Immersion and Presence in Virtual Reality Training for Mass Casualty Incidents

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ABSTRACT

Preparation for mass casualty incidents (MCIs) is highly important but difficult to accomplish. Incidents are rare, often complex, and training is costly. However, with the development of consumer grade virtual reality (VR) hardware, immersive training simulations have become affordable for competency training. To make simulations effective, users have to be immersed and feel present in the simulation. We have developed a VR training system for MCIs in a user centered design process with emergency personnel and further improved the system to increase immersion and presence. In an evaluation with eighteen paramedic trainees, we compare six hypothesized design improvements between the two simulations, such as using a menu or a simulated emergency bag for interaction. Results indicate clear user preferences of interaction styles related to immersion and presence in MCI VR simulations.

Keywords

User-Centered Design, Virtual Reality Training Simulations, Mass Casualty Incidents, Immersion, Presence

INTRODUCTION

A mass casualty incident (MCI) is defined as an “event which generates more patients at one time than locally available resources can manage using routine procedures” (World Health Organization, 2007, p. 9). MCIs can include anything from area-wide natural disasters (e.g., earthquakes, hurricanes), large scale accidents (e.g., massive car crashes, industrial fires) or terrorist attacks, to smaller incidents (e.g., a car crash) when the number of injured persons overwhelms the available resources. Thus, an essential task for first responders in MCIs is to perform an initial quick examination of the casualties in order to prioritize treatment. This process, commonly named “triage”, is often defined in form of algorithms (e.g. START, e.g. Kahn et al., 2009). It aims to provide the basis to make optimal use of these limited resources.

In addition to overwhelming the available resources, MCIs are also exceptional cases in emergency care (Mentler & Herczeg, 2013). They are infrequent, vary widely (e.g., natural disasters, car crashes, train derailments, terrorist attacks) and the nature of the incident is often unpredictable. The paramedics who are the first responders also have a high responsibility. The triage process is “perhaps the most important point in mass casualty management" (Frykberg, 2005) and literally decides about life and death. In addition to the huge responsibility, treatment approaches are fundamentally different to daily routine of emergency personnel. Adding the time pressure, MCIs can lead to extreme stress (Zinke et al., 2010). As the classic studies by Berkun et al. (1962) have shown, stress and urgency generated by an emergency can severely impair performance. Intensive training is an important way to prepare paramedics for these challenges.

However, despite the necessity to face MCIs with calm, deliberate action grounded in sound training, MCI trainings are insufficiently done. The scope of such trainings places huge demands on time, effort and costs (Hsu et al., 2013) as MCIs involve multiple casualties that have to be simulated by lay actors in order to create an as realistic situation as possible for the paramedics. Additionally, the desired locations for training (e.g., locations with a high risk for MCIs like harbors and major motorways) cannot be closed for training purposes in many cases. Thus, trainings cannot be conducted as frequently and as realistically as needed, even though being important for readiness of the paramedics, including the self-perceived readiness (Hsu et al., 2013).

Given the need and the difficulties of training in real physical settings (number of actors needed, impossibility of closing down likely areas), computer simulations seem to be an obvious choice for MCI training. However, simulations come with the risk of trainees not taking the simulated situation seriously and treating it too much like a game (Heldal & Wijkmark, 2017). To take the simulated incident seriously, it is crucial for trainees to become immersed in the simulation and feel present in the simulated MCI.

The degree of immersion partly depends on the technology used. Virtual reality technology can encompass anything “from simple environments presented on a desktop computer to fully immersive multisensory environments experienced through complex headgear and bodysuits” (Ausburn & Ausburn, 2004). Immersion differs depending on the technology used – with limited immersion on desktop computers with mouse and keyboard controls to higher immersion with CAVEs (cubic rooms with image projection on each wall; Wilkerson et al., 2008) or head-mounted displays (HMDs, Gutiérrez et al., 2007). HMDs seem to be very promising – providing not only sensory input that completely replaces the real world, but also allowing for more direct behavioral feedback. Several studies show the advantage of HMDs to non-immersive computer screen setups for training in emergency care and MCIs (e.g. Vincent et al., 2008; Gutiérrez et al., 2007).

While originally expensive and requiring a huge technical overhead, the recent mass production of consumer grade VR HMDs (e.g., Oculus Rift, HTC Vive) promises to make these immersive simulations available for a wider audience. VR is no longer limited to large training schools or stations. However, it remains unclear which factors and design elements increase immersion and presence in MCI VR simulations using consumer-grade HMDs.

