Evaluation of the Effectiveness of Traditional Training vs. Immersive Training

A Case Study of Building Safety & Emergency Training

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Abstract. Virtual Reality (VR) has revolutionized training across healthcare, manufac-turing, and service sectors by offering realistic simulations that enhance en-gagement and knowledge retention. However, assessments that allow for evaluation of the effectiveness of VR training are still sparse. Therefore, we examine VR's effectiveness in emergency preparedness and building safety, comparing it to traditional training methods. The goal is to evaluate the impact of the unique opportunities VR enables on skill and knowledge development, using digital replicas of building layouts for immersive training experiences. To that end, the research evaluates VR training's advantages and develops performance metrics by comparing virtual performance with actions in physi-cal reality, using wearable tech for performance data collection and surveys for insights. Participants, split into VR and online groups, underwent a virtual fire drill to test emergency response skills. Findings indicate that VR training boosts urgency and realism perception, despite similar knowledge and skill acquisition after more traditional lecture-style training. VR participants re-ported higher stress and greater effectiveness, highlighting VR's immersive benefits. The study supports previous notions of VR's potential in training while also emphasizing the need for careful consideration of its cognitive load and technological demands.

Keywords: virtual reality, building evacuation training, wayfinding

1 Background

Virtual Reality (VR) has emerged as a transformative force in modern training methodologies, significantly influencing sectors such as healthcare, manufacturing, customer support, and skill enhancement programs. This technology's primary advantage lies in its capacity to generate immersive, lifelike scenarios that safely replicate complex, real-world situations, thereby enhancing participant engagement and retention of learning material. VR facilitates users in practicing and refining their skills within environments that are precisely controlled and reproducible, an invaluable feature particularly in contexts where risk mitigation or resource constraints are critical. Additionally, VR's flexibility in crafting customized experiences caters to diverse learning preferences and requirements. For instance, Adami illustrated the effectiveness of VR-based training for construction workers [1], while Menin examined the impacts of various VR devices on virtual training environments, emphasizing perception and knowledge acquisition [2]. Chae's research compared VR training to video training in the context of passenger ship abandonment training, highlighting VR's superior efficacy [3].

A notable aspect of VR training is its positive effect on learner motivation. The immersive and interactive nature of VR transforms passive learning into active exploration, thereby increasing engagement and participation. Studies in game-based VR education have shown significant improvements in the learning experience and teaching quality, markedly different from traditional methods focused primarily on knowledge transfer. The integration of VR and artificial intelligence in training scenarios, such as in-hospital training [4] and surgical skills training [5], has demonstrated instances where VR training outperforms conventional methods. Furthermore, academic research has been directed towards understanding how different levels of immersion influence cognitive functions like attention and memory. VR has been identified as an effective tool for assessing these cognitive functions [6]. Research also explores the relationship between immersion levels and attention restoration[7], comparing different VR devices such as cardboard VR and VR head-mounted displays [8]. Huang's study focused on the impact of VR immersion on learner motivation, engagement, performance, and spatial reasoning over time [9], while Kwon investigated how the realism of VR environments affects anxiety under specific conditions [10].

In conclusion, VR's unique capabilities in simulating realistic training environments offer significant advantages in various training contexts, enhancing engagement, retention, and skill acquisition. Its adaptability to different learning preferences and requirements further solidifies its role as a pivotal tool in contemporary training methodologies.

2 Research questions and objectives

Supported by the University of Cincinnati's Industry 4.0/5.0 program, a multidisciplinary research team and industry partners started an initiative named "Immersive vs. Traditional Training: Evaluating Fire Drill and Navigation Training Approaches." The project constructs a virtual equivalent of real-world settings through a VR system that precisely simulates building environments, enabling participants to engage with virtual fire emergency scenarios reflective of genuine architectural designs. The study seeks to resolve two fundamental inquiries: (1) Does immersive VR training surpass traditional training methods in effectiveness? (2) Are there particular advantages of immersive training for specific types of learning outcomes (e.g., skill development) as opposed to others (e.g., knowledge acquisition)?

The aim is to assess the efficacy of immersive training protocols compared to traditional training methods. This includes evaluating each modality's benefits for various learning objectives and establishing evaluative criteria for comparing VR training to other methods. This approach helps us understand how to enhance conventional training techniques, providing realistic and relevant emergency preparation.

3 Method

The goal of this project is to evaluate the efficacy of VR training through a data-centric approach that quantifies both skill-based behaviors and knowledge gain. To address this, we first defined the training context – a fire drill, the real-world environment for which the drill is designed – the building of the College for Design, Art, Architecture, and Planning (DAAP) on the UC Campus, and the training goals. We then developed a realistic VR replica of that building. To ensure the comparability and consistency of VR and traditional training materials, the training content was developed in VR – and then, in a follow-up step, matched with a training slide deck that can be used in the traditional lecture-style training (e.g., online training). Finally, by contrasting participant performance in VR scenarios with their physical reality counterparts, a nuanced framework for gauging the effectiveness of VR in enhancing emergency response preparedness was established. The data collection method encompassed wearable sensors for real-time physiological tracking, post-training assessments to gauge knowledge retention and comprehensive surveys for a holistic evaluation of human performance and training outcomes. This analysis facilitated an in-depth understanding of the dynamic between human operators and immersive technology, shedding light on potential enhancements for building safety protocols through VR.

3.1 Development of Training - Traditional vs. VR Modules

The training content across both traditional online and VR modules was meticulously designed to ensure consistency in the dissemination of information. Both modalities covered the exact same fire drill training content, presented through different formats to match the specific advantages of each platform. The consistent content across both formats ensured that all participants received the same information, while the delivery method was tailored to exploit the performance of each training modality.

Information Presentation:

Online Module: Training materials, including crucial fire safety information, were displayed through videos and slides. Consistent with typical online fire drill training, the training was delivered like a lecture using the created slide deck. Besides presenting necessary information about escape routes and appropriate behavior in emergency situations, like who to call, what to say, and what to do, the slide deck also included information about who to help during evacuation.
VR Module: The same informational content as in the online module was integrated into the VR environment. A notable feature was the use of an information poster that was visible in the first room trainees entered, showing the exact same information as the slide deck, including the use of the same color scheme and symbols. Furthermore, the VR module featured four non-player-controlled characters (NPCs) positioned along the evacuation route, visually representing individuals requiring assistance during a fire emergency. This direct visual representation aimed to enhance understanding and empathy by allowing participants to interact with scenarios mirroring real-life situations.

Navigation Training:
Online Module: Participants were shown a 2D map of the building, complete with moving arrows to guide them along the evacuation route, replicating the navigational cues provided in the VR version.
VR Module: Participants navigated through the virtual DAAP building, following dynamic, moving arrows that guided them through the evacuation route, offering a more immersive experience in spatial orientation and route-finding under emergency conditions.
Motivation and Realism:
Online Module: A screenshot from the VR simulation depicting an active fire scenario in the DAAP Rapid Prototyping center was used to convey the urgency and critical nature of fire safety training (see Figure 1). This visual aimed to impress upon participants the dangers of fire emergencies and the importance of being prepared. The screenshot from VR ensured consistency in the imagery presented between training modalities.
VR Module:Participants were placed in a simulated active fire situation within the virtual rapid prototyping center at the virtual DAAP building, enhancing the realism and immediacy of the training. This immersive experience was designed to foster a deeper understanding of the seriousness of fire emergencies and the critical nature of prompt and effective response.

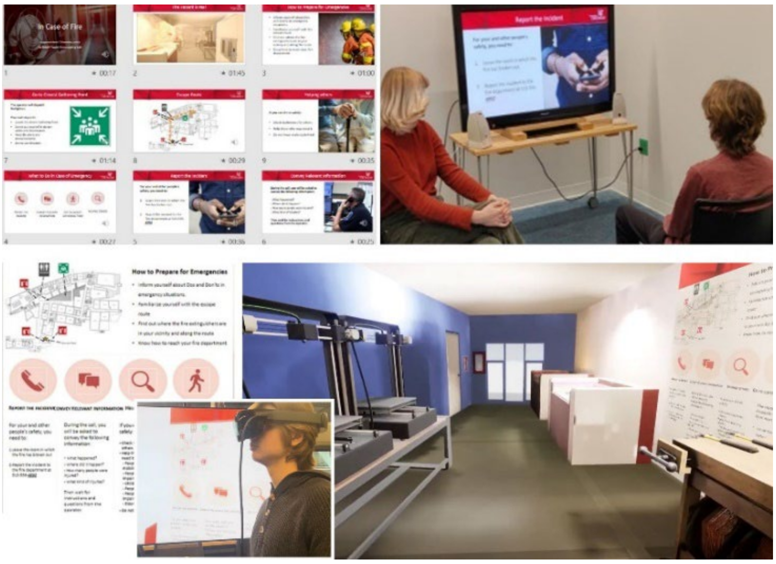

Fig. 1. Online training slide deck and presentation mode (top); Poster derived from slide deck for presentation in VR (bottom). The consistent content across both formats ensured that all participants received the same information, while the delivery method was tailored to exploit the performance of each training modality.

3.2 Creation of Virtual Building Replica for Immersive Testing.

For the VR module, a detailed simulation accurately representing the UC DAAP building's layout and interior was created, including its grand staircase, café areas, and specific rooms relevant to the drill. For trainees, the training starts in a basic VR lobby designed for initial interaction familiarization with the VR equipment and functions. Afterward, participants are immersed in three scenarios to prepare them for real-life fire evacuation procedures.

DAAP Rapid Prototyping Center Fire Scenario: After leaving the lobby, the VR training begins in a simulated version of the DAAP Rapid Prototyping Center, where fire safety information is displayed on a poster (see Section 3.1), including a map pinpointing the assembly area and the emergency contact number. Complete with fire extinguishers, the environment mirrors the actual setup of the physically existing room to enhance realism. Participants engage with interactive billboards with questions, guiding them on evacuation protocols. As participants navigate this scenario, a virtual fire outbreak and smoke are triggered alongside an acoustic alarm signal, simulating an emergency (Figure 2). Instructions on a billboard compel the participant to exit the room and contact emergency services via a virtual phone.

Phone Interaction Scenario: After escaping the initial fire scenario, participants face the task of contacting emergency services. Utilizing VR technology, participants use a virtual phone keypad and hands to dial the correct number, simulating an actual call to emergency responders (see Figure 2). This interaction involves speaking to a live person representing emergency services, who instructs the participant to proceed to a safe gathering area within the virtual DAAP Café, blending virtual interactions with real-life communication skills.

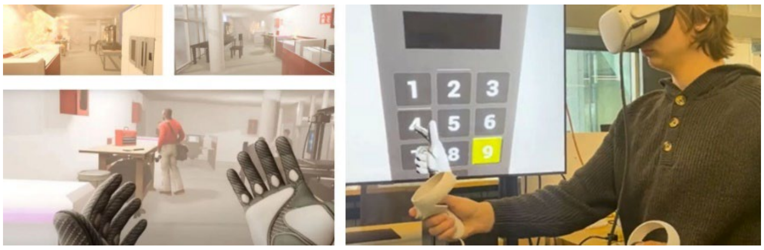

Fig. 2. VR training fire scenario and phone scenario.

Evacuation Drill Scenario: Guided by animated arrows, participants navigate through the virtual building to reach a designated safety point, also looking for and engaging with virtual characters needing assistance, both in the hallways and in restrooms along the way (see Figure 3). These characters represent individuals who might face challenges during an evacuation, such as a child, a person in a wheelchair, someone wearing headphones, and a visually impaired individual. This scenario not only trains participants on the evacuation route but also emphasizes the importance of assistance and empathy in emergency situations. The drill culminates at the final assembly point, marked by a virtual firefighter, signaling the completion of the VR training.

Fig. 3. VR training evacuation drill scenario. This comprehensive VR training module leverages detailed simulations and interactive scenarios to provide an immersive experience that closely replicates real-world emergency response actions, from initial fire discovery to the final evacuation assembly point.

3.3 Experimental Design

To assess the difference in training experience, effectiveness with respect to knowledge and skill learning, and induced motivation to learn, we crafted an assessment plan that allows for comparison at all relevant levels (see Figure 4).

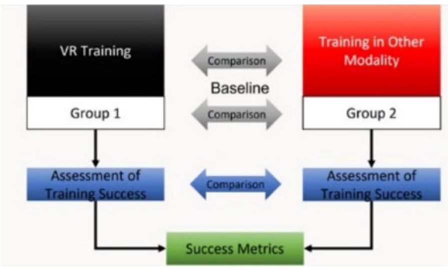

Fig. 4. Assessment Plan that compares training experience, training group prior experience and motivation, and training success in both modalities.

Participants. Fourteen undergraduate Psychology students at the University of Cincinnati participated in this study for course credit. They were divided into two groups: one receiving online training and the other undergoing VR training. The VR group consisted of seven individuals aged 18-23, including three females, while the online group comprised seven participants aged 18-22, with two females.

Initial Consent and Pre-Survey. Participants start by reading the information about the study and verbally consenting to their participation (UC IRB # 2022-0701). They then receive group-specific instructions about their assigned training and take an entrance survey to evaluate their initial motivation and interest in the fire drill subject. The survey includes questions about demographics, prior knowledge and experiences, learning preferences, the importance of knowing fire emergency procedures, and overall self-assessments related to their ability to memorize, learn, and navigate.

