945	Small	1.346654
26	1	64.41095	1.24285	1.602791	-0.05063	Small	1.243881
27	2	51.10977	1.075533	1.676724	0.025906	Small	1.075845
28	2	38.86411	0.633029	1.533389	0.065903	Small	0.63645
29	1	61.24411	0.968703	1.610013	0.005875	Small	0.96872
30	2	203.9213	1.318758	1.681858	0.012942	Small	1.318822
31	2	97.75836	1.833229	1.633777	0.614224	Small	1.933391
32	1	76.6524	1.026612	1.533511	-0.01797	Small	1.026769

*The explanation to the title of each column:

No, the number of the subject.

Group, 1= Treatment group, 2= Control group.

Time, the time when the data was recorded during the experiment, the unit is second.

[X], the distance from the origin of the virtual fire (X, Y, Z) = (0, 0, 0) on the length of the space.

[Z], the height difference from the origin of the virtual fire (X, Y, Z) = (0, 0, 0).

[Y], the distance from the origin of the virtual fire (X, Y, Z) = (0, 0, 0) on the width of the space.

Scale, the scale of the virtual fire the subject met when the data was recorded.

Distance, the one-dimensional distance from the virtual fire. Its value equals to $([X]^2 + [Z]^2)^{0.5}$.

Table of the front side questionnaire answer data

No	Group	Ages	Gender	Discomfort	Fire Background	VR	Game	Fire Experience
0	1	23	2	0	0	2	1	0
1	1	23	1	0	1	1	4	0
2	1	28	1	0	0	3	3	0
3	1	27	1	0	1	2	2	1
4	1	23	1	0	1	1	3	1
5	1	34	2	0	1	3	1	0
6	1	24	1	0	1	1	1	1
7	1	27	1	0	1	2	4	1
8	1	24	2	0	0	5	3	1
9	1	38	1	0	0	3	1	0
10	1	21	2	0	0	1	3	0
11	2	32	2	0	1	2	2	1
12	2	21	2	0	1	1	2	1
13	2	31	1	0	0	5	3	1
14	2	23	1	0	1	1	1	1
15	2	28	2	0	0	2	2	0
16	2	26	2	0	1	1	1	1
17	2	23	1	0	1	3	3	1
18	2	26	2	0	1	1	1	1
19	2	31	1	0	1	1	1	0
20	2	30	1	1	1	1	2	1
21	2	20	1	0	0	2	4	1
22	2	28	1	0	1	1	4	1
23	1	23	1	0	1	3	3	1
24	2	26	2	0	0	3	2	1
25	1	24	1	0	0	2	3	1
26	1	24	1	0	1	2	1	1

27	2	25	1	0	0	3	4	0
28	2	24	2	0	0	2	1	1
29	1	26	1	0	0	2	1	1
30	2	23	1	0	1	2	3	1
31	2	27	2	0	0	2	2	1
32	1	26	1	0	1	2	4	1

*The explanation to the title of each column:

No, the number of the subject.

Group, 1= Treatment group, 2= Control group.

Ages, the subject's age.

Gender, the subject's gender, 1= Male, 2= Female.

Discomfort, if the subject feel discomfort during the experiment, 0= No, 1= Yes.

Fire background, the answer to the second question regarding subject's education/career background, 0= No, 1= Yes.

VR, the answer to the third question regarding subject's VR experience, from 1= first time to 5= more than 10 times and on a regular bias.

Game, the answer to the fourth question regarding subject's game experience, from 1= don't/rarely play to 4= more than 7 hours per week.

Fire experience, the answer to the fifth question regarding subject's experience of approaching a similar fire, 0= No, 1=Yes.

Table of the back side questionnaire answer data

No	Group	Realism	Unsafe	Heat	[Flames]	[Sound]	[Smoke]	[Heat]
0	1	5	5	4	1	0	0	1
1	1	5	4	2	1	1	1	0
2	1	4	5	2	1	1	0	0
3	1	2	5	4	1	1	0	1
4	1	2	3	4	1	1	0	0
5	1	6	4	3	1	0	1	0
6	1	5	1	2	1	0	0	0
7	1	3	2	3	1	0	1	0
8	1	5	6	4	1	1	1	1
9	1	3	2	1	1	0	0	0
10	1	6	5	4	1	1	0	0
11	2	6	4	2	1	1	1	0
12	2	4	1	1	1	0	0	1

13	2	4	4	1	1	0	0	0
14	2	4	4	3	1	0	1	0
15	2	3	1	1	0	1	0	0
16	2	5	5	5	1	1	0	0
17	2	3	1	1	1	0	0	0
18	2	4	4	2	1	1	0	0
19	2	2	4	2	1	1	1	0
20	2	5	1	5	0	0	0	1
21	2	1	5	5	1	1	0	1
22	2	4	2	1	1	0	1	0
23	1	5	4	4	1	1	0	0
24	2	4	3	2	1	1	1	0
25	1	5	2	2	1	0	1	0
26	1	5	6	4	1	1	1	0
27	2	4	4	1	1	0	0	0
28	2	5	4	2	1	0	1	0
29	1	4	2	2	1	1	0	0
30	2	2	5	1	1	0	0	0
31	2	5	2	1	0	0	0	0
32	1	6	1	2	1	0	1	0

*The explanation to the title of each column:

No, the number of the subject.

Group, 1= Treatment group, 2= Control group.

Realism, the answer to the sixth question's description regarding the realism of the VR experiment, from 1= Strongly disagree to 6= Strongly agree.

Unsafe, the answer to the seventh question's description regarding the unsafe feeling as approaching the virtual fire, from 1= Strongly disagree to 6= Strongly agree.

Heat, the answer to the eighth question's description regarding the heat feeling, from 1= Strongly disagree to 6= Strongly agree.

[Flames], the first factor in the ninth question, 0= No, 1= Yes.

[Sound], the second factor in the ninth question, 0= No, 1= Yes.

[Smoke], the third factor in the ninth question, 0= No, 1= Yes.

[Heat], the fourth factor in the ninth question, 0= No, 1= Yes.