In this paper, we use recent developments in consumer grade VR technology and compare two traditional methods of MCI training for paramedics (large-scale exercises and paper-based simulations) with the characteristics of VR simulations. While the precise representation of behavior for the treatment of causalities is an important and a long-term goal, we first focus on immersion regarding different forms of user interactions and the sequence of triage behaviors (see description of the Systems A and B below). For evaluation, we conduct an experimental comparison of two MCI training simulations using consumer VR technology (Oculus Rift) and look specifically on the impact of different design aspects on paramedics' immersion and perception of presence. The participants in the study came from the main target group of paramedic trainees, who are currently trained with the aforementioned traditional approaches. Other areas of application are formal trainings of experienced paramedics (to refresh existing skills), or self-directed learning of individual paramedics. The results of this experiment with paramedic trainees are discussed regarding the suitability of consumer technology-based VR simulations for MCI training. We also discuss possible future developments to increase immersion and presence and provide conclusions on the suitability of VR MCI trainings.

BACKGROUND AND RELATED WORK

In this section, we describe immersion and presence and look at trainings for MCIs before we focus on MCI VR simulations and recent technological developments.

Immersion and Presence

As mentioned in the introduction, trainees must be immersed and feel present in a simulation to accept it. However, the term “immersion” is not clearly defined. According to Witmer and Singer (1998) involvement and immersion of the user are necessary for achieving presence. Sherman and Craig (2003) differentiate between "mental immersion" (meaning "a state of being deeply engaged" or involvement) and "physical immersion" (meaning the "stimulation of the body senses") as two aspects of immersion. Especially when it comes to replacing the sensory input from the real world by simulated input and reacting to the user's actions in real time, the right technology and a robust technical implementation are important.

"Presence" describes the subjective perception of being in the simulated environment, of "being there" (Minsky, 1980). It can be distinguished in physical ("the sense of being there") vs. social presence ("the sense of being together with another"; Biocca et al., 2001; Schwab & Lange, 2016). Given the importance of the simulated environment (incl. its hazards) and the importance of the people involved in the incident, both physical and social presence are important for simulated MCIs.

Current Trainings for Mass Casualty Incidents

Asking domain experts of MCIs in Germany, two non-digital approaches for MCI training are frequently used: large-scale exercises and paper-based simulations. Other training approaches are less common, e.g. simulation games using physical or digital landscape models.

Large-scale exercises are conducted with lay actors and props (e.g., wrecked vehicles), if possible at locations with a high potential risk for MCIs. They allow many emergency personnel to train at once. However, they are costly and have a huge organizational overhead. Individual training for paramedics is limited, as many paramedics usually participate in these exercises and a paramedic can often do only a few tasks during the whole exercise. According to a study with more than 1500 German participants with a qualification similar to a paramedic, only 69% participated in an exercise that contained a triage process in their working careers (Ellebrecht, 2013). The actual triage process was likely done by even fewer participants. Given the high number of participants and the limited number of observers, individual feedback is often limited as well (Sautter et al., 2016). Also, despite actually "being there", immersion and presence should not be taken for granted, as constraints of the exercise (e.g., no actual fire or hazardous materials) as well as the use of lay actors can break the illusion. Some medical symptoms cannot be simulated in a realistic way (e.g., respiratory failure or cardiac arrest) and lay actors might not always present the injuries convincingly during the exercise.

Paper-based simulations are used in training courses to simulate MCIs. They make use of paper cards as a substitute for lay actors. Emergency personnel can check symptoms and simulate treatment by applying adhesive stickers to the cards. These trainings are cheap to conduct and require little effort. They are also easier to supervise and to replicate. Unlike large-scale exercises, in paper-based simulations time is monitored with stopwatches, and treatment times as well as changes of the situation can be simulated. Thus, they are often referred to as "dynamical" simulations (BBK, 2012). However, they are much less realistic than large-scale exercises, and both immersion and presence are poor.

Virtual Reality Simulations as Trainings for MCIs

Virtual Reality training applications have been used in various domains, including emergency contexts. For example, Farra et al. (2013) looked at virtual reality simulations in disaster training, Wilkerson et al. (2008) and Vincent et al. (2008) highlighted the potential of VR for first responder training. Thus, such simulations seem to be an appropriate choice for MCI trainings, especially considering the benefits:

