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Abstract

Background: Mass-casualty incidents (MCIs) are catastrophic. Whether they arise from natural or man-made disasters, the nature of such incidents and the multiple casualties involved can rapidly overwhelm response personnel. Mass-casualty triage training is traditionally taught via either didactic lectures or table top exercises. This training fails to provide an opportunity for practical application or experiential learning in immersive conditions. Further, large-scale simulations are heavily resource-intensive, logistically challenging, require the coordination and time of multiple personnel, and are costly to replicate. This study compared the simulation efficacy of a bespoke virtual-reality (VR) MCI simulation with an equivalent live simulation scenario designed for undergraduate paramedicine students. **Methods:** Both simulations involved ten injured patients resulting from a police car chase and shooting. Twenty-nine second-year paramedicine students completed the live and VR simulation in a random order. The training efficacy of the VR and live simulation was evaluated with respect to student immersion and task-difficulty, clinical decision-making (i.e. triage card allocation accuracy and timeliness), learning satisfaction, and cost of delivery. **Results:** While perceived physical demand was higher in the live simulation compared to VR ($p < 0.001$), no differences were observed across mental demand, temporal demand, performance, effort or frustration domains. No differences were found for participant satisfaction across the two platforms. No differences were observed in the number of triage cards correctly allocated to patients in each platform. However, participants were able to allocate cards far quicker in VR ($p < .001$). Cost of running the VR came to AUD $712.04 (staff time), compared to the live simulations which came to AUD $9,413.71 (staff time, moulage, actors, director, prop vehicle), approximately 13 times more expensive. Conclusion: The VR simulation provided near identical simulation efficacy for paramedicine students compared to the live simulation. VR MCI training resources represent an exciting new direction for authentic and cost-effective education and training for medical professionals.
Key words: mass casualty incidents; education; training; virtual reality; clinical decision-making; simulation

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Introduction

Mass-casualty incidents (MCIs) are catastrophic. Whether they arise from natural or man-made disasters, the nature of such incidents and the multiple casualties involved can rapidly overwhelm the resources and personnel dispatched to these incidences. The infrequent nature of MCIs limits the amount of exposure of emergency personnel to these events, rendering many ill-equipped to deal with the sheer number of casualties and the allocation of resources. It is therefore necessary to ensure that paramedics are provided with the appropriate systematic training and preparation to equip them with the necessary skills to ensure an effective and safe response (1).

The emergency preparedness of many healthcare organizations and individuals in responding to MCIs is far from adequate (1–5). One of the most essential components of MCI response is patient triage. Mass-casualty triage requires rapid and accurate decision-making to ensure patients are appropriately prioritized. This has traditionally been taught via classroom lectures, seminars and tabletop exercises covering basic elements of disaster response. This training involves little participant immersion, limits contextualization of the emotional and environmental stressors of a MCI, and typically only provides training for a limited number of people (6, 7). Given the limitations of this training to realistically portray MCIs, many advocate for the use of simulation for MCI training. MCIs are highly chaotic, and the responses so multifaceted, that re-creating a calamitous event is a better way to teach and reinforce core concepts (8, 9). However, the design and delivery of live simulation exercises are logistically challenging, require coordination and time of multiple personnel, and are costly to replicate (10–12). The development of cost-effective, highly immersive MCI training exercises would be beneficial in addressing the current limitations associated with both classroom and simulation MCI triage training.

Virtual reality (VR) is a simulated environment which uses digital sound and visual effects to create an authentic experience. Three-dimensional VR environments are produced using multiple cameras, computer-generated imagery (CGI), surround sound and specialist software to create an immersive digital world in which a user can be placed in and explore. Since first appearing in the 1960s, VR technologies have evolved to become increasingly similar to the real world. VR can be classified as either ‘non-immersive’ or ‘immersive’. The former is associated with computer-based settings that can simulate environments in real or conceived worlds; the latter takes this concept a step further by providing the user with the perception of being present in the nonphysical world. While non-immersive VR can be based on a standard computer, the advent of new tools such as the ‘Oculus Rift’ (Oculus, Irvine, USA) has seen immersive VR technology progress to become far more user-friendly and economically accessible. Further, the advent of new game engines are enabling development of immersive VR applications by independent game designers at a level of quality only previously possible by major corporations. With modern graphical and computational processing units enabling increasingly immersive VR experiences with interactive and user involvement capabilities, immersive VR is becoming more popular in the education setting and is making learning environments more engaging and motivating for learners. Furthermore, immersive VR is considered novel in the healthcare education setting, with technology only very recently becoming available that makes education and training in this sector viable (13). In the healthcare education setting, VR has been shown to be effective in the training of skills such as communication, teamwork and empathy (14–16). In addition, VR is able to expose learners to rare or dangerous situations that are difficult to replicate through traditional simulation environments (17–19).

