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Virtual reality for ambulance simulation environment

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Abstract

Simulations are beneficial in evaluating clinicians' empirical competencies through practical skills, prioritizing, and decision-making as part of patient care scenarios generally run in a full-scale physical context. However, such simulations require physical space, manufacturing, and replacement of damaged or used equipment. On the other hand, virtual reality (VR) computerized simulators are comparatively modern instruments for use in practical training. VR can be employed to simulate real-world situations without the actual need for physical devices. This work presents an ambulance patient compartment VR simulation that can be used by emergency medical services (EMS) staff to customize the configuration of the ambulance patient compartment according to their preference as well as for vehicle orientation or training purposes. The proposed simulation can be used repeatedly enabling the paramedics to access equipment in a fully immersive and safe environment. The user studies have demonstrated the usability and perceived effectiveness of the proposed simulation.

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1 Introduction

Paramedics or Emergency Medical Services (EMS) staff are prone to occupational injuries inside an ambulance due to rapid vehicle movements as well as non-ergonomic body positions for equipment access and patient re-assessment or treatment. Studies have shown that musculoskeletal injuries are more common in the ambulance crew than in other hospital staff [25]. These injuries are generally a result of being unrestrained during the drive. The non-ergonomic design layout of the patient compartment prevents the paramedic from efficiently performing many of their duties while restrained [15]. Paramedics mundanely deal with emergencies that require them to swiftly respond to patients who are suffering from varying illnesses and types of injuries. Therefore, the vital role of paramedics is to deliver immediate and effective care at the place of the emergency and during patient transportation to the hospital. The latter requires quick and easy access to the required equipment inside the ambulance patient compartment. Thus, to deliver urgent care, paramedics tend to compromise with their posture while being restrained or not wear their seatbelts as they should. Consequently, they may need to leave their seat to reach the required equipment which is quite risky inside a moving vehicle [15]. Besides, survey results have indicated that 87% of the respondents do not fasten restraint belts during patient treatment inside the ambulance [16]. The unsatisfactory design of the ambulance patient compartment will often result in paramedics suffering from musculoskeletal injuries [16].

Minimizing the risk of musculoskeletal injuries requires an ergonomic optimization of the patient ambulance compartment. This is to enable paramedics to respond to patient care requirements effectively while at the same time accessing the necessary equipment. This should be done with minimal movement so the paramedics can remain restrained and without exerting stress on their posture. The layout of the ambulance patient compartment has evolved over the years as a result of suggestions from the comparative analyses performed by researchers and direct input from paramedics [15, 16]. Thus, the concept of using simulations for training in healthcare is getting more ubiquitous with the advancement in technology [14]. Several virtual reality (VR) simulations are developed to train paramedics to access devices from their best places in case of emergency and disaster [3, 5, 7] and to train paramedics on handling different critical paramedic cases [4, 26, 27, 33]. However, the positioning of equipment and storage compartments in a VR environment and considering the posture of paramedics is still missing [15, 16]. In this study, we propose an immersive VR environment with a real scale to give a paramedic the ability to move equipment and storage cabinets in the ambulance patient compartment according to their personal preference. This is to optimize the internal layout of their working environment and to ensure paramedic safety. Using the proposed system, multiple layouts can be tried out practically and efficiently without the risk of harming oneself or exerting much physical strength. Moreover, our proposed simulation can be used at any time by paramedics and can improve their skills and empirical knowledge while accessing equipment to provide patient care.

We compared the usability and feasibility of our proposed VR ambulance simulation with a real ambulance equipped with the same modular elements in the patient compartment. Moreover, we asked participants to fill out a survey to show their satisfaction and share their experiences while taking part in the simulation. Following this introduction (Section 1), the rest of the article is organized as follows:

In Section 2, we discuss related literature on the ambulance emergency simulations. In Section 3, we provide details about our proposed simulation. In Section 4, we present and discuss the experiments. In Section 5, we reveal the user feedback and other results related to this study. In Section 6, we discuss our findings, and finally, in Section 7, we conclude the paper.

2 Review of the literature

Diverse medical emergency ambulance simulations have been proposed due to their readiness and effectiveness [3, 5, 7]. These simulations vary from partially-immersive solutions [2, 9, 23] to VR fully-immersive solutions [2, 7, 9, 23]. Power et al. [23] proposed, in Ireland, a high-fidelity full-scale simulation to train paramedics for emergency care situations. It also included ambulance operations and rapid response vehicles to increase the realism of harnessed scenarios. The evaluation results of the simulation from the overall participants showed considerable satisfaction with a high engagement level. Mills el al. [20] compared the simulation efficacy between VR simulation and live simulation of triage training; the VR simulation provided near identical simulation efficacy for paramedicine students compared to the live simulation. General performance evaluation for AR/VR training technologies for EMS in ambulance buses presented by Koutitas et al. [17] suggested that training improved the accuracy by a factor of 46% and the speed of executing tasks by 29%. However, the tasks were mainly about finding objects with no ability to walk or move objects, therefore, the system cannot address the ergonomic optimization of equipment as the proposed system. Engström et al. [8] proposed a health care simulation to assess how contextualization affects the sense of belonging or integration into the simulated event by using immersion score rating instruments. The scenarios included ambulance emergency driving. The overall simulation results showed that contextualized conditions gave a higher immersion rating score. Alinier and Newton [2] proposed a training ambulance as a mobile simulation unit that can be used at ambulance standby locations instead, or as a complement to conventional training rooms. The simulation uses a converted ambulance manned by paramedic educators meeting other ambulance crews at their standby location to facilitate an emergency scenario with them. The proposed simulation unit does not give the ability to access materials virtually as it relies on using real resources from the training ambulance. Hagiwara et al. [9] presented a content-valid immersive simulation instrument to rate and identify the immersion level between the different participants. The simulation consisted of several healthcare scenarios including ambulance contextualized missions. These missions included driving, transportation, on-scene treatment, and patient handover. The proposed instrument stressed the usage of video recordings and triggers to score the scenarios. As a limitation, recorded videos can be stopped when a trigger is identified in the program. The recorded video did not allow assessing deeply the practical interaction of the user, leading to wrong scoring results. Consequently, Dubovsky et al. [7] developed a VR platform for the emergency department (ED) to simulate the work of nurses. The computerized simulation showed its effectiveness and was perceived to be equivalent to the physical nurses' workload.