- **Sinking Costs due to Consumer-grade Technology:** As mentioned, consumer-grade plug-and-play VR technology has become available, especially in the gaming sector with VR systems being introduced for specific consoles (e.g. PlayStation VR) or for personal computers in general (e.g., Oculus Rift). These recent advances in consumer-grade VR technology provide an opportunity to make virtual reality simulations affordable and scalable. Regarding the hardware, the system comes out of the box and the costs are manageable. Promising possible future developments might include omnidirectional treadmills (e.g., Cakmak & Hager, 2014) which might be market-ready soon. Additionally, environments suitable for 3D development are available (e.g., Unity).
- **Efficiency and Ease of Use, especially for Individuals:** One of the main advantages of simulations is their cost-effectiveness. Simulations can allow single paramedics to train for MCIs under realistic circumstances, without the costly need for additional human actors or organizational overhead. Thus, they allow for an increase in the number of trainings. Moreover, paramedics could focus on scenarios or aspects of MCIs they personally find difficult or for which training needs have been identified before. By selecting predetermined scenarios that require minimal oversight by instructors, instructor effects could be eliminated (instructor's engagement/involvement influencing learning, see Heldal &

Wijkmark, 2017). As all inputs and actions are computer-mediated, detailed recordings of all events in the MCI simulation are possible. This data can provide the basis for automatic, objective and reliable feedback and performance measures, or used as data-basis for face-to-face debriefings (cf. Heldal & Wijkmark, 2017).

- **Plasticity:** Simulations can cover the wide heterogeneity of situations in which crises and disasters can occur (cf. Mentler, 2017). Variables like extraordinary operational conditions (e.g., heavy rain, snow, time pressure), dynamic changes (e.g., number of casualties, area), or perceptual, cognitive and physical workload (e.g., difficulty to reach an area with inherent dangers) can be simulated. Simulations can also be adapted to include new scenarios, like new technological developments or hazards.
- **Realistic Timing and Display of Consequences:** Akin to paper-based simulations, time for the treatment can be enforced in the MCI VR simulation. Moreover, results of treatment or missing measures can be simulated (e.g., blue lips for shortness of breath). Physics engines can show the physical consequences of actions or developments, including safety hazards.
- **Safety and possibility for making mistakes):** In contrast with exercises on site, there is little if any danger to the paramedics in a VR simulation. Mistakes can be made without adverse consequences (Mantovani & Castelnuovo, 2003), allowing for experimentation and learning by experience. Because of safety requirements on site, some risks can be presented in an even more realistic way in VR simulations (e.g., fire, explosions, toxic gas).
- **Replicability:** Simulations can be exactly replicated, allowing not only individual paramedics to repeat trainings, but also allowing for empirical comparisons of conflicting best practice approaches.
- **Scalability and Adaptability:** The same simulations can be distributed to many people and locations and may also be adapted to the specific hazards the paramedics are likely to face in their environment, as well as the resources they will likely have available (Hsu et al., 2013).
- **Motivational aspects**: When combined with features from serious games, simulations can be highly motivating (see Heldal & Wijkmark, 2017). However, participants must be prevented from "gaming the game" (Werbach & Hunter, 2012) in order to "win" in the simulation – on cost of correct procedures or other learning goals.
- **Adaptive difficulty and use of stressors:** By determining prior experience, accessing user data, or monitoring performance/physiological data, simulated MCIs can be adapted to the skill and stress level of the user. For example, it is possible to increase stress via a lack of time, to increase perceptual and cognitive load via environmental conditions and hazards, or to use emotional stressors like the category of casualties (e.g., children) or the type of injuries (e.g., result of violence, burn victims). Looking at news reports (e.g., Bucktin, 2016), even subtle stimuli like the repeated ringing of a cellphone of a deceased victim could have strong emotional effects.
- **Group Use and Distributed Trainings:** While often seen as isolated experience, VR can be used for group trainings, even when the participants are not at the same location (akin to multiplayer games, cf. Heldal & Wijkmark, 2017). This advantage is extremely important in sparsely populated areas.
- **Testing, Accident Analysis and Prevention**: Simulations can also be used for testing, e.g. of emergency response plans to identify gaps and areas of improvement (Hsu et al., 2013) and for recreation of real-world MCIs for accident analysis and learning purposes. Accident documentation can be used as suggested by Heldal and Wijkmark (2017). Using actual incidents could also increase the authenticity of the MCI, compared with fictional MCIs.
- **Testing of New Technologies:** New technology can be simulated and examined in exactly the same triage situation, e.g. different interfaces of a simulated device. Testing can also include the effects of failing technology on the paramedics, for example due to harsh environment.