Following initial equipment hardware purchase and content software development, VR simulations have minimal ongoing maintenance costs. By comparison, effective live mass-casualty simulations involve multiple actors, various settings, patient moulage and substantial coordination of personnel to provide a viable learning experience, with these contributions required each and every time a training exercise is offered. Furthermore, providing realistic live simulation environments is problematic given most institutions are not equipped with necessary simulation infrastructure. Therefore, given the logistic and financial opportunities associated with VR compared to live simulation training, we aimed to compare the simulation efficacy of a bespoke VR MCI triage training simulation against a comparable live simulation scenario.

METHODS

Design

A within-subject comparison trial was conducted to compare the simulation efficacy between a VR MCI training simulation (produced via a collaborative partnership between Edith Cowan University [ECU] and VR software development company Virtual Guest Ltd) and a comparable live-simulation event amongst undergraduate paramedicine students for measures of 1) immersion, 2) clinical decision-making, 3) learning satisfaction, and 4) cost.

Mass-Casualty Training VR Design

An iterative research process was undertaken to design and develop the immersive VR MCI triage training exercise for emergency healthcare students. A scenario script was formulated, involving ten casualties, each with a carefully generated clinical story, including a set of observations (conscious state, open vs. obstructed airway, respiratory rate and pulse rate) and an associated triage category (immediate, delayed, walking-wounded, deceased). The script was story-boarded and piloted amongst a small group ($n = 5$) of paramedicine students from ECU, as well as with currently practicing paramedics ($n = 5$), to ensure the scenarios were realistic and met identified learning objectives.

Clinical Scenario. Learning objectives focused on the user’s ability to make decisions for fast and effective

TABLE 1. Patient descriptions and vitals

Patient No.	Primary injury description	Correct triage card allocation	Patient vitals Breathing	Respiratory Rate	Pulse rate
Patient 1	Gunshot wound to head	Immediate (Red)	Yes	<9	>120
Patient 2	Gunshot to center chest	Immediate (Red)	Yes	<9	>120
Patient 3	Gunshot to abdomen	Urgent (Yellow)	Yes	10–29	>120
Patient 4	Traumatic brain injury	Deceased (Black)	No	n/a	n/a
Patient 5	Impaled through armpit	Urgent (Yellow)	Yes	10–29	>120
Patient 6	Gunshot to neck	Deceased (Black)	Yes	>30	>120
Patient 7	Blunt force to head	Immediate (Red)	Yes	>30	>120
Patient 8	Panic attack	Walking-wounded (Green)	Yes	10–29	>120
Patient 9	Open fracture to arm	Walking-wounded (Green)	Yes	10–29	>120
Patient 10	Blunt force to abdomen	Urgent (Yellow)	Yes	10–29	>120

*Patient vitals were available for view within the VR experience, allowing participants to make a clinical decision as to the appropriate triage card.

triage of patients. The scenario itself opened at the aftermath of an incident resulting from a car chase between a perpetrator and police. The car chase ended with the vehicle crashing into pedestrians and the perpetrator shooting one police officer, two pedestrians and then himself, resulting in multiple casualties with varying injuries. Participants were tasked with triaging all ten patients. The triage method utilized was based on the Simple Triage and Rapid Treatment (START) adult triage algorithm (20). Since the development of the START triage method in the 1980's, it has been adopted by pre-hospital trauma life support education providers, health care systems and ambulance service providers all over the world (21). Patient profiles with corresponding vitals provided to participants can be seen in Table 1.

Mass-Casualty Training VR Development

360 degree VR compatible footage was recorded at the Western Australian (WA) Police Academy's Joondalup Police Village using a purpose-built OZO VR camera (Nokia Pty Ltd, Espoo Finland). This camera synchronizes eight cameras mounted and outward facing from a single camera housing. Footage is then 'stitched' together to produce stereoscopic 360-degree spherical video and sound. The camera footage can also be formatted for viewing on a standard desktop or camera screen. Filming took place on a single day. Moulage was applied to ten patient actors by moulage experts from TraumaSim (WA, Australia) to simulate wounds acquired by the MCI. Following filming, the 360-degree film content was then edited to produce the finished immersive VR experience suitable for display via an Oculus Rift (Oculus, Irvine, USA) or HTC Vive headset (HTC Corporation, New Taipei City, Taiwan).

Customized software was built into the game engine to enable user interaction with the 360-degree film. Using the HTC Vive controller, participants could click on designated icons attached to each patient within the virtual world to gather basic clinical information (i.e. airway, respiratory rate and pulse rate), and also allocate an appropriate triage card. Software analytics quantified the user's triage decision-making with respect to correct versus incorrect triage categories, as well as timeliness of triage. The bespoke software provided feedback to users regarding correct versus incorrect triage assignment of patients, as well as the order and timeliness of their triage assignments. Software analytics could be exported to a spreadsheet for further analyses.

Live Mass-Casualty Simulation Scenarios

Live simulation scenarios took place in a controlled outside area of the university campus. The same actors utilized during filming of the VR footage portrayed the same patients with identical injuries in the live simulation. Similarly, moulage and patient scripts across both platforms were uniform. For the live simulation scenario, participants entered the scenario alongside a clinical preceptor (a confederate actor with a paramedic clinical background) who provided basic clinical information matching that provided on-screen in the VR environment. Preceptors were instructed to in no way prompt or influence the participant's decision-making processes with respect to triage allocation. All live scenarios were video-recorded (first-person point-of-view) via Garmin VIRB Action Headcams (Garmin, Kansas, USA). In the VR environment, students were provided with the opportunity to gather this clinical information themselves by clicking on designated icons. Participants were also provided with a series of prompts (built into the VR program) that depicted a series of triage options for

FIGURE 1. An undergraduate paramedic student wearing the virtual reality headset (left image) and a representation of participant's view of designated icons depicting clinical information and triage card options while completing the virtual reality scenario (right image).

them to choose from (immediate, urgent, walking-wounded, deceased). Prior to undertaking the VR experience, participants completed a virtual tutorial introducing control functions, allowing them to practice obtaining vital signs and triaging a patient. Participants were informed they could practice these components as many times as they liked prior to beginning the scenario (Figure 1).

Participants

Twenty-nine students enrolled in a Bachelor of Science (Paramedical Science) at ECU participated in the study. All participants undertook both the VR MCI simulation and the matched live MCI simulation. However, the order of exposure to VR was randomized across the participant cohort. To ensure participants preexisting scope-of-practice and skillset were of relative standing, for participants to be eligible they were required to be enrolled into their third-year practical-unit entitled Advanced Paramedical Practice 2. Students had previously undertaken a table-top didactic MCI discussion/workshop session embedded into the unit. The research was approved by the ECU Human Research Ethics Committee (#19446).

Measures

Immersion. Heart-rate data was recorded at 5-second intervals via Polar s610i watches and chest straps (Polar, Kempele, Finland). Baseline heart rate was established for 60 seconds immediately prior to scenario commencement for both the VR and live simulation study conditions. Students' perceptions were also measured via the National Aeronautics and Space Administration Task Load Index (NASA-TLX), a paper and pencil instrument requiring students to rate their perceived burden of the simulation along 20-point scales across six dimensions of demand; mental, physical, temporal, performance, effort and frustration. The NASA-TLX underwent a rigorous 3-year development and validation period and has appeared in over 200 publications (22). The NASA-TLX has previously been used in successful studies of aviation simulation, perceived workloads in the health industry (23–25) and more recently in studies specifically investigating simulation fidelity (26, 27).

Clinical Decision-Making. For the live simulation, two paramedic clinical educators viewed each of the scenario videos and confirmed the triage card placement on each patient, the order of placement on patients and the timing of each card placement from scenario beginning. For the VR scenario, the customized software automated this process by providing output on triage placement for each patient, the order of card placement and the time from scenario beginning of each card placement. For both the live and VR simulations, the scenario 'start-point' was uniformly interpreted (i.e. when the police officer introducing participants to the scene had ceased talking, allowing participants to approach patients).

Satisfaction. Satisfaction with each simulation environment was assessed using the Simulation Design Scale (SDS). The SDS is a 20-item scale assessing student perceptions of information, support, problem solving, feedback and fidelity in simulation using 5-point Likert scale responses. The tool has undergone psychometric evaluation with undergraduate health students with authors concluding the tool meets appropriate standards of validity and reliability and is suitable for use in educational research (28).

Focus Groups. Two focus groups consisting of a sub-set of eight participants each were conducted following exposure to both VR and live simulation-based learning conditions. The focus groups delved into the participant's perceived value of the two learning environments, focusing on their experiences, perceived performances and satisfaction with each. A pragmatic, action-research orientated, interpretive inquiry approach was utilized as participants recalled their immediate experiences, feelings, beliefs and perceptions regarding the scenarios. Participant interviews were audio-recorded and transcribed verbatim. QST NVivo software was used to organize text, code and identify consistent themes. Bracketing techniques were used during coding to minimize researchers' preexisting biases and suppositions (29). To ensure rigor, two researchers independently reviewed the transcriptions before meeting together to compare notes and arrive at a final consensus on coding and theme identification.

Cost Analysis. Using the methods applied by Maloney and Haines (30), a cost analysis was undertaken. This method produces an estimate of cost difference per participant. The cost of the resources required to expose students to the VR content were compared to the cost of exposing students to the live simulation. Maloney and Haines (30) suggests development costs and preexisting infrastructure costs should not be included in cost-analysis comparisons.

Procedure. Data collection took place over two consecutive days in August, 2018. A random selection of 15 participants completed the VR scenario on the first day of data collection, and the live scenario on the second day. The remaining 14 participants completed the live simulation on the first day and the VR scenario on the second day. Following the gathering of informed consent, all participants signed a confidentiality agreement confirming they would not discuss the clinical scenarios with anyone before data collection was completed on the second day. This approach has been used in the past by the researchers to limit discussion of clinical content amongst participants whilst data collection is ongoing (26, 27, 31). Prior to entering scenarios, participants put on the heart-rate monitor and were provided with a short brief before entering the scene. This brief was designed to mirror the detail provided to paramedics in the field via radio prior to arriving on scene:

> *"You have been called to an incident. Car versus multiple pedestrians. Firearm may be involved. Police have secured the scene and it is safe to approach. Approximate number of patients is 10. You have back-up enroute."*

Following this and immediately prior to entering the scene, participants (for both study conditions) were approached by a policeman (same actor for both study conditions), who provided further information on the incident:

> *"Thanks for getting here so fast. OK so the scene is secure. I have removed the weapon. The suspect has driven through a crowd of people and then fired at them. He then shot himself in the head. There are a lot of people that need attention, and he's shot my partner in the chest. Come on through."*

Upon completion of the scenario, participants were debriefed and thanked for their time.