Several screen-based simulations have been designed and developed for emergency response training [5, 15, 16, 24]. A simulation model proposing an improved design layout for an ambulance was developed by Roberts et al. and Kibira et al. [15, 16]. It included different scenarios related to the tasks carried out by a paramedic. The virtual environment did not only simulate tasks, object placements, and restraint systems but also replicated the task performance of the clinician according to the old and new layout [15, 16]. Cohen et al. [5], in the UK, created three scenarios using two virtual worlds (Second Life and OpenSimulator) which presented the aftermath of a bomb blast and included trauma patients. The scenarios represented one pre-hospital and two in-hospital settings for a major incident. The simulations were evaluated by 23 hospital clinicians from the Ambulance Hazardous Area Response Team (HART). Participants gave positive feedback and expressed their eagerness to use such an environment for further emergency response training. A serious game, Zero Hour,[1] designed to train EMS providers to respond more promptly to mass casualty incidents was described by Ricciardi and Paolis in a comprehensive survey of serious games [24]. The participant was taken to the place of the incident upon receiving an emergency phone call. Upon reaching the place of incident, they are required to select the necessary equipment needed for the situation and make use of it.

Consequently, studies have shown that immersive VR training and desktop simulations [5, 15, 16, 24] prepare participants for medical emergencies by allowing them to experience the management of various incidents and related patient care aspects [32]. The effects of psychological conditions due to unpredictable scenarios affect an individual's response and their ability to make correct decisions [13, 34]. Moreover, VR training ensured minimal harm to self and surroundings, and the resulting performance of participants was sometimes demonstrated to be better in contrast to face-to-face training [32]. Thus, an immersive VR environment proved it can help people improve their decision-making skills during emergencies through frequent practice [18, 19, 28, 32, 34]. Sharma et al. [28] developed a prototype of an interactive and collaborative fully immersive VR environment called Megacity. It can be used for evacuation training aiming to develop the emergency personnel's response in such emergency situations. The simulation was not tested with real subjects. However, the authors claimed that participants would experience an emotional immersion in the simulation and their behavioral responses corresponding to varying levels of stress and panic would be observable and ultimately predictable [28]. Mossel et al. [21] also presented a fully immersive VR environment for training first responders. They aimed to simulate realism by incorporating certain psychological and physical parameters depicting reality. A fire eruption and traffic accident are simulated including wounded people and bystanders. Initial experiments were performed on 35 participants and a usability survey was conducted to get feedback. The medical staff did not give positive feedback about the simulation due to the low visual quality of the environment presented. Similarly, Taylor-Nelms et al. [32] observed the participants' behavior in a virtual environment whereby participants were trained as first responders and were confronted with the aftermath of a tornado. They required different emergency vehicles in a virtual space according to their roles. One of these roles required the paramedic to load the patient on the stretcher, move them into the ambulance, and use the necessary equipment to provide lifesaving treatment [32]. Moreover, Wilkerson et al. [34] proposed an immersive VR scenario simulating a chaotic environment as the result of a massive explosion in an attempt to train first responders for emergency response. The simulation considered the usage of ambulances and paramedics. The performance of the participants was evaluated according to their behaviors. Paramedics like everyone else tend to make errors in an emergency, albeit having gone

[1] http://www.virtualheroes.biz/ZeroHour/

through prior training [34]. The trainees provided valuable feedback about the simulation and also expressed interest in the opportunity to perform this type of simulation training repeatedly [34].

While several studies [15, 16, 34] concerning ambulance simulations have been conducted, there is no study considers the ergonomic optimization of equipment and storage compartments positions according to the preference of the paramedics in a VR environment. We aimed to develop a novel immersive VR environment that simulates the ambulance's patient compartment and determine if it provided an experience comparable to that of the real setting in terms of usability, sense of immersion, time to perform a task, and cost. The main research question is: does a VR environment provide a comparable experience to the real setting for qualified paramedics tasked with configuring the mobile storage elements according to their individual preferences, in terms of sense of immersion, usability, and time to complete the exercise?

3 The proposed simulation

A. *VR Simulation*

The proposed VR application is an ambulance simulation concentrating mainly on the patient compartment and developed using the Vizard software [35]. During the design process of the simulation, we considered both interior and exterior parts of a prototype ambulance from Hamad Medical Corporation Ambulance Service (HMCAS, http://as.hamad.qa). Similar to the physical vehicle, the VR ambulance contains detachable objects which can be fixed in various positions on the track panels attached to the ambulance patient compartment walls (iNTRAXX system by Ferno[2]). The user can move inside the ambulance and access its different devices and storage cabinets which have been made to look like the real ones. Devices include monitors, external chest compression devices, suction units, oxygen flow meters, electronic patient care report devices, etc. Materials include medical and first aid kits, IV stand, response bags, etc. The simulation was configured to place the users next to the door of the ambulance to enable them to acclimatize to the realism of the simulation while getting into the ambulance as is usually done in full-scale simulation whereby participants generally receive a succinct scenario briefing just before entering the simulation room [22]. The ability of the user to interact through actual movements adds an element of reality to the entire experience. Moreover, the feeling of immersion into the virtual environment creates an ambiance of virtual presence.

