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The Use of Virtual Reality in Training Paramedics for a Mass Casualty Incident

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Abstract: This paper presents the design of a virtual reality learning module inspired by the exercises of healthcare professionals and its limitations as a result of action research carried out by the authors' collective. The module is implemented on a car crash scenario as a emergency event. Virtual reality training is presented here as an important supplement to traditional paramedic training with the potential to reduce costs and make paramedic training more effective as part of their refresher training for their job roles. Real-time training and its limitations are described, especially regarding patient triage, this aspect being considered as one of the key aspects in the context of virtual reality. Furthermore, the results of a questionnaire survey among the mannequins and interviews with the trainees are presented, while the virtual reality environment of the module was designed to be intuitive for each student with the possibility of self-service without major demands on the logistical organization of the staff for the updating training. The authors relied on an expert group of multi-disciplinary experts for development. The outcome of the action research and the data collected by it is a fully prepared module for teaching selected skills in reflection of the situational context of a traffic accident with mass casualties. In the context of the presented module, measurements are being prepared to compare selected variables between real training and virtual reality training with the same scenario on student paramedics and professional paramedics.

Keywords: virtual reality; paramedics; training; visualization

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1. Introduction

START (Simple Triage and Rapid Treatment) triage is a tool available to paramedics in the event of mass casualty. In view of the fact that triage of mass casualties using the START methodology could significantly increase mortality by inappropriately assigning low acuity (undertriage) status to casualties with critical injuries, delaying vital treatment, as well as the fact that assigning high acuity status to stable patients (overtriage) could lead to overwhelming hospital infrastructure with non-critical patients, this method has been the subject of several exercises by paramedics and the integrated emergency response system [1,2]. The basic idea of the international project GURD—a concept for the coordination and implementation of cross-border cooperation of emergency medical services—was to achieve permanent cooperation of emergency medical services of Bavaria and the Pilsen, Karlovy Vary and South Bohemia regions in creating conditions for fast, high-quality, effective, and legislation-compliant cross-border medical assistance to urgently ill persons, both in individual and mass cases. Its promoters were the Bayerisches Rotes Kreuz, Kreisverband Cham, the University of West Bohemia in Pilsen, the Medical Rescue Service of the Pilsen Region and the Technische Hochschule Deggendorf. It was one of the projects that focused, among other things, on joint exercises of integrated rescue system crews on both sides of the Czech–German border. One of the key activities of the project was also the implementation of trainings as a key means of preparing all components of rescue systems, specifically trainings focused on events with the occurrence of injured or disabled persons, including emergencies with mass occurrence of injuries. Such trainings are considered as tools for ensuring theoretical and practical training, and thus maximum preparedness, of rescuers for possible real situations. The training was used as the initial phase of a planned action research to verify to what extent the training and exercises of paramedics in the field using masked figures in the form of real subjects—often classmates or colleagues—are effective and to what extent they could be complemented or replaced by another form of training. The subject of analysis and subsequent inspiration for the creation of a virtual module for teaching and training of paramedics was a tactical exercise, which is typical in that it takes place in the field using real people, means and resources. This is where the tactical exercise differs from the operational exercise, in which emergency situations are practised theoretically.

However, a well-prepared tactical training encounters several barriers and limits. Each training requires time and money, which is on the other hand compensated by the increase in skills on the part of the participants. It is true that, if possible and cost effective, all medical personnel, doctors, and paramedics, should be trained to the highest possible level. One of the foundations of a tactical team is the ability to anticipate and plan for any possible outcome, including the so-called "worst case scenario" [3].

Action research was conducted, which included observation of a tactical exercise within the GURD project, a questionnaire survey among the participating mannequins in the roles of affected patients, interviews with a participant in the roles of paramedics, semi-structured interviews with professional paramedics focused on the needs of the training modules, and analysis of mass casualty incidents provided by the ambulance service and the Police of the Czech Republic. Based on the observation of a tactical exercise within the GURD project called Rozvadov 2018 (named after the location and year in which it took place) and follow-up interviews and analyses, an exercise module was prepared in a virtual reality environment with a scenario focusing on a traffic accident with mass casualties. The aim of this paper is to present the action research carried out based on which a training module for paramedics was prepared for cases of mass casualties, which are some of the most challenging situations that paramedics must deal with professionally. A learning module "car crash" was prepared, which reflects and transfers into a simulation virtual and fully immersive environment the real form of a car crash in which six to nine participants are affected. A trained individual (student or paramedic) arrives at the scene of the accident in an ambulance where he/she learns the details of the scene. Upon reaching the scene, his/her main task is to report to dispatch, triage and secure the affected persons. This is a semi-structured scenario, as trainees do not have a clearly predetermined course of action and can influence it themselves.