Analysis. A series of paired sample t-tests were utilized to compare differences between simulation environments for 1) average and peak heart-rate, 2) perceived workload (NASA-TLX), 3) satisfaction (SDS), and 4) clinical decision-making (i.e. number of correct triage card allocations and timing of allocations). Chi-square tests were used to assess differences in the number of correct cards allocated to the individual patients between the VR and live simulation study conditions. A power analysis using G*Power (v3.1.7) suggested a sample size of 27 was sufficient to detect a statistically significant difference for a medium effect size ($f = 0.4$) with an alpha value of 0.05 (two-sided) and power of 80% ($\beta = 0.20$). A cost analysis was undertaken following the recommendations of Maloney and Haines (30).

RESULTS

Immersion

Average heart rate was significantly higher during live simulation scenarios compared to the VR simulation ($p < 0.001$; Table 2). Furthermore, heart rate increase relative to resting and maximum heart rate were significantly higher during the live simulation compared to the VR simulation ($p < 0.001$). No significant difference was observed in resting heart rate in the 60 second lead-up to entry within the VR

TABLE 2. Immersive value of the virtual reality platform compared to live simulation

Immersion	Virtual Reality	Live Simulation	p-Value[#]
Heart rate (beats per minute)			
Resting heart rate	99.74 ± 14.64	105.73 ± 16.64	0.342
Average heart rate during scenario	101.87 ± 16.92	124.09 ± 19.73	<0.001*
Heart rate increase (relative to resting)	2.13 ± 5.28	18.36 ± 12.11	<0.001*
Maximum heart rate	117.13 ± 19.84	145.54 ± 20.18	<0.001*
NASA-TLX			
Total score	48.24 ± 19.20	62.28 ± 16.41	<0.001*
Mental demand	11.41 ± 5.18	14.10 ± 4.35	0.066
Physical demand	3.41 ± 2.95	6.52 ± 3.51	<0.001*
Temporal demand	8.97 ± 5.59	12.41 ± 5.30	0.160
Performance	7.79 ± 4.34	8.31 ± 3.69	1.000
Effort	10.86 ± 4.38	13.48 ± 3.75	0.066
Frustration	5.79 ± 4.48	7.45 ± 5.67	0.705

[#]Holm-Bonferroni correction was used to adjust for multiple comparisons.
*Values are significant at $p = 0.05$.

and live simulation platforms, indicating no between-group differences in anticipation of the upcoming scenario. Upon visual inspection of the average heart rate data across the duration of the mass-casualty scenarios (Figure 2), a distinct peak can be seen within the first 20 seconds of the live simulation in comparison to the VR platform. It is possible that this peak in heart rate is due to movement artifact (i.e. the onset of walking from a resting state).

Comparisons between the VR and live simulation scenarios when assessed using the NASA-TLX revealed a significantly higher perceived workload in the live simulation compared to the VR simulated scenario ($p < 0.001$; Table 2). The component of the NASA-TLX that seemingly mediated this difference in perceived workload was physical demand ($p < 0.001$), with no differences observed across mental demand, temporal demand, performance, effort or frustration domains ($p > 0.05$).

Clinical Decision-Making

No differences were observed in the number of triage cards correctly allocated to patients in the VR compared to the live simulation scenarios ($p > 0.05$; Table 3), indicating comparable decision-making across the two platforms. Participants took a significantly longer time to assess and triage patients 1–5, 7 and 10 in the live simulation compared to the VR scenario (Table 3), which resulted in a significantly longer overall time taken to complete the live simulation ($p < 0.001$).

Satisfaction

No significant differences were observed in the total scores on the satisfaction and importance components of the simulation design scale ($p > 0.05$; Table 4), indicating no difference in satisfaction with the design elements or perceptions of importance of the simulation design elements between the VR and live simulation scenarios. Of a total of 26 participants who completed the simulation design scale for both study conditions, 65% were in agreeance or strong agreeance that the objectives and information, support, problem solving, feedback and fidelity provided in the VR scenario were satisfactory, compared to the 54% in agreeance or strong agreeance for the live simulation scenario (Figure 3).

Focus Group Discussions

Virtual Reality and Live Simulation Comparison. Participants expressed that the VR experience was graphically realistic and therefore comparable to the live simulation with respect to visual and auditory information provision. Participants conveyed that the graphics of the VR scenario exceeded their expectations.

> *I was really in awe of the level of graphics, how much it matched the live situation, it was really a lot like the live simulation.*

However, participants did suggest the VR, in contrast to the live simulation, was unable to replicate the human interaction and emotional immersion element of the experience to the same extent. While participants noted the VR experience was not completely void of these elements, it did not provide this form of immersion to the same extent as the live simulation. In contrast though, participants expressed that in VR they could better focus on their triage skills and could better 'drown-out' the background noise of the patients.

> *Like, you still need to consider the screaming patients in the scenario, and think about where you are, like the petrol-station or whatever it is. All that is still thrown at you. It's right there. You're in it, but you can remove the emotion from it. You can walk in and absolutely just think clinically. These people can't hear me and these people can't see me so I just do my 'thing' and get out.*

> *I think once you know how to triage, then you can be put in that real life situation and have that extra pressure. So, I found that VR, doing that first was really good for me because I haven't done that in real*

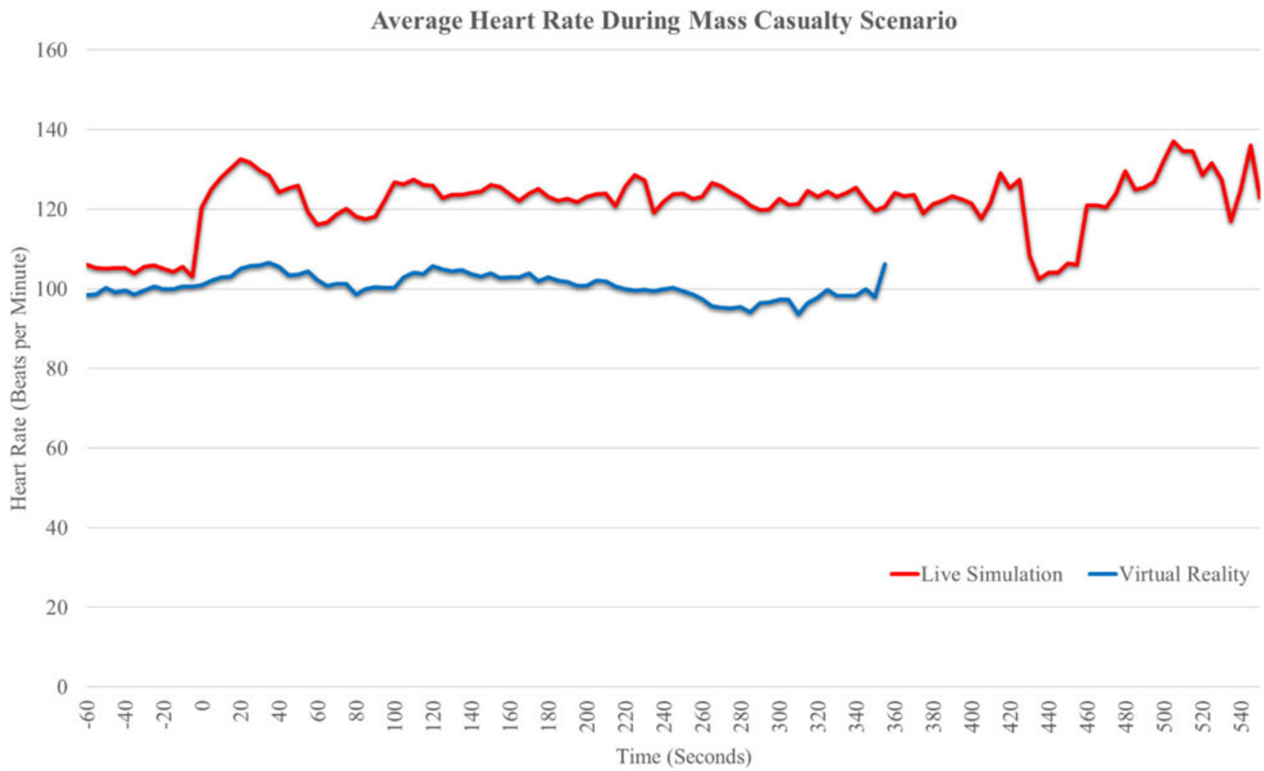

FIGURE 2. Visual representation of the average heart rate during the VR (blue) and live simulation (red) mass-casualty scenarios.