B. *3D Architectural Models*

To create a factual simulation that represents realistic scenes, the authors were kindly granted permission to use the Mercedes-Benz portal[3] and the Daimler database[4] to obtain the required 3D models of the vehicle. However, the provided 3D Models did not have textures. Therefore, in the first stage, the different 3D model parts were assembled to create the model of the

[2] Ferno: http://www.ferno.com
[3] Mercedes-Benz: https://bb-portal.mercedes-benz.com/
[4] Daimler Database: https://www.daimler.com/

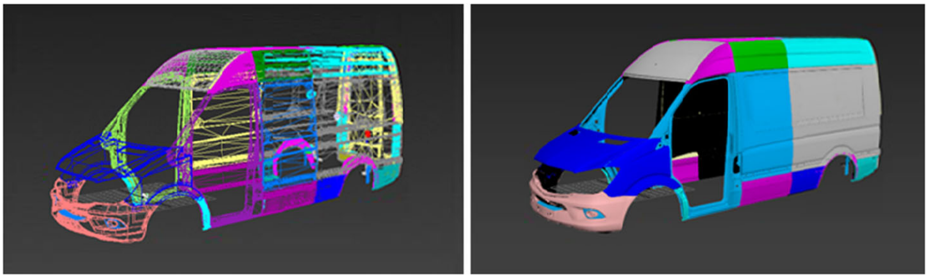


Fig. 1 Architectural model of the ambulance during the assembling phase

vehicle used in the state of Qatar. Figure 1 shows the architectural model of the ambulance. Also, we contacted Ferno, a global emergency, and healthcare company, to obtain the 3D models of the ambulance emergency supplies. These supplies include tracks with modular wall cabinets, patient stretchers, medical kits, defibrillator mounts, and others.

In the second stage, several panoramic photos of the ambulance vehicle were snapped including devices from different angles acquiring complete coverage for it. Autodesk Recap[5] software was used to produce some textured 3D models with point clouds and mesh surfaces. We linked the generated vertices with the vertices of the previously assembled models to obtain an optimal view.

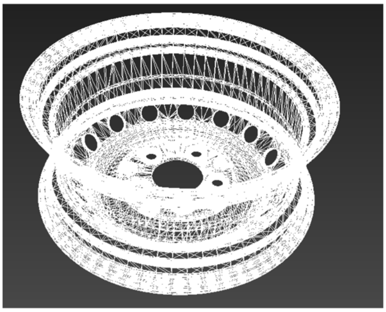
C. *Models Optimization*

Autodesk 3DS MAX 2018[6] was used to edit the 3D models. Also, some scripts to optimize, reduce, and increase the processing speed of these models were developed and utilized. Such scripts are responsible for converting triangular meshes into quad meshes. This is performed by detecting faces that form triangles in the model and then merging the two triangles into one single quad face shape. Figure 2 shows an example of a model before optimization and after optimization.

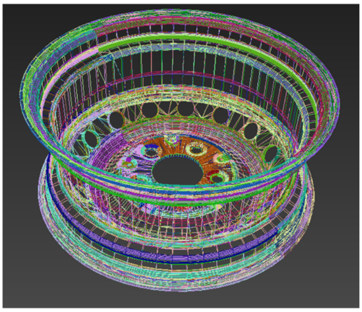
D. *System Operation*

At startup, the system loads the 3D scene and attempts to create the required files to log user interaction data. Recorded data include the start time of the application, end time, movement of the user, and the final equipment layout. It connects to the PPT tracking cameras to enable the user to move in the VR environment. PPT tracking cameras were selected because it can track a larger area (6 m × 6 m) than the current state-of-art htc© Vive base stations which can provide a maximum of (4 m × 4 m) and can also be extended as required by adding more cameras. The system allows a 360-degree immersion into the virtual ambulance through the Oculus HMD (Head Mounted Device) [6]. The system includes a wand controller with sensors and a selection button that enables the user to interact with movable items from the scene and reposition them. For item placement, the system validates whether the item is repositioned in an appropriate place, near a railing attachment point. The view of the scene is updated according to the physical movements of the user by tracking the HMD and wand controller

[5] AutoDesk ReCap: https://www.autodesk.com/products/recap/overview
[6] 3DS MAX 2018: https://www.autodesk.eu/products/3ds-max/



(a) Before optimization



(b) After optimization

Fig. 2 Optimizing 3D models: before and after converting triangular meshes into quad meshes

sensors. Figure 3 shows the user during an experiment to arrange the virtual modular elements. The simulation was configured to restore elements to their initial position when the user finished their session. Figure 4 shows a snapshot of the ambulance patient compartment with objects placed in a neutral position at the start of the simulation. Figure 5 shows snapshots of the real ambulance vehicle and the virtual simulated environment.

4 Methods

The main objective of the experimental study was to explore the option of using immersive VR simulation for setting and optimization of the equipment inside the ambulance patient compartment. The experiment was arranged in two settings, "virtual" in the virtual environment and "physical" in the real ambulance.

This pilot study was approved by Hamad Medical Corporation as a quality improvement project (#17116/17). It made use of a convenience sample of ambulance paramedics working for HMCAS, Qatar and who responded to the study participation invitation sent by staff circular, corporate text messaging, and social media to attend one of the scheduled sessions in the Qatar University Virtual Reality laboratory. This was a pilot study using a convenience sample of qualified paramedics, therefore, no sample size calculation was performed. The subjects were 25 males and 2 females with 22.2% having previous VR experience and 77.8%

Fig. 3 A subject in the VR simulation of the ambulance during a real experiment to position the modular elements

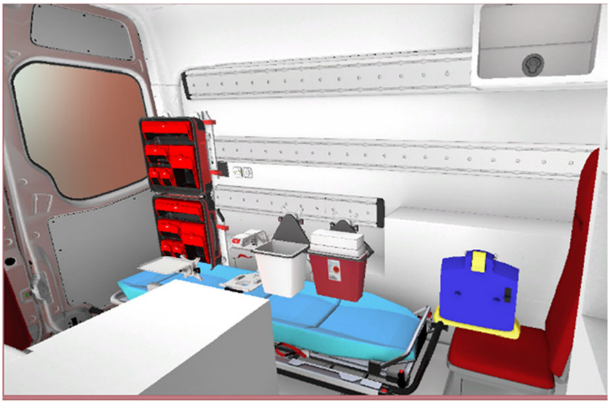


Fig. 4 A snapshot of the internal ambulance elements at the start of the simulation

with no previous VR experience as shown in Fig. 6. The other participants' demographics are presented in Table 1. It is worth mentioning that all the participants were qualified paramedic professionals, however, one subject had only 5 months of experience working in Qatar, therefore it was reported as 0 in Table 1.

The study relied on participants' subjective evaluation in a 3-part questionnaire and on a timed observation of their interaction with the ambulance patient compartment modular elements in the VR and physical setting. The questionnaire requested demographic information from participants and feedback about their experience of positioning the modular elements in both settings. The questionnaire is to gauge two important measures which are usability

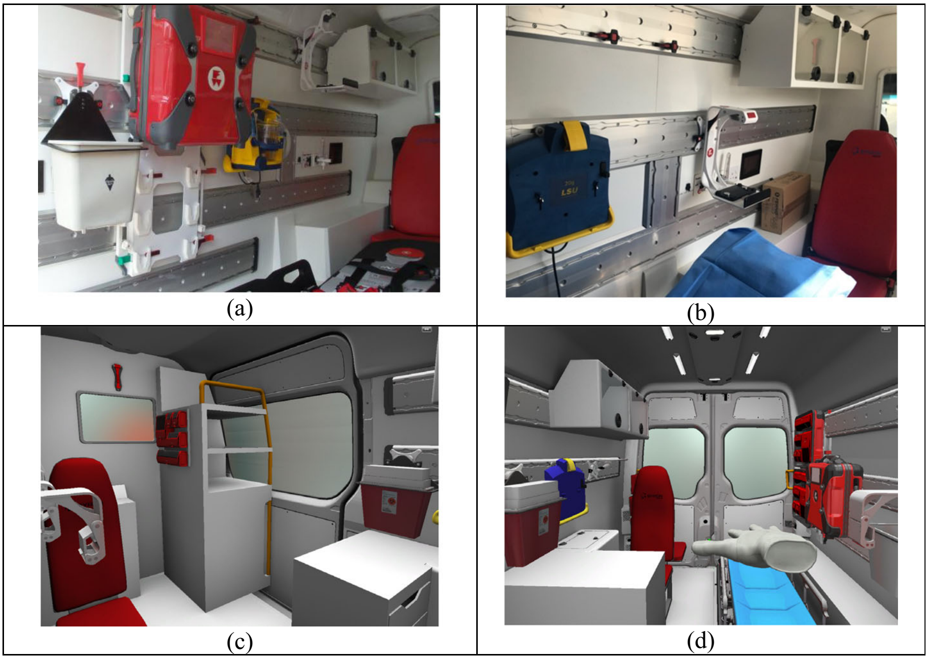


Fig. 5 Images of the real ambulance patient compartment in (**a**), (**b**) and images of the virtual ambulance in (**c**), (**d**)

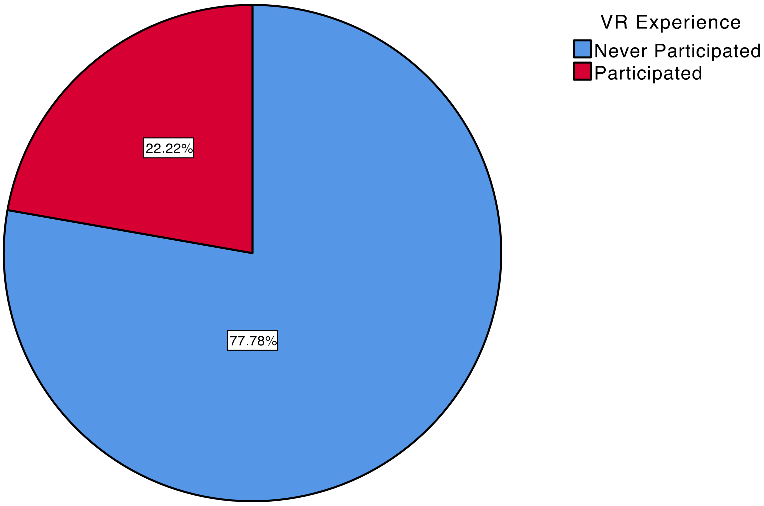


Fig. 6 The VR experience of the participants

and presence based on well-established questionnaires. The usability questions are adopted from Lee et al. study to measure and enhance learning in VR environments [1] with some self-developed to reflect the specificity of the system in this study. For presence, Slater et al. [29–31] recommended using behavioral data gathered during a virtual reality experience to complement a Likert-style questionnaire measuring subjective experience.

The section about their interaction with the prototype vehicle allowed them to record their optimal configuration of the modular elements and to provide feedback. At the start of each session, participants completed the demographic information part of the questionnaire and attended an interactive 15-min presentation about ambulance safety and ergonomics, and at the end, they were explained about the rest of the session and discovered the VR HMD and wand controller. After that, participants took part in the rest of the session individually. They first had 10 min to familiarize themselves with a generic VR setting representing a library with cardboard boxes they could move and stack on top of one another. They were then immersed in the VR ambulance and asked to position the modular elements (Response bag, storage cabinets, bin and sharps container, patient monitor bracket…) of the patient compartment according to their preference to create an ergonomic and safe working environment. The initially floating elements, some of which are shown in Fig. 4, could be grabbed by the paramedic using the wand controller and moved into a position of their choice. Unknowingly to them, the facilitator was timing how long it was taking them to complete the task. The same process was followed when it came to interacting with the real physical prototype ambulance and they were informed that they did not have to try to replicate the configuration they created

Table 1 Subjects demographics statistics

	N	Minimum	Maximum	Mean	Std. Deviation	Variance
Age	27	28	48	33.81	4.558	20.772
Ambulance Work Experience [years]	27	0	15	5.19	3.329	11.080
Weekly Gaming Time [hours]	27	0	81	18.56	21.698	470.795

in the VR setting. After each interaction, they completed the corresponding part of the questionnaire and their time was discreetly recorded.