In conclusion, VR simulations can combine the realism of large-scale exercises with the economy of paper-based simulations. However, VR training simulations are also seen critically. While arguing for the advantages of simulations and serious games, Heldal and Wijkmark (2017) warn about the potential problems in implementing successful VR trainings. Crucial differences are the lack of the same physiological stimulation, the longstanding problem of possible simulator sickness (Kolasinski, 1995), and the lack of tactile feedback and "hands-on" experience of real-life exercises (Hsu et al., 2013). Tactile feedback is usually limited to vibrating controllers, thus providing only a very limited range of stimuli. Until augmented reality can be used to monitor the physical environment and match actual physical props (e.g., position of actual car wrecks, CPR-puppets), or

VR gloves are introduced that provide situation-dependent resistance, tactile feedback is unlikely to be achieved. However, while perfect correlations with the behavior in the real-world are unlikely to be achieved in simulations, behavior only has to be similar enough to be useful (cf. Reimer et al., 2006, regarding driving simulators and real-world driving).

Thus, we agree with Heldal and Wijkmark (2017) and see simulations as a complementary training method instead of a replacement for other training types. Furthermore, the development of immersive MCI simulations is not trivial and should be well-considered. Thus, the question remains how immersion and presence can be achieved with out-of-the-box consumer technology.

TWO ITERATIONS OF MCI VR SIMULATIONS

The need for MCI training and the developments in consumer VR technology have raised interest in the development of MCI VR simulations at our institute. Two training simulations (here referred to as System A and System B) have been developed using a user-centered design process (for more details about UCD in MCI, see Mentler, 2017). Both simulations were developed for the Oculus Rift, with System B being a redesign of System A – enhanced with features designed to enhance immersion and presence (see Figure 1). Both simulations enable the user to select treatment options needed in triage (e.g., checking breathing, placing casualty in recovery position) as well as some distractors, like treatment options only suitable for individual care. In particular, the user must prioritize casualties using triage cards. The focus is on the procedure (e.g., sequence of treatment and chosen options) and not on the specific step-by-step implementation of the measures themselves.

System A (2016)

System A was developed iteratively via a user-centered design process to understand the triage context and determine the necessary functionality. The first iteration used mock-ups, the second one an actual implementation. As MCI scenario, a large-scale traffic accident was chosen, containing damaged vehicles as well as casualties with different injuries. To ensure adaptability, the number of casualties and the weather can be configured by the instructor. The system was formatively evaluated with three domain experts. For development, the Development Kit 2 of Oculus Rift was used; however, we ensured compatibility with the newer Consumer Version 1 of the Oculus Rift device.

System B (2017)

System B was developed using the Oculus Rift Consumer Version 1. This version allows for spatial tracking and can be used with specialized VR controllers (compared to the previously needed standard console controller). More importantly, several design aspects of System A were identified as detrimental to immersion and presence. A formative evaluation with three instructors from a school for emergency personnel was conducted to ensure consistency with the triage process. To add realism, videos from large scale exercises were examined to determine behavior of casualties. These aspects were redesigned to create an improved and consistent MCI VR simulation.

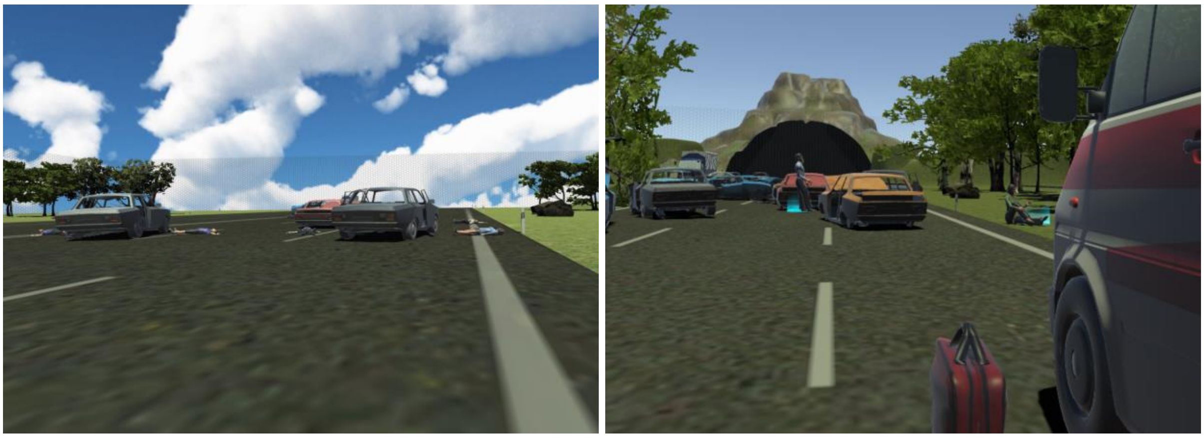
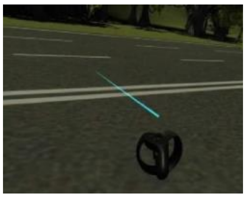


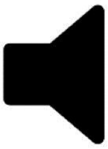
Figure 1. Screenshots of System A (on the left) and System B (on the right)

Differences between System A and System B

While both simulations run on the same system (Oculus Rift Consumer Version 1), the changes between the systems allow for a comparison of the design elements in their effect on immersion and presence. Key differences between the two systems are actual user movement, simulated movement, the used controller, the interface for the treatment of casualties, movement of casualties, and sounds. Table 1 illustrates the key differences between System A and System B.

Table 1. Differences between System A and System B

	System A	System B
Actual User Movement	 The user sits on a chair during movement and treatment.	 The user has limited movement in the room (2x2m) and can kneel near a casualty for treatment.
Simulated Movement	 The user moves forward, backward or sideward by pressing the left stick of the controller. He or she can turn left and right in a limited way by gaze control or turn completely using the right controller stick.	 The user teleports by indicating the target with a simulated light beam. Starting the beam and teleporting is done via a controller button. Treatment positions are highlighted near casualties. Teleportation was implemented to avoid simulator sickness and to allow for user movement within a limited physical space (see above).
Controllers	 A standard Xbox game controller is used. Typically, the user holds the controller with both hands.	 Oculus Touch Controllers are used. Interaction is done by both hands separately for some treatment options, e.g., turning the casualty in a recovery position.
Treatment of Casualties	 Treatment is done by opening a circle menu with a controller button. The items are selected via gaze control and confirmed by pressing a button.	 Instruments and tools are in a simulated emergency bag. The bag opens when kneeling near a casualty. The user must grab instruments and hold them onto the

	System A	System B
		correct body part of the casualty for treatment. To place people in the recovery position, the shoulder and the leg must be grabbed. Pulse can be checked by touching the wrist.
Movement of Casualties	 All casualties lie on the ground and do not move until treatment.	 Casualties can be unconscious but also can have injury-dependent motion. They also look at the user to get attention when he or she is approaching.
Sounds	 Basic sounds are used, like footsteps of the user, breathing sounds when the user has chosen to check the breathing of a casualty, and simple answers of the casualties when being asked to stand up.	 Casualties cry out to get the users attention. They are also able to express pain, in general as well as related to their injuries. Behavior was modelled after participants in MCI trainings (using video recordings) and by asking volunteers to act as if they had been injured. Additional ambient sounds are simulated (e.g., car engines, wind).

Essentially, the user in System A sits on a chair uses the control stick of the controller to move in the simulation and selects treatment options from a menu to select on casualties. The casualties show little movement and only give a few verbal reactions to treatment. In System B, the user actually moves, can kneel next to the casualties, can teleport in the simulated world, and treats casualties by selecting the instruments or tools and holding them to the correct body parts. The casualties scream or shout and move or contort realistically depending on their injuries. The realization of the key differences for System B was much more time-consuming than in System A since the model is much richer and tracking of user movement (see "actual user movement" in Table 1) had to be implemented.

SUMMATIVE EVALUATION OF KEY DIFFERENCES REGARDING IMMERSION AND PRESENCE

The evaluation has two goals: First, to determine the degree of immersion and presence of each system, and second, to directly compare the design differences between the two systems regarding immersion and presence.

Method

Design: A within-subjects design was used to allow for direct comparisons between the two systems. To avoid sequence effects, the order of the systems was changed after each participant (e.g., A-B, B-A, A-B, B-A, …) to avoid training effects due to increased familiarity with VR environments over the course of the study. As the number of participants was unknown beforehand, this approach ensures an equal distribution of the two possible sequences.

Sample: Participants were 18 paramedic trainees (“Notfallsanitäter” in Germany) in their second year of training as trainees are the main target group for the system. Age varied between 19 and 38 years with a mean of

23.1 years (SD = 5.26, n = 17, one missing value). The participants had comparable knowledge and experience, and already knew the procedures for MCIs. Eight participants had prior experience in emergency medical service, one of them for more than two years. As for MCIs, all but one stated to have at least some knowledge about it due to their training.

Setting and Simulations: The evaluation was conducted in a classroom of a paramedic school (see Figure 2). The setting was chosen because it is the place in which these VR trainings would be conducted if the technology gets adopted. In both simulations, six casualties of a large car crash were simulated. The location of casualties stayed the same to keep the simulated physical distances equal; however, the injuries were swapped to avoid learning effects by knowing the specific injury beforehand.

Measures: In addition to socio-demographic information and prior experience (medical emergencies, MCIs, gaming, VR), a translated and modified version of the "Presence Questionnaire" was used (Witmer et al., 2005, values from 1 "not at all" to 7 "completely" and middle value 4 "somewhat"). This questionnaire measures presence and includes 10 items measuring "immersion". For forced choice between the design features, a differential scale with ten steps was used. The images of the respective design features of System A and B (see Table 1) were used as endpoints, and users were asked to indicate which implementation they experienced as more immersive. Users were also interviewed regarding the different simulations and observed while solving the task. We also asked for prior experience in emergency medical service (e.g., prior qualifications or volunteering) and whether they already had experiences with MCIs (see sample).

Procedure: Participants were briefed and asked to fill in the socio-demographic/experience questionnaire. They then saw a short introductory video of the first simulation and were tasked with treating the six casualties. Once finished, they were asked to fill in the presence questionnaire for that simulation. Afterwards the same procedure was repeated for the second simulation. After both simulations had been evaluated, participants filled in the forced-choice questionnaire, were interviewed, and thanked for their participation.

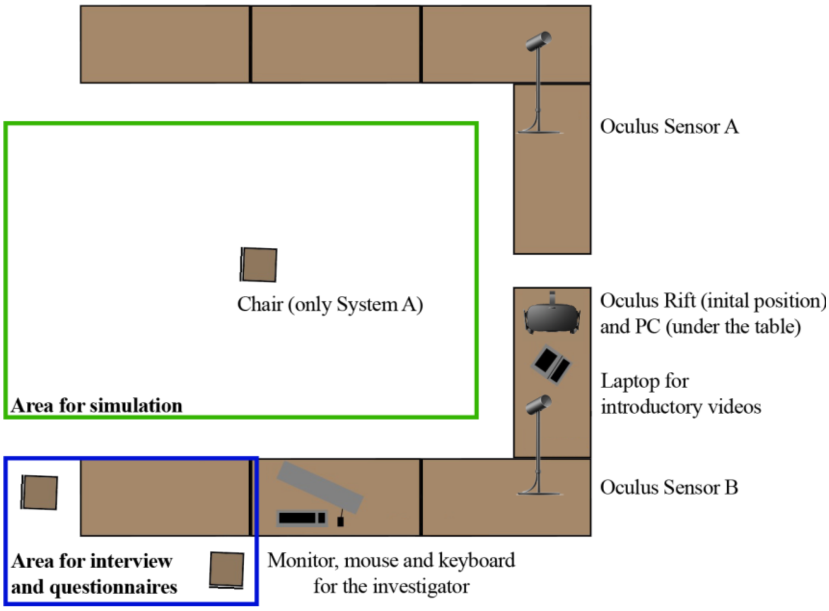


Figure 2. Experimental setup for the evaluation in a classroom of a paramedic school

Results

For the results, we first describe the results of the statistical analysis of comparisons in presence and immersion, followed by observation and interview results.

Presence (separately): The average value for the presence questionnaire was computed for each participant and system (Cronbach's alpha for System A = .80, and for System B = .79). One-sample t-tests were used separately for both systems to determine whether the values were statistically significantly different from the middle value of the scale (4, "somewhat"). Average values for System A (M = 4.85, SD = 0.52; $t(17)$ = 6.90, p < .001) and B (M = 4.82, SD = 0.49; $t(17)$ = 7.17, p < .001) were statistically significant above the middle value of the scale.

Prior Knowledge and Presence: No statistically significant influence of prior experience in gaming or experience as paramedic could be found. However, participants with VR experience did show higher presence in System B.

Immersion (separately): Regarding the immersion items, a subset of the presence scale, the 10 items could be combined as well (Cronbach's alpha for System A = .82, for System B = .71). As with the overall presence questionnaire, the values in System A (M = 5.25, SD = 0.91, $t(17)$ = 5.83, p < 0.001) and B (M = 5.57, SD = 0.64, $t(17)$= 10.43, p < 0.001) differed statistically significant from the middle value of the scale ("somewhat").

Comparison of Presence and Immersion between System A and B: Comparing the values of the presence questionnaire between System A (M = 4.85, SD = 0.52) and B (M = 4.82, SD = 0.49), a paired-samples t-test did not show statistically significant differences ($t(17)$ = 0.167, p = .869). Likewise, the mean of the 10 immersion items did not differ statistically significantly either between systems (M_A = 5.25, SD_A = 0.91; M_B = 5.57, SD_B = 0.64; $t(17)$ = -1.35, p = 0.19).