TABLE 3. Analysis of decision-making of participants on the virtual reality platform compared to live simulation

Decision-making	Virtual Reality	Live Simulation	*p*-Value[#]
Time taken to complete scenario (sec)	210.55 ± 35.14	360.14 ± 74.47	<0.001*
Number of cards allocated correctly	7.97 ± 1.81	8.52 ± 1.66	1.000
Time taken to allocate card to patient (sec):			
Patient 1	19.79 ± 11.19	44.76 ± 21.25	<0.001*
Patient 2	20.96 ± 9.21	45.86 ± 21.20	<0.001*
Patient 3	18.82 ± 8.21	38.24 ± 13.35	<0.001*
Patient 4	17.36 ± 6.91	30.41 ± 16.48	<0.001*
Patient 5	18.52 ± 6.65	36.83 ± 14.69	<0.001*
Patient 6	25.76 ± 21.47	29.48 ± 13.09	0.704
Patient 7	22.67 ± 9.57	42.93 ± 18.82	<0.001*
Patient 8	21.15 ± 11.48	25.86 ± 19.86	1.000
Patient 9	20.38 ± 12.37	18.90 ± 10.93	1.000
Patient 10	20.64 ± 8.10	38.66 ± 15.82	<0.001*
Number of correct cards allocated to patient (number, %):			
Patient 1	26 (89.7)	28 (96.6)	1.000
Patient 2	23 (79.3)	26 (89.7)	0.856
Patient 3	16 (55.2)	23 (79.3)	0.861
Patient 4	28 (96.6)	29 (100)	1.000
Patient 5	23 (79.3)	22 (75.9)	0.956
Patient 6	26 (89.7)	22 (75.9)	0.749
Patient 7	26 (89.7)	25 (86.2)	1.000
Patient 8	23 (79.3)	28 (96.6)	0.462
Patient 9	26 (89.7)	28 (96.6)	1.000
Patient 10	14 (48.3)	16 (55.2)	0.562

[#]Holm-Bonferroni correction was used to adjust for multiple comparisons.
*Values are significant at $p = 0.05$.

TABLE 4. Comparison of the satisfaction experienced by the participants upon exposure to the virtual reality versus the live simulation platform

Satisfaction	Virtual Reality	Live Simulation	p-Value#
Simulation Design Scale: Satisfaction			
Total score (/100)	83.69 ± 11.92	81.88 ± 10.03	1.000
Objectives and information (/25)	23.58 ± 2.32	22.73 ± 2.77	1.000
Support (/20)	17.96 ± 3.91	16.85 ± 4.05	1.000
Problem Solving (/25)	21.31 ± 3.32	19.92 ± 4.26	0.697
Feedback/guidance reflection (/20)	12.04 ± 7.67	12.62 ± 6.17	1.000
Fidelity (realism; /10)	8.81 ± 1.52	9.77 ± 0.86	0.378
Simulation Design Scale: Perceptions of Importance			
Total score (/100)	88.88 ± 10.44	90.96 ± 7.62	1.000
Objectives and information (/25)	22.92 ± 2.26	23.69 ± 1.78	1.000
Support (/20)	17.69 ± 3.63	17.77 ± 2.61	1.000
Problem Solving (/25)	21.38 ± 3.11	21.88 ± 3.23	1.000
Feedback/guidance reflection (/20)	17.62 ± 3.35	18.08 ± 2.79	1.000
Fidelity (realism; /10)	9.27 ± 1.46	9.54 ± 1.03	1.000

#Holm-Bonferroni correction was used to adjust for multiple comparisons.
*Values are significant at $p = 0.05$.

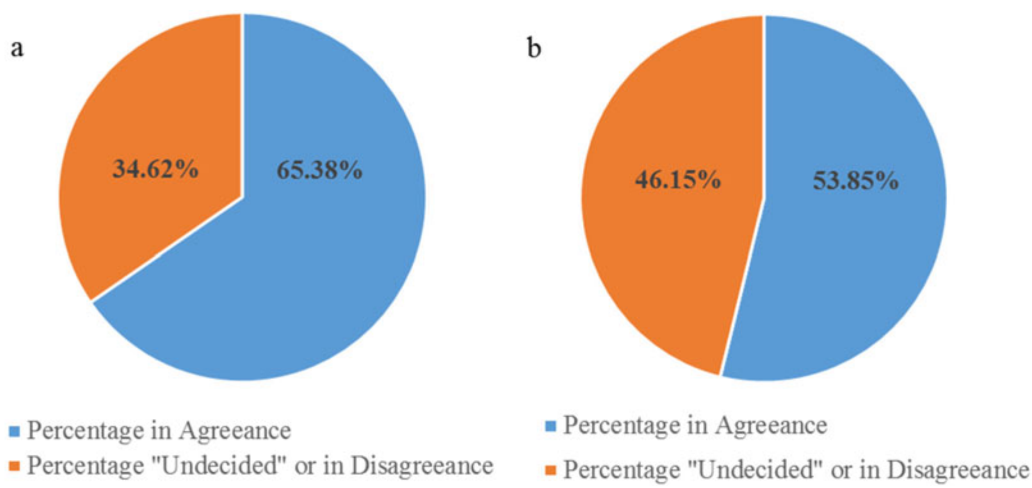

FIGURE 3. Percentage of participants in agreeance or strong agreeance (blue) that the objectives and information, support, problem solving, feedback and fidelity elements of the simulation were satisfactory for (a) the virtual reality and (b) the live simulation scenarios using the simulation design scale (SDS).

life before. Simulation or not. So, I found the VR really good just to practice that skill alone without the extra stress.

This was reflected by several students, who described the VR experience to be a suitable "stepping stone" to the live simulation.