5 Results

5.1 System usability

The main objective of the experiment is to evaluate the usability of the proposed VR ambulance in terms of functionality and sense of presence. First, a system usability survey to get feedback from users regarding the system functionality was conducted. A 7-point Likert scale was used to get the responses of the users to the survey questions, where 1 was indicating 'Strongly Disagree' and 7 signifying 'Strongly Agree'. Table 2 shows the questions and summarizes the descriptive statistics about each question. Figure 7 illustrates the rating for the usability survey for each question with a rating greater than five. The results show that users were able to find modular and fixed elements easily and position them in other locations. They were also able to distinguish between elements positioned close by and far away. Moreover, their overall experience was enjoyable. However, for almost half of the participants, the game was a bit tiring. This might be due to their previous non-existent or limited exposure to VR activities as wearing the headset might feel cumbersome for some people.

5.2 Virtual presence

The second objective of the experiment was to evaluate the sense of presence as an important indicator of the realism of the VR simulator. A second survey was utilized to determine the level of immersion experienced by the users in the VR environment. This survey is to gauge the quality of the VR environment presented to the user in addition to the usability discussed earlier. Moreover, it also gives an insight into whether the VR simulation is comparable to the real ambulance for interacting with the equipment. Table 3 shows the questions and summarizes the descriptive statistics about each question. The rating percent for each question that was greater than 5 is shown in Fig. 8. The overall response of the users was highly positive. The virtual environment presented a sense of reality to the users resulting in an intensified feeling of presence in the environment for the users. 88.9% of the users claimed that they felt

Table 2 Usability descriptive statics

	N	Minimum	Maximum	Mean	Std. Deviation	Variance
It was easy to look for modular element.	27	2	7	5.63	1.334	1.781
It was easy to look for fixed element.	27	2	7	5.81	1.360	1.849
It was easy to grab an element and fix it in a different location.	27	3	7	5.59	1.421	2.020
It was easy to move around the available space.	27	2	7	5.70	1.382	1.909
It was easy to distinguish close objects from far objects.	27	2	7	5.74	1.430	2.046
It was easy to play the game in general.	27	3	7	6.07	.958	.917
I had fun playing the game.	27	4	7	6.26	.903	.815
It was tiring playing the game.	27	1	7	3.07	2.074	4.302

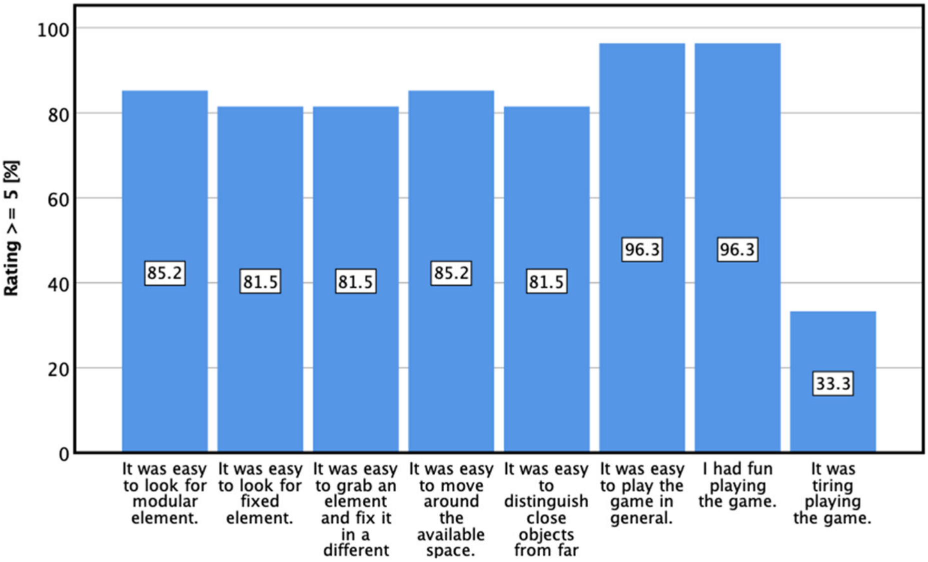


Fig. 7 The rating percent for each usability question with responses > = 5 (in agreement with each statement)

present in the virtual space. However, only 66.7% of the users reported that their VR ambulance experience was consistent with the real ambulance experience, this may be related to the fact that sometimes the subjects were not able to precisely identify the distance to the virtual objects they end up with positioning too close to their seat. This issue needs to be explored more to make the users able to identify the clearance distance by giving them some hints or enabling different views.

5.3 Cost analysis

Development of a real simulation to allow layout optimization of the patient compartment requires the assembling of a test vehicle fitted out with the necessary equipment and materials. These supplies include defibrillator mounts, patient stretchers, equipment bags, oxygen tanks, and others. To perform a cost analysis for a real "physical" simulation, a cost survey for the price of different emergency equipment and materials required was carried out. Acquiring real

Table 3 Presence descriptive statistics

	N	Minimum	Maximum	Mean	Std. Deviation	Variance
In the computer generated world, I had a sense of being there.	27	3	7	6.11	1.121	1.256
There were times during the experience when the virtual space was the reality for me.	27	2	7	5.89	1.502	2.256
I felt like I was just perceiving pictures.	27	1	7	4.44	1.968	3.872
I was completely captivated by the virtual world.	27	3	7	5.56	1.251	1.564
The virtual world seemed real to me.	27	1	7	5.22	1.649	2.718
The experience in the virtual environment seemed consistent with my real world experience.	27	1	7	4.74	1.289	1.661

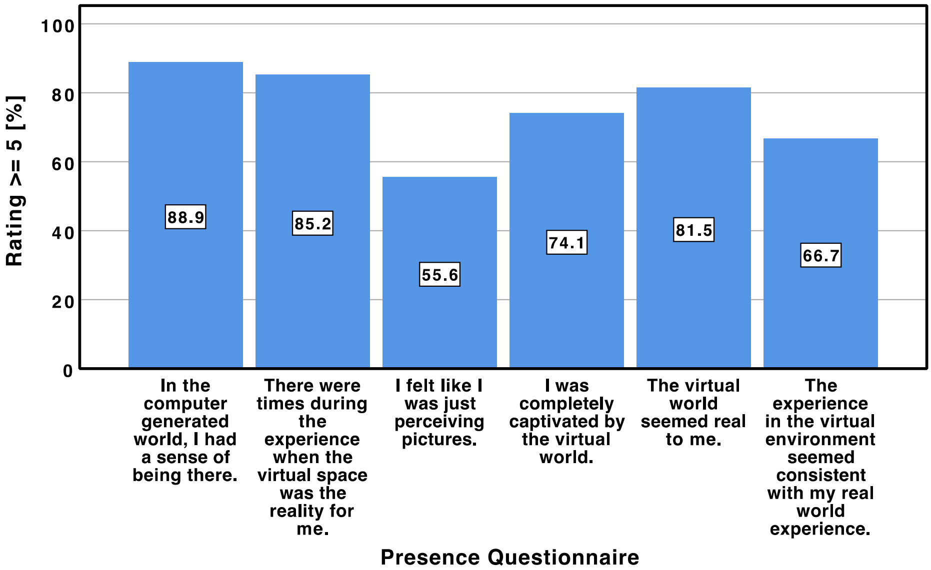


Fig. 8 The rating percent for each presence question with responses > = 5 (in agreement with each statement)

equipment, materials, and the test vehicle costs over 250 k USD. On the other hand, the cost of setting up an immersive VR simulation consists of purchasing the required hardware, maintenance charges, and application development charges. The VR hardware devices include VR technology, HMD, and a high-performance computer. The cost of the VR simulation solution is around 10-15 k USD.

5.4 Time analysis

The time to finish each experiment for both settings was observed without letting the subject notice to keep them natural and away from the time stress to finish quickly. The first essential result noticed is that the users required less time to arrange the items in the virtual ambulance as compared to performing the same task in a real ambulance. Figure 9 shows that the time to complete the task is less in the virtual setting regardless of the subject's VR experience. However, it is evident that the variance is less in the subjects with VR experience, especially for the virtual setting which indicates that prior VR experience affects the results. To study how prior VR experience and ambulance experience can affect the result, the time according to both previous factors is created as can be seen in Fig. 10. Ambulance experience is also affecting the time to finish the arrangement, the more experienced, the less time required. This may lead to an important conclusion that the subjects were able to transfer or apply their experience in the virtual environment as they usually do in the real environment. This is even more evident in the subjects that have VR experience. We can expect reciprocity, which means that training users through VR simulation can increase their experience and that it can be applied in the real environment.

A non-parametric hypothesis test that is robust for data that is not normally distributed is needed since the distribution is not entirely normal. In this case, Mann-Whitney-Wilcoxon was opted for because of its robustness concerning the lack of normally distributed data as well as its efficiency on data that was distributed normally. The result of the MWW test related to

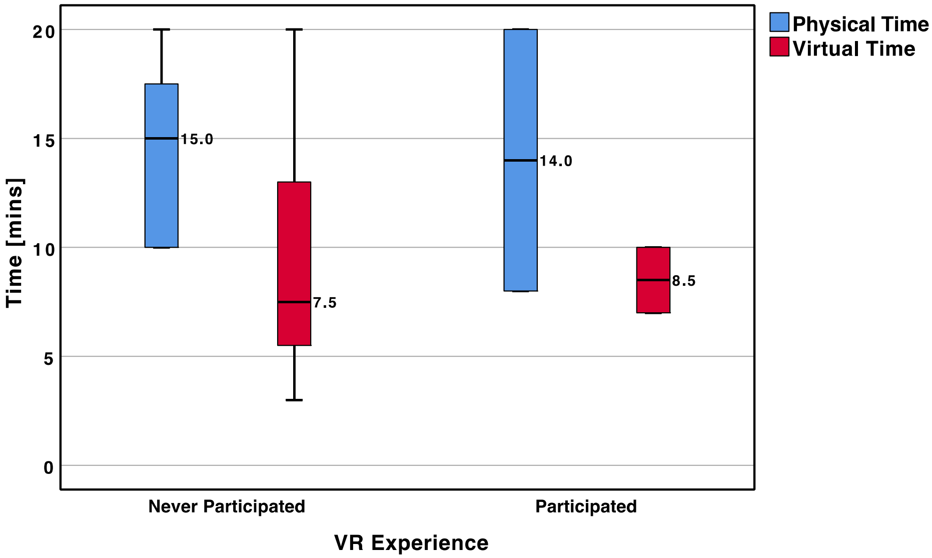


Fig. 9 The overall time required to finish the arrangement in both virtual and physical mode with classification according to the VR experience

virtual and physical at a 95% confidence interval. For both settings, the time illustrated that the mean value of virtual time stood at (M = 8.78, SD = 4.47) and at (M = 13.05, SD = 5.04) for physical time. The *p* value for the MWW test is 0.011 which is adequate for rejecting the null hypothesis. Thus, it can be inferred that the time difference is statistically significant.