Direct Comparison of the Effect of the Design Differences on Immersion and Presence: Table 2 shows the results of one-sample t-tests against the neutral middle of the forced-choice scale (values ranged from 1-10, thus 5.5) for each design difference. Figure 3 shows the distribution of answers as box plots. Four out of six design differences were in favor of System B – treatment of casualties, movement of casualties, sounds, and actual user movement. For simulated movement, simulated walking (A) was preferred to teleportation (B). The kind of controller used was not significant.

Table 2. Results for the evaluation of the key design differences. Differences of System A and B (see Table 1) as endpoints. 1 = System A absolutely preferred, 10 = System B absolutely preferred

Design feature	*M*	*SD*	*t*	*P*
Actual User Movement (A: sitting, B: room-tracking)	8.28	2.72	4.34	< .001
Simulated movement (A: controller, B: teleportation)	3.28	2.56	-3.68	.002
Controllers (A: Xbox game controller, B: Oculus Touch)	7.06	3.78	1.75	.099
Treatment of casualties (A: menu, B: medical bag)	8.33	2.03	5.92	< .001
Movement of casualties (A: little, B: injury-dependent)	9.50	0.71	24.00	< .001
Sounds (A: only basic, b: casualties cry out)	9.22	1.17	13.54	< .001

Direct Comparison of System A vs System B: Asked whether participants were more present in the situation in System A or System B, 15 out of 18 decided for System B. Participants emphasized the interaction style (treatment of casualties), movement of casualties, and sounds. However, teleportation was seen as both complicated and too fast – especially given the role of time, incl. movement time, during MCIs.

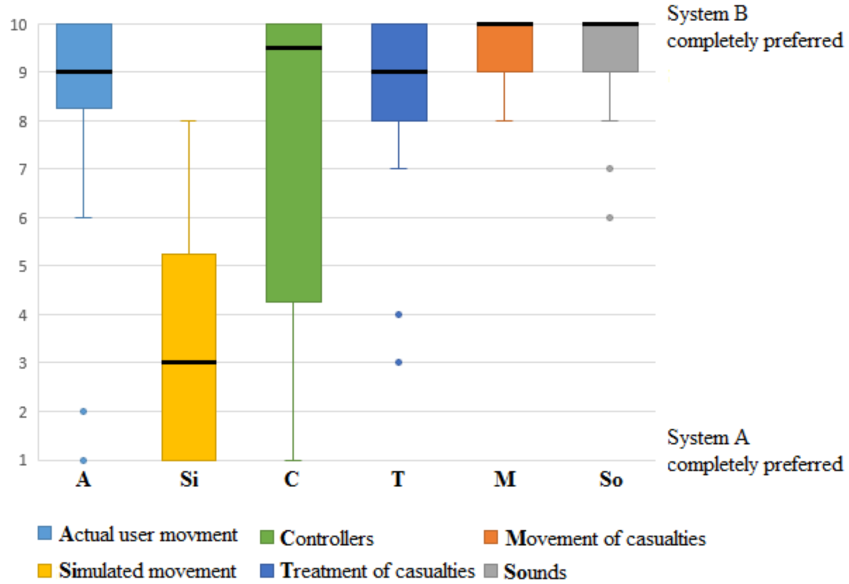


Figure 3. Box plots for the evaluation of the key design differences

Interviews and Observations: Some participants complained of simulator sickness while using System A. They moved more slowly and stopped more frequently. While using System B, participants turned away from the sensors, resulting in a loss of tracking. Despite using teleportation in the simulated world, participants also tried to move out of the tracking area of the device. When a participant came nearer to the borders of the simulation, a blue rectangle showing the borders became visible on the ground. In some cases, attempts to walk out of the area led to participants bumping into the surrounding tables. In severe cases, they tugged at the cables, resulting in a temporary signal loss (black screen).

Discussion

The focus in this evaluation was on immersion and presence as necessary conditions for learning and to ensure that participants take the simulation seriously. Both examined simulations use consumer grade VR hardware and both lead to moderate presence and immersion. Thus, both can be seen as promising. This supports the assumption derived from literature research (e.g., Gutiérrez et al., 2007) that VR technology facilitates immersion. While System B is richer and should be more immersive than System A, the values for presence and immersion were similar. However, loss of tracking and the temporary black screen might have temporarily broken immersion and presence in System B, thus attenuating the overall impression of immersion and presence. An additional sensor would likely prevent the loss of tracking, while wireless transmission would likely avoid the signal loss. System A did not have this problem, as the participants were sitting the whole time. These results suggest that improvements in the technical stability of the simulation are crucial. Currently, the results cannot show that the richness of the simulation is positively correlated with immersion.

However, regarding the design differences, clear preferences became visible. Users strongly preferred using an emergency bag to treat casualties, moving casualties, sounds (incl. shouts and screams), and to move physically, including kneeling by the casualties. They preferred walking in the simulation to teleportation, despite some participants suffering from simulator sickness. While teleportation reduced the simulator sickness problem as expected (see Table 1), it was seen as too complicated and unrealistic, thus likely impeding immersion. Hence, both movement options have specific problems, likely explaining the lack of significant differences between the two systems. Giving the problems with this alternative form of movement, other options should be explored. In a recent study comparing a gamepad, a hand interface, and a walk-in-place approach, Lee and others (2017) conclude that users must actually move their legs in order to facilitate immersion and to avoid VR sickness. Thus, walk-in-place should be considered in further studies. Moreover, once they are ready for market, omnidirectional treadmills might be a worthwhile investment. The reason for the non-significant preference in controller use might be prior experience with gaming controllers. The Oculus Rift controllers are new and might have been unfamiliar to the participants. It is possible that higher familiarity with gaming controllers influenced the results. On the other hand, prior general gaming experience did not influence presence. While VR experience did have a positive effect in System B, all participants were quickly able to interact with both systems.

Compared to traditional methods of training (paper-based simulations and large-scale exercises), MCI VR environments can be seen as a worthwhile addition. While they require more effort and investments than paper-based simulations, which likely continue to have their use to train processes, communication and organization in MCIs, they require much less effort and investments than large-scale exercises. Once developed, they are easily scalable and can be implemented even for individual, self-directed learning (in addition to the other potential benefits of VR simulations mentioned before). However, large-scale exercises have their use, as VR training environments are unlikely to accurately replicate the situation in all aspects (not only in sensory experiences like smell, but also in the required physical actions and stressors). Thus we see MCI VR trainings as occupying an important and needed place between paper-based simulations and large-scale exercises.

However, the benefits of VR are not guaranteed and VR training simulations must be developed with care. Developing richer VR experiences to improve immersion can result in higher development costs as well as potential technical issues that can prevent the users from being immersed in the simulation. At the same time, cost-effectiveness and organizational effort in operation should be considered. In our study, the richer System B not only required more development effort than System A, but also a free space (2x2m + safety distance per user) and a more complex setup for the sensors. The proposed use of omnidirectional treadmills could solve the simulator sickness problem, but adds additional costs to the simulation (see section "Virtual Reality Simulations as Trainings for MCIs"). The right scope has to be defined carefully.

Comparing the design aspects directly with forced choice has its limitations. It is not possible to determine the influence each variation had on overall immersion and presence in the simulation. Doing so would require testing all variations independently, resulting in 64 comparisons. This design would require a prohibitive high number of participants or repetitions. However, to determine which design aspects were seen as more beneficial to presence, the used within-design worked well. We did not assess the number of errors as the focus was on immersion and presence. However, if the performance is recorded (e.g., screen capture or log files), detailed analysis can be performed.

CONCLUSION

In this paper, we examined the two traditional methods of MCI training for paramedics and compared them to virtual reality simulations. Given the resurgence of VR and the availability of consumer grade (and thus affordable) VR hardware, we identified the potential for immersive VR training simulations. The preliminary work highlighted the potential of VR technology to facilitate immersion. To research the effect of design options on immersion, we developed two MCI VR simulations for consumer hardware. The simulations varied in key aspects related to immersion, with richer features implemented in System B. Both systems were evaluated with the main target group of MCI VR simulations: trainees from a paramedic school. Both simulations were sufficiently immersive and led to presence. However, presence can likely be increased by using an emergency bag with direct control approach, movement of casualties, sounds (screams/shouts), and allowing for actual user movement. Movement in the simulation itself is still a crucial open question, with game controllers directed movement leading to simulator sickness and teleportation seen as unrealistic. A walk-in-place approach or omnidirectional treadmills might be possible ways to solve this dilemma.

Our study did show that immersive MCI trainings with consumer grade technologies are possible. They can also occupy an important place between paper-based simulations and large-scale exercises. If developed further and made available in paramedic schools and rescue stations, paramedics can train for MCIs in order to allow them to face these situations with increased confidence and perform the right actions, even if MCIs – thankfully – happen rarely and infrequently.

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