I quite enjoyed both. I think the live one was a bit more intense, like more full-on. It felt more real, but in the VR I could tune out everything that was happening and just focus on what I was doing.

VR Mechanics and Useability. Some participants did express some initial difficulty navigating the VR controls. One participant felt they missed a measurement of vitals because they pressed the wrong button. Similarly, another participant suggested they accidentally allocated the wrong card and, due to self-imposed time pressures, chose not to return to re-card that patient. However, the clear majority of students agreed that, although they found the controls troublesome in the beginning, they did achieve competence with the controls by the end of the scenario, and suggested they would not have any further trouble in subsequent scenarios once they were familiar with the controls. Several participants agreed they found the pre-scenario tutorial useful in conveying information about what they were required to do, and given their time again would have elected to spend more time to practice using the buttons prior to moving on to the actual scenario.

I definitely underestimated that it would maybe be harder to use the controls once the scenario started. It was so easy in the tutorial but then when it all began

Table 5. Analysis of variable costs alone of VR compared to live simulation platform

Cost Breakdown	Virtual Reality	Live Simulation
Variable costs alone*		
Moulage	–	$3,481.00
Actors	–	$4,200.00
Prop vehicle	–	$350.00
Director	–	$625.00
Staff	$712.04	$757.71
Total for 29 participants	**$712.04**	**$9,413.71**
Total per participant	**$24.55**	**$324.61**
Total per 100 participants	**$2,455.00**	**$32,461.00**
Total per 400 participants	**$9,820.00**	**$129,844.00**
Fixed costs of VR inclusive#		
Moulage	$2,580.75	$3,481.00
Actors (casting included)	$7,272.73	$4,200.00
Prop vehicle	$350.00	$350.00
Director of film, photography & sound	$4,090.91	$625.00
Post production editing	$17,363.63	–
Software development	$10,790.00	–
Staff	$712.04	$757.71
Total for 29 participants	**$43,160.06**	**$9,413.71**
Total per participant	**$42,472.57**	**$324.61**
Total per 100 participants	**$44,903.02**	**$32,461.00**
Total per 400 participants	**$52,268.02**	**$129,844.00**

*Ongoing costs once VR content and equipment has been secured.
#includes fixed costs of VR content development. Does not include costs of procuring VR equipment/hardware or infrastructure to facilitate live mass casualty incident training event. Calculated by VR development cost + ($24.55 * no. of participants)).

there was a lot to think about so I forgot some of the controls. It was easy to pick it back up but it was a factor.

Cost Analysis

A cost analysis was conducted to determine the costs involved with running the VR scenario compared to the live simulation scenario for the 29 individuals that participated (Table 5). As per the recommendations of Maloney and Haines (30), costs were separated into fixed and variable costs. Based on our cost analysis, when including VR content development costs, cost neutrality would occur at the 145 participant mark.

A comparison of the running costs associated with the VR and live simulation platforms revealed that the VR platform is a more cost-minimising means of delivering mass-casualty simulation, costing a total of $712.04 over the course of a half day in comparison to the $9,413.71 for the live simulation platform (Table 5). These data suggest the costs of running the VR scenario are less than 10% of the costs of running a comparable live simulation over the course of one teaching year. When extrapolating this information to a cohort of 200 students, an estimated 3.5 days would be required, equating to a total of $4,984.28 for the VR platform compared to $65,895.97 for the live simulation platform.

Discussion

There is a need to find low-cost, comparable alternatives to table-top exercises and live simulation that can be used to enhance training for MCIs for emergency medical personnel. While several studies provide descriptions of VR systems used for training personnel for MCI response (32–34), this is the first study to our knowledge that compares an equivalent immersive VR and live simulation platform for MCI triage training across factors of immersion, decision-making, satisfaction and cost. One previous study did undertake a similar comparison between a non-immersive virtual-based aeromedical evacuation training system and a comparable live simulation, but focused on decision-making elements only (35). Another investigated differences in knowledge improvements between immersive VR and a standardized patient drill amongst postgraduate medical residents (36). Results of both these studies suggested improvements for their respective measures were comparable between the VR and live simulation environments.

Based on data generated from heart rate measures, the NASA-TLX questionnaire and focus group data, the live simulation platform seemingly had greater immersive potential compared to the VR platform. However, upon analysis of the individual components of the NASA-TLX questionnaire, the higher total score of the NASA-TLX for the live simulation was driven by the physical demand of the scenario, while the mental, temporal, performance, effort and frustration components of the scale were comparable across both platforms. This was also reflected in the heart rate data. While the average heart rate during the scenario and the maximum heart rate were higher during the live simulation compared to the VR scenario, it is important to note that participants had a higher physical demand during the live simulation scenario. This is likely due to participants needing to physically walk between patients in the live scenario, as opposed to remaining stationary during the VR scenario, which is likely to have caused an increase in heart rate. Taken together, this data suggests that the VR platform has comparable immersive potential to the live simulation platform.

Participants performed equally well on both the VR and live simulation platforms and the majority were satisfied with the objectives, information, support and feedback given, as well as the approach to problem solving and fidelity across both platforms. However, one aspect that was lacking, according to the focus group interviews, was the human interaction and emotional experience that would be evident when assessing and treating live patients. Emotional distress has been shown to affect health professionals' decision-making and may impact on the speed and accuracy at which patients are assessed and triaged (37, 38). This may somewhat explain the significantly greater time taken to triage patients in the live compared to the VR scenario. However, it is important to note that participants suggested the lack of emotional demand in the VR scenario had both positive and negative connotations. From a more positive standpoint, the VR environment allowed participants to target their focus on clinical decision-making aspects, without being distracted by accompanying environmental factors, yet still encompassed sufficient environmental fidelity to facilitate adequate buy-in. In contrast, participants suggested the live simulation engendered a greater sense of urgency and corresponding immersion (although this finding was not supported by the NASA-TLX data) and better reflected a real-world MCI. In this fashion, it appears the two mass-casualty simulation environments are not without their own individual merits, and it is likely dependent on the prescribed learning outcomes and experience educators are striving to provide for their students to suggest which is more appropriate. It is entirely likely that a combination of both, with VR training first, followed by live simulation experiences, would best prepare students for performing in real-world MCIs. Future research should investigate different progressions of VR versus live simulation, perhaps also incorporating table-top exercises into experimental design, to identify the best training progression and allocation of resources for MCI response preparation.

A major strength of the present study was the random exposure of participants to the VR and live simulation scenarios. As participants completed both scenarios on consecutive days, it is possible that some individuals performed better on the second day, as they had the opportunity to practice their triage skills. However, by randomizing the exposure of the participants to each environment, improvements in performance due to practice effects would have been negated. The within-subject randomized-crossover design also allowed for direct comparison of decision-making, immersion and satisfaction across the two platforms with comparisons free of confounding from between-subject random effects, such as students preexisting clinical abilities. Further, researchers worked hard to ensure consistency of factors across study conditions (e.g. scenario, patients, actors, moulage) allowing a more direct comparison between the VR and live simulation environments.

This study is not without limitations. Comparative to some mass casualty incidents the number of patients in our scenario was small. However, we note that mass casualty incidents can range from major or significant incidents through to more catastrophic events involving larger numbers of patients. It is unclear (and beyond the scope of this study to determine) how many attempts at patient triage would typically be required to achieve skills mastery and knowledge retention. This could provide an interesting avenue for future research. Also, heart rate data may have been confounded by movement artifact during the live simulation and therefore may not be an accurate representation of arousal or immersion. Although, heart-rate data was interpreted in alignment with NASA TLX and focus group data. Further, while we based our study sample size on a number of other published studies undertaking similar work utilizing between-subject study designs comparing VR applications to traditional training methods with similar or smaller sample sizes (35, 36, 39, 40), some may consider our study sample to be small which may limit the generalizability of our results. Although, the utilization of a within-subject study design does enhance our studies statistical power by comparison. In addition, participants in this study were third-year paramedicine students who have not yet had extensive practice experience and would likely not have experienced an incident involving multiple casualties. While care was taken to interview practicing paramedics and paramedic educators to ensure applicability of the scenario, future studies should assess the utility of VR training in practicing paramedics—ideally who have experienced an incident involving multiple casualties—to better ascertain the applicability of the training.

VR MCI resources show promise as a valuable training tool within the paramedic student curriculum. While the physical and emotional demands of VR training may be limited in comparison to live simulations, VR showed comparable immersion, decision-making and satisfaction outcomes to live simulation and provides a cost-minimizing method of delivering MCI response training. Granted, in order to ensure comparable learning environments between the VR and live simulation study conditions, we employed professional actors, high-fidelity moulage and props that would have contributed to scenario realism. Other educators may choose to limit these costs by utilizing patient volunteers and forgo sophisticated moulage to depict patient injuries. Although, previous research makes clear that such cost-cutting endeavors is accompanied by lower contributions toward student learning (27). Exposure to mass-casualty simulation using a VR platform may allow students to hone their skills in the assessment and successful triage of casualties, likely better preparing them for live MCI response, but certainly enhancing future learning potential in live simulation MCI response training.

Ours and other VR applications may provide an avenue for education providers to deliver highly realistic training for MCI triage to emergency medical professionals at a substantially decreased cost. Given the difficulties associated with provision of large-scale simulations for MCI response training (6, 7), training facilitated through VR could greatly increase the number of students and practicing health professionals able to be trained in and exposed to mass-casualty simulation training each year. However, further research is likely required investigating retention of knowledge and skills over time between the two learning platforms before education institutions should invest heavily in VR environments, or rely on VR environments to replace live simulation for mass casualty triage training.

Nonetheless, given the catastrophic nature of real-world MCIs, and their potential threat to life and long-term injuries, the ability of VR to provide realistic education and training is a significant benefit. Moreover, the highly programable and structured format training provided via a VR platform could work to standardize training across providers, as well as improve the accessibility and feedback potential for MCI response training (1), without overly sacrificing scenario authenticity.

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