Toward VR-based Training Modules for Public Safety Scenarios

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Public safety (PS) scenarios require timely responses under stressful and dynamic conditions. Training emergency responders for incidents such as wildland fire, search and rescue, or an active shooter requires knowledge acquisition and skill development, as well as the ability to generalize this core training to unique events. Unfortunately, practicing response protocols in the actual scenario is expensive and often infeasible to replicate. Virtual Environments (VEs) remove some resource constraints and offer improved training through safe practice and repetition of realistic emergency scenarios. We discuss the usefulness of highly immersive, adaptive Virtual Reality (VR) simulations to train emergency responders for intense PS scenarios, presenting three key areas of research: 1) integration of biological and physiological measures, 2) recruitment of multiple senses for increased immersion, and 3) the social environment. Expanding VR training research in these areas can support PS capabilities and time-sensitive emergency response.

CCS Concepts: • **Human-centered computing → Virtual reality**; Mixed / augmented reality; Haptic devices.

Additional Key Words and Phrases: public safety, emergency response, firefighting, training, user experience

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1 INTRODUCTION

Virtual Environments (VEs) hold great potential for advancing public safety (PS) response training by replicating complicated scenarios (e.g., a structural fire burn) with high fidelity at low cost. Through VEs, trainees can gain experience in a wide range of scenarios with health and safety risks. The increased training capabilities of VEs create new challenges for designers, including stimuli selection, feedback presentation, and data collection. To support design of effective VEs, we suggest consideration of three features of VE user experience: 1) collection and integration of bio-and physiological signals, 2) recruitment of multiple senses and 3) the role of the social environment.

The quality of a VE is often defined in terms of "immersion" (i.e., the objective level of sensory realism the virtual environment provides [6]), and "presence" (i.e., the subjective or psychological sense of being in the virtual environment [25]). An immersive VR PS scenario replicates the hazardous environment including situational stressors, such as intervention failures and time constraints, which is rarely feasible with traditional 2D training modules. During emergencies, responders face an excess of content, which may be imprecise and inaccurate [7]. Responders are trained to sort through this content to make decisions, take actions, and report reliable summaries (e.g., a victim's location and triage categorization (Fig 1)). VR modules can comprehensively represent these complicated, real-world scenarios.

Fig. 1. Physical (left) and virtual (right) representations of victims in triage scenarios. Ailments and instructions could be overlaid onto the virtual representations with the physical manikins providing haptic feedback for triage training.

Preparing first responders for emergency scenarios requires effective training. Research on training in firefighting [21] and active shooter incident response [22] recommends simulating the response scenario with the stress-inducing features generated by the emergency event. Nonetheless, stressful simulations may impede information recall [21]. This more stressful simulation-based training can be coupled with didactic training allowing instructors to understand how first responders will react in such scenarios and assess the degree of skill transfer. The need for simulation of dangerous scenarios matches the capabilities of VR to provide low-cost, repeatable, and high-fidelity replications of the target emergency response scenarios (for a demonstration of how VR capabilities can improve training see [13]). In the remainder of this position paper, we will discuss our vision for VR to improve training practices in PS contexts.

2 VISION FOR VR TRAINING IN PUBLIC SAFETY

Prior research in PS training on the use of VR in firefighting [15], search and rescue [31], and active shooter [24] scenarios show promise for low-cost deployment of VR training for emergency responders. VR training effectiveness in PS contexts illustrates the value of continued research on training and skill transfer through VR simulations.In the following section, we discuss a vision for VR training research, considering three critical aspects of VR training for PS: 1) collection and integration of biosignals, 2) recruitment of multiple senses, and 3) the role of the social environment.

2.1 Bio- and Physiological Data and Dynamic Training Scenarios

Wearable technologies record a broad set of biosignals and responses that allow designers to track how different stimuli affect users' physiological systems. Here, we use "biosignal" as to cover biological and physiological measures broadly, including non-electrical and non-continuous physical measures, as well as biometrics. These technologies have been used to assess training for non-VR platforms (e.g., video, 2D screens) [12, 34]. Trainers and developers can record heart rate, electrograms, galvanic skin response, eye gaze, or pupil dilation and apply these measures to application design and execution. These devices can assess presence, trust, and stress induced by VR [1, 8, 9]. Monitoring users' biosignals in emergency response simulations provides insight into the processes behind responder performance, such as cognitive capacity. For example, VR researchers could adapt training simulations depending on the user's cognitive load (see [28] demonstrating improvement in task performance and reduction in errors by manipulating cognitive load types).

Adaptive VR training enables dynamic environments, real-time feedback, and personalized experiences. While previous studies have shown the ability to adjust training difficulty levels with machine learning, gaps remain in

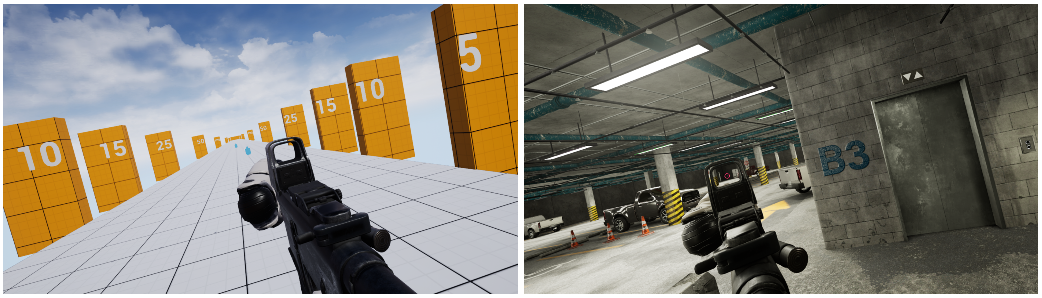

Fig. 2. Low-fidelity (left) and high-fidelity (right) representations of target practice in VR with a haptic prop representing a gun. With the greater realism in the high-fidelity representation, trainees are more immersed in the training scenario.

dynamically modifying the feedback type, content, and timing [33]. Physiological data for adaptive VR can enable closer collaboration between the trainer and trainee by allowing the trainer to more precisely assess trainee performance and thereby suggest methods to improve performance. For example, biosignals as an input for VR training scenarios may allow for dynamic scene and context generation that responds to the user's physiological state. Combining biosignal feedback with adaptive VR training environments can be further validated through assessments of skill transfer, performance (e.g., reduction in error), initial knowledge capture, and knowledge retention.