Sensor Setup. The team measured the stress level of participants. As Córdova suggested, "correct management of emotions in stressful situations could promote effective learning through enhanced attention and capacity to solve problems" [11]. Ji concluded, "using stress reasonably, controlling stress appropriately, channeling stress properly, and enhancing self-management abilities can aid college students in learning autonomously online" [12].Participants were equipped with Empatica wristbands to monitor their heart rate throughout the training session. The physiological assessment aimed to measure the perceived realism and immersion of the training by observing heart rate variations and the overall stress response. A higher heart rate was interpreted as an indicator of stress, suggesting that if the heart rate remained elevated during scenarios such as a fire breakout, it would provide a metric of how well the training modality mimics real-life emergency responses. Consequently, if the experience felt "more real," the derived higher stress response might enhance the trainee’s motivation to learn, thereby maximizing the training's impact and perceived importance.

Training (online/VR) and Post-Survey. After sensor setup, participants in the online training group engage in a video-based training module, while participants in the VR group engage in the VR training experience. Both trainings are set to approximately last 10 mins. In the VR sessions, detailed interaction data were collected, including participants' responses to questions, the response time, and the sequence of actions in dialing emergency numbers After the training session, participants fill out an exit survey that revisits questions from the entrance survey and includes additional feedback questions about their training experience, explicitly inquiring about aspects of confidence in wayfinding and believed retention.

Distraction Period and Knowledge Test. Once the exit survey is completed, a 30-minute distraction period follows, during which participants all watched the same cartoon. This interval is designed to mitigate recency effects and evaluate the short-term retention of skills and knowledge acquired during the training. The distraction period is directly followed by a knowledge test in which participants are asked specific details from their training, such as the phone number of the emergency services, details of the evacuation route, and why/how to help individuals who require assistance.

Skill Test. The final step of our evaluation is an onsite fire drill skill test in which we monitored participants for wayfinding in the DAAP building. Participants were instructed to find their way from the RPC to the assembly point, i.e. the route they were trained on in both modalities. They were also instructed to do everything they learned in the training on the way. Participants' movements through the building were tracked via a mobile phone's geolocation, with a technical assistant following behind them, documenting their progress. This practical exercise tested their ability to recall and apply the evacuation procedures learned, including checking restrooms for individuals who might need assistance and reaching the designated assembly point at the DAAP café.

3.4 Data Analysis and Results

All surveys used 5-point Likert scales. All responses were coded with 1 = strongly disagree, 2 = slightly disagree, 3 = neutral/not sure, 4 = slightly agree, 5 = strongly agree. Statistical analysis was done in JASP. All t-tests are two-sample independent t-tests. Student's t-tests are used if group variances are equal, Welch's t-test is used if variances differ.

Group Comparison. None of the participants had previous firefighter training or significant familiarity with the DAAP building, though nearly all had some experience with online learning environments. Participants in the VR group had an average of 3.14 fire drills in the last year, while participants in the online learning group had an average of 1.57. Participants in the VR group also had slightly more experience using VR equipment (VR 5, Online 2).

Prior Experience and Motivation. There was no significant difference between groups with respect to the preference for online or VR learning modality, $t(12)=1.44$, $p > .05$, general self-assessment of navigation abilities, $t(9.89)=0.00$, $p = 1$, reported performance under stress, $t(9.20)=0.45$, $p > 0.5$, and belief that fire drills are relevant, $t(12)=0.00$, $p = 1$ (see also Figure 5).

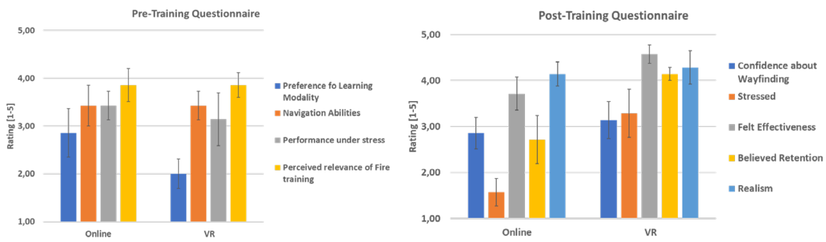

Fig. 5. Results of Pre-Training Questionnaire (left panel) and Post-Training Questionnaire (right panel)

Training Experience. During training, we recorded participants' heart rates to assess their stress response during the experience. People showed marginally higher stress response during the VR training (M=93.1Hz, SE = 3.75Hz) than in the Online Training (M=81.8Hz, SE = 4.05Hz), t(12) = -2.04, p = .06. This disparity is attributed to the VR training's high fidelity and immersive nature, which likely intensified the perception and realism of the fire drill scenarios, thereby elevating the perceived stress levels.