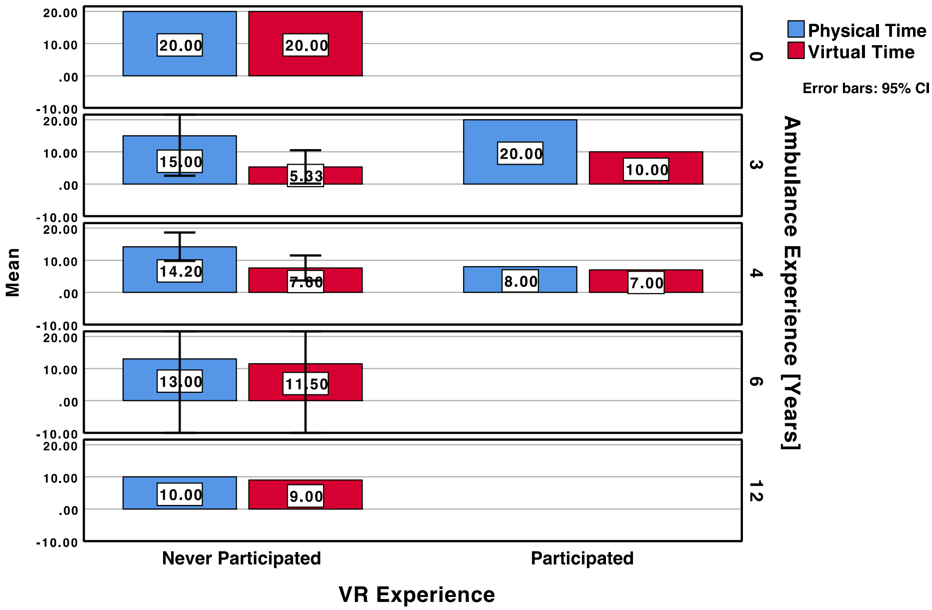


Fig. 10 The time to finish the task in both virtual and physical settings according to both VR experience and ambulance experience factors

The main objective was to investigate if experience in the virtual environment can contribute to the real experience and if knowledge can be transferred to real settings. A regression analysis was performed to know what are the factors that significantly contribute to the perdition of the physical time, and the time to complete the task in the real ambulance. An automatic linear regression modeling was used and the result shows that mainly six factors can predict the physical time, namely, age, virtual time, ambulance experience, presence Q2 ("*There were times during the experience when the virtual space was the reality for me*"), weekly gaming time, and usability Q8 (it was tiring playing the game) as can be seen in Fig. 11. When physical time was predicted, it was found that age ($F = 19.650$, $p < .001$, importance = 32%), virtual time ($F = 10.991$, $p < .006$, importance = 18%), ambulance experience ($F = 9.971$, $p < .008$, importance = 16%), presence Q2 ($F = 8.179$, $p < .014$, importance = 13%), weekly gaming time ($F = 6.440$, $p < .026$, importance = 10%), and usability Q8 ($F = 5.567$, $p < .036$, importance = 9%) were significant predictors. Presence Q4 (I was completely captivated by the virtual world) size was not a significant predictor ($F = 1.564$, n.s.). Table 4 summarizes the result of the regression model. The overall accuracy of the fit prediction model was 55.7% with adjusted R square = 0.557. Further analysis indicated that the accuracy can be boosted to 72% with additional consideration of all presence questions, which suggests how essential is the realism of the VR simulation to achieve high efficiency VR-based simulation training.

6 Discussion

VR technology experienced rapid development in recent years and became an established technology in many sectors after being the technology of the future in science fiction movies. Many large industries started to embrace technology by using VR immersive technology in engineering and training. Immersive VR enables engineers to interact and visualize prototypes to identify and fix issues in the product before a physical prototype is made. VR improved

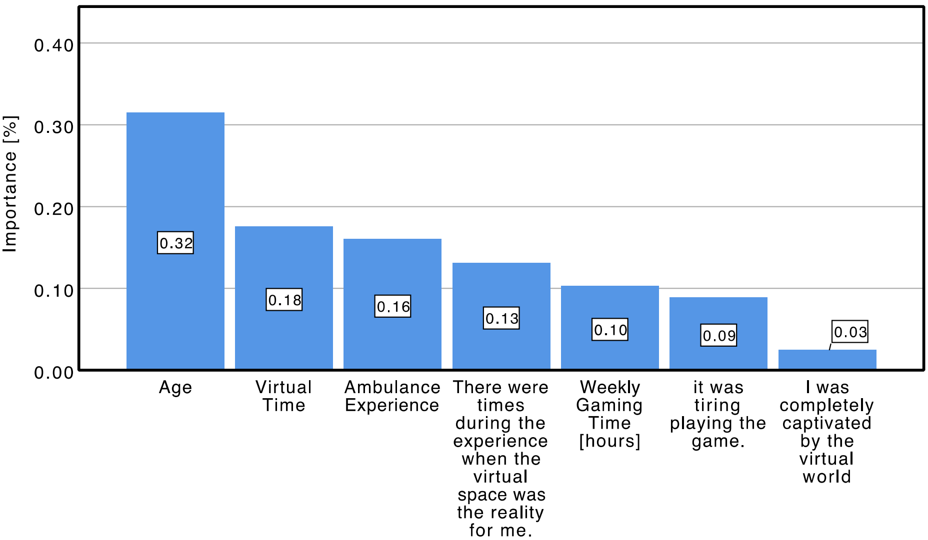


Fig. 11 The factors that can predict the physical time and the importance of each predictor

Table 4 The result of the linear regression model to predict ambulance experience

Source	Sum of Squares	df	Mean Square	F	Sig.	Importance
Corrected Model ▼	347.717	7	49.674	4.408	.012	
age_transformed	221.439	1	221.439	19.650	.001	0.315
virtualTime_transformed	123.864	1	123.864	10.991	.006	0.176
ambulanceExperience_transformed	112.368	1	112.368	9.971	.008	0.160
presenceQ2_transformed	92.176	1	92.176	8.179	.014	0.131
screenTime_transformed	72.569	1	72.569	6.440	.026	0.103
usabilityQ8_transformed	62.733	1	62.733	5.567	.036	0.089
presenceQ4_transformed	17.629	1	17.629	1.564	.235	0.025
Residual	135.233	12	11.269			
Corrected Total	482.950	19				

presenceQ4_transformed age_transformed

Least Important Most Important

Display effects with sig. values less than...

.0001 .0005 .001 .005 .01 .05 .10 .20 1.00

teaching-learning environments to examine and develop new designs and improve communications skills [10–12]. This work is also about designing and inspecting the arrangement of the ambulance patient compartment, which is very similar to the aforementioned concepts. Therefore, it is expected that VR will help in reducing the time and efforts to optimize the ambulance before even the manufacturing process starts and a prototype is produced.

The main question of this work is addressing whether the real ambulance can be replaced by a virtual ambulance for familiarization or interior reconfiguration testing purposes. We started with an essential and realistic task which is related to customizing the configuration of the patient compartment to decide the optimum layout of each modular component. This is not a task usually performed by paramedics at the start of their shift as all vehicles remain identically configured until there is a new vehicle design implementation. Redesigning the patient compartment interior involves a committee with various stakeholders and takes a considerable amount of time and resources for prototyping and testing. In many cases, it would be faster and less costly to finalize the configuration and address all issues identified in a virtual setting. A sense of presence is essential to achieve a high level of realism in VR simulation. The more subjects feel that the simulation is close to reality, the more they get serious about the training, and the easier it will be for them to transfer the learning experience into the real world. 88.9% of the subjects reported that they had the sense of being there, which reflects that they were able to have an experience similar to that in the real world. Also, only 55.6% reported that they were paying attention to the real world which means that 44.4% of the subjects could immerse

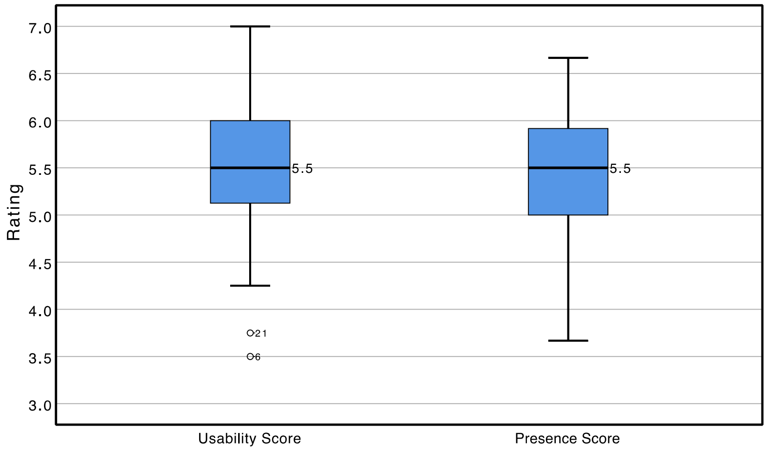


Fig. 12 The total score distribution for the usability and presence questionnaire

themselves completely in the VR simulation. We believe that with proper setting and adding sound effects, the results could increase significantly. The total score for usability (M = 5.76, SD = 0.81) was higher than the total score for presence (M = 5.32, SD = 0.73), however, the median was the same for both (Median = 5.5) which means 50% of the subjects' rating was above 5.5. It can be noticed that 50% of the subjects' rating was between 5 and 6. However, the top 25% of the subjects rated the usability between 6 and 7, meanwhile the top 25% of the subjects rated presence between 5.8 and 6.7 as can be seen in Fig. 12.

The time to complete the task in VR was 67.28% faster than that in the real ambulance and even faster in subjects with VR experience which makes it also attractive in saving time of the required paramedics. The ambulance experience affected both the virtual and physical time in the same manner which indicated that users were able to utilize their real experience in the virtual ambulance. The prediction model shows that age, ambulance experience, and other presence and usability criteria contribute to the prediction of physical time. One important result is that the virtual time to perform the required activity in the VR setting is an important predictor of the subjects' performance in the physical setting, therefore, training subjects in VR simulation and improving their performance can directly be reflected on their performance in the real environment. Nevertheless, the most important and attractive factor is that the cost of VR is at least 60% less than performing the same activity in a real setting. Above all, the VR simulation is portable and convenient as it can be arranged in any location.

7 Conclusion

In this paper, a solution of an immersive VR system that enables paramedics to ergonomically reconfigure the layout of an ambulance patient compartment according to their personal preference was proposed. The system allowed testing of different layouts of equipment and storage compartments relevant to different emergency scenarios resulting in an optimized spatial configuration specific to the situation. The proposed system can solve the limitations of real simulations that require dedicated space, time, and effort while moving them. The novelty of the system lies in providing the ability to perform the same tasks in VR with attractive savings on time and cost, thereby addressing the limitations posed by real-world physical simulations. Thus, the implementation of the tried and tested ergonomic layout will assist the paramedic in delivering quick optimization to the equipment inside the ambulance before manufacturing thus making it a convenient and economical solution. The cost analysis showed that the proposed VR solution is an economical alternative to real simulation. The usability and presence surveys also indicate the importance of increasing the overall usability and presence to achieve realistic VR simulation. Moreover, the time analysis proved that the proposed solution can save valuable time in the task of layout reconfiguration. In conclusion, the evaluation feedback by the users proved the effectiveness of the proposed VR simulation. In the future, experiments on a large group of prospective users will establish the efficiency and effectiveness of VR for ambulance equipment reconfiguration. Also, there is a need to explore carefully how virtual simulation can be improved by investigating different factors and studying how virtual training can contribute to the subjects' ambulance experience.

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