2.2 Integration of Other Senses for Increased Immersion

To increase a user's perception of presence, VR simulations integrate senses beyond vision. Research on dynamic haptic feedback for room-scale VR applications used wheeled robots to simulate surfaces to align physical walls to the virtual environment [26, 32]. Similarly, olfactory displays (ODs) can be coupled with VEs to supplement educational VR applications [20], reduce visually-induced motion sickness [19], and reduce stress in VR [17]. Previous Mixed Reality research integrated spatial audio to improve performance in collaborative tasks between a local AR user and remote VR user [29]. Use of haptic, audio, and olfactory stimuli would increase the fidelity to the real-world scenario and elicit the intended response from trainees.

Future research on how mismatches between the physical environment (e.g., the walls and furniture in the room) and the virtual representations affect the user's sense of immersion will provide precision in designing VR training modules. Prior work quantified allowable discrepancies between visual and haptic stimuli in a seated environment [23], and can be extended to consider room-scale VR, specifically in intense scenarios required for first response training. This extension to room-scale VR should also consider the negative impacts of mismatches between the physical and virtual environments to the immersion of the VR training scenario (e.g., virtual furniture rendering without physical furniture present; rendering virtual hands as the user reaches toward a wall). Vibrotactile integration through haptic props (e.g., those representing firearms in Fig. 2) and interactions with mannequins for triage (similar to [11]) could enhance VR training. Incorporation of auditory cues can increase the realism of the VE as well as improve communication between a trainer and a VR-based trainee [29]. VR-based PS scenarios should study how ODs can extend beyond visual-only experiences to affect user performance and physiological responses. In doing so, trainers can offer increased fidelity (e.g., smell of smoke), and variations in stress for trainees, as appropriate.

Merging the virtual scene with the physical environment is necessary to maintain user immersion in the training module. This approach includes corresponding virtual and physical walls (e.g., furniture, 3D printed parts (Fig. 3); and mannequins to represent people (Fig. 1)), as well as perceptual cues such as spatial audio.

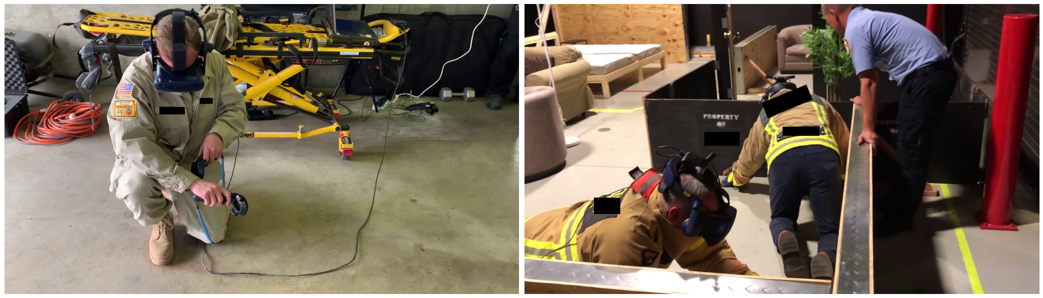

Fig. 3. VR firefighting simulation (left) and locomotion with prop integration (right). Pairing the virtual representation of the training environment with physical props would improve the environment's fidelity and elicit natural engagement with the training module.

2.3 Social Environment in VR Training

Beyond physical cues, social stimuli also form the user's experience. Social design decisions can strongly influence a user's experience of immersion [14], presence [21], self [5], and connection [2]. Just as synchronicity of physical and virtual objects matters, so does synchronicity of user actions and virtual humans [27]. The demonstrated influence of social stimuli suggests that VEs may be well-suited for PS communications training.

PS incidents require coordinated responses within a team and across multiple domains, each with its own practices and customs. A wildfire response could include fire and rescue workers, hazardous materials teams, emergency medical services, multiple levels of government, and private entities. Even with extensive fire suppression training, a responder may have limited experience navigating these parties and incident command. VEs allow trainees to practice navigating this complicated social structure and for trainers to assess how task performance may be influenced by social aspects.

In addition to technical skills, trainees learn the preferences and habits of their colleagues and supervisors. This social understanding is central to emergency communications. Responders must accurately transmit vital information and take actions based on communication veracity, where small errors could have severe consequences. Networked VR simulations [16], VEs with virtual humans [4, 10], and displays of a virtual self [3, 30] allow trainees to practice communications and experience the consequences without physical colleagues. An ongoing VE design challenge is the inclusion of social elements without disrupting user immersion or presence (as with questionnaire administration [18]).

3 CONCLUSION

VR technology enables trainees to immerse themselves within an emergency response scenario to apply knowledge in a realistic and dynamic virtual representation. This position paper describes a vision for extending VR research to support immersive VR as a primary modality for training first responders in PS contexts. We highlight the importance of integration of biosignals and physiological measures, multiple senses, and social VR engagement for improved VR training. Future research in developing highly immersive VEs will enable low-cost, repeatable implementation of training that effectively prepares first responders.

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