Subjective responses about the training experience (see Figure 5) show that participants do not differ in their confidence about being able to follow the escape route post-training in either modality, t(11.7) = -0.54, p = .60, with their confidence ranging around "neutral/don't know". After both trainings, people also agreed that the training they received was an accurate representation of a possible fire emergency scenario (realism), t(10.95)=-.32, p = .75, which was ranging around "slightly agree" in both groups.

Participants are however significantly more stressed after being in the VR training (M=3.29, SE=.52) than after receiving the online training (M=1.57, SE=.30), t(9.53) = -2.86, p = .018, which is in line with the physiological measurements. They also believe that they can recall information much better after the VR experience (M = 4.14, SE = .14), than after the online training (M = 2.71, SE = 0.52), t(6.89) = -2.64, p = .03. In line with this, they also tend to believe that VR training (M=4,57, SE=.20) is more effective than online training (M=3.71, SE=.36), t(9.44)=-2.08, p = .06. This suggests that the immersive experience provided by VR enhanced the perceived realism of the training scenarios and left participants feeling more confident about the skills they had acquired.

Knowledge. With the knowledge test, the goal was to find out how much short-term retention participants had based on different training modalities after a distraction period. Three out of seven participants in each training group remembered the location of all fire extinguishers. Note, that this was not explicitly instructed, but they had to pick up from exploring the room in VR, or the map in the Online Training. All participants in both groups remembered that checking the bathrooms on the escape route for others needing assistance was part of the protocol. Four out of seven participants in the online group remembered the emergency phone number correctly, while five out of seven did so in the VR training group.

Skill. Out of seven participants in both groups, two participants were able to find the gathering spot after the online training, and only one participant made it to the gathering point after VR training. All arrived there within 2 min. Despite having remembered in the knowledge test that checking the bathrooms on the escape route was part of the protocol, none of the participants in the online training put this into practice, while two participants in the VR group did.

4 Conclusion and Future Directions

Introducing VR into training regimes offers innovative and immersive techniques that enhance learner engagement and may significantly improve skill development and knowledge retention. Although derived from a limited participant pool, this study's findings highlight the fire-escape simulation as a viable platform for exploring the impact of modality on learning success. Moreover, this research demonstrated a systematic approach to designing and comparing VR and traditional online training modules, establishing a foundation for assessing the effectiveness of training across various domains.

However, the cognitive load and stress associated with VR learning environments necessitate careful consideration. In scenarios where the learning objective involves emergency situations, heightened stress levels may emphasize the importance of these scenarios, thereby enhancing attention and retention. Conversely, if the stress becomes excessively disruptive, it could impede learning by inducing tunnel vision responses. Therefore, maintaining a balance in stress levels and potentially incorporating positive stress through competition and gamification might prove beneficial. To further understand VR's educational impact, future studies could integrate neurofeedback and EEG analysis alongside current data collection methods, including real-time interaction metrics, biometric responses, and comprehensive surveys. Huang has implemented this EEG and physiological data method in safety training [14].

The comparative efficacy of VR training versus traditional methods appears to be contingent on the training's design and the specific learning context. Thus, it is imperative for institutions and educators to carefully evaluate the advantages and disadvantages of VR training to tailor educational strategies that best meet their unique goals and learners' needs. In essence, VR heralds a transformative era in training and emergency preparedness, offering unparalleled realism, interactivity, and a safe learning environment that could potentially extend to tactile experiences, as evidenced by Wang's work in operator training for clinical vascular interventional surgery [15]. Nevertheless, the successful integration of VR into educational programs requires a nuanced understanding of its cognitive implications, technological demands, and alignment with specific educational objectives.

Appendix: Building Navigation Instructions.

This segment of the study requires you to traverse the DAAP building, adhering closely to the route you learned during training. Your journey will commence in the Rapid Prototyping Center (RPC) and conclude at the designated assembly area. Focus solely on following the prescribed path without undertaking additional tasks.

1. Starting Position: Position yourself with your back to the RPC door as your initial stance.
2. Navigation Device Setup: A researcher will provide you with a mobile device equipped with a location-tracking feature. Activate the device by pressing the play button before you start your navigation. Assistance will be provided if needed.
3. Video Documentation: A technical assistant will discreetly follow and record your navigation for analysis. To ensure your privacy, please face away from the camera throughout the recording. Maintain a steady pace akin to your normal walking speed. If at any moment you find yourself unsure of the next step, recall the training guidance to proceed.
4. Conclusion of Task: Upon completing the navigation task, halt the recording by pressing the stop button on your tracking device. The device will then be collected by a researcher.
5. Return and Next Steps: Following the task, researchers will guide you back to Clifton Court Hall. Here, you will be briefed on the next phase of the study before departure.

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