The uniqueness of this approach lies in its being based on a real need, where action research is based on the current state of the situation and based on a questionnaire survey and consultations with specialists in the field, a scenario is designed and a module is programmed in virtual reality, which is a powerful, albeit very new tool for training paramedics. The contribution of this paper can be seen not only in the presentation of a rather unique educational and training tool, but also in the presentation of the prepared scenario, which is based on real cases of mass casualties in the Czech Republic and has been commented on and repeatedly modified based on the needs of the paramedics themselves, thus ensuring coherence with practice.

The paper, in the section "Related Work", will present the use of virtual reality in education, focusing specifically on the education of paramedics in reflection of mass casualty cases. The main benefits of the use of virtual reality for paramedic education will be named. In the "Methods used" section, the design of the action research will be presented, including the initial state represented by the large-scale exercise Rozvadov 2018, which represented the initiation phase of the action research in terms of auditing the current state and naming the biggest problems of real field exercises, thus also naming the claims for the use of virtual reality to substitute part of these activities. Furthermore, the research among the exercise figures is presented. These data and follow-up consultations with experts in the field were used as a basis for the design of the "Car Accident" teaching module. The aim of the action research is not to conduct an experiment, the action research here is to help identify pitfalls within the existing state of the practice and then address these through specific interventions. The initial exercise was part of finding and establishing a starting point for the actual research and innovation activity and then the observation and collection of the actual data was carried out, including analysis of the necessary documentation. The data were evaluated and interpreted and based on this, relevant conclusions were drawn for the change of the analysed situation in the sense of preparation of paramedics for situations of mass casualties. Implications of the conducted exercise and the obtained data were drawn for further work and the creation of a training module, which is now presented and will be the basis for further partial experiments, which; however, are not the content of this paper. Part of the paper "Tactical Exercise Rozvadov 2018—limits and restriction" describes the initial phase of the action research presented by the authors' collective and at the same time defines the basic problems of exercises of a similar type, to which the authors' collective decided to respond using a complementary module in virtual reality. The section "Virtual Scenario Car Accident" is the part of the paper where the created virtual module is described as an action that has been taken based on the conducted research. The "Discussion" part builds on the previous part and discusses in general the issue of training paramedics in virtual reality including its evaluation. The "Conclusions" section summarizes the main conclusions from the action research conducted, including the output in the form of a training module focused on car crash.

2. Related Work

Unlike mixed reality and augmented reality, virtual reality has a wide range of applications, whether it be video games, virtual parks, modern gadgets, and education [4–8]. As needs have changed over time, virtual reality, especially from the gaming sphere, has moved into commercial applications where its nature and use of experiential learning has come into play [9]. Virtual reality in the context of employee training brings several benefits not only in industrial fields, but also in fields focused on the care of human life and health. The main advantages include the complete autonomy of training within the framework of staff update training, which in practice means that the employee can train, practise, and generally develop at any time and virtually anywhere, there is no need for the presence of another person, everything is taught by a specialized virtual reality application. In addition, in the field of paramedicine, the demanding logistical operations in terms of legislative, administrative, material, financial and personnel preparation for real-time exercises are eliminated.

The rare encounter with critical situations, which undoubtedly include mass casualty situations, makes the practical training of a paramedic challenging within the limited time frame of a curriculum or development plan. In addition to structured procedures based on medical algorithms, the experience helps paramedics develop competencies in task coordination and teamwork in dynamically changing situations. Such comprehensive competence can hardly be acquired through existing conventional training methods. Virtual reality environments are proving to be a suitable alternative [10–13]. Each training course should be designed to promote a positive learning experience in a supportive environment to enable students to reproduce the experience in their professional practice. For these reasons, it is recommended to incorporate constructivist teaching methods into the educational process, especially active learning, which is a method that allows students to actively try and work with the knowledge and skills they already have or need to acquire. This is based on the premise that learning is an active rather than a passive process, whereby students learn best in an appropriate environment the skills and knowledge that they try out and practise themselves. The whole process of active learning is related to the system of cognitive assimilation and accommodation, and the importance of a suitable educational environment is crucial. An integral part of active learning is also a part of reflection on performance, whether it is one's own or provided by another person [14]. Several previous studies have already shown that paramedics can be trained remotely, and the effectiveness of virtual reality as a platform for training paramedics has been demonstrated [15]. Research suggests that simulating infrequently performed procedures or training for infrequent to rare situations leads to increased professional confidence when performing a procedure on a real patient or accident scene [16].

In the event of a mass casualty incident, a paramedic is required to perform several tasks that are regularly trained in disaster management exercises. These tasks include determining the organizational structure, diagnosing all involved patients, administering medications to patients depending on their health status and injuries, and transporting them to the hospital facility. In such situations, there are usually a limited number of paramedics available to treat all injured patients. For this reason, too, the so-called triage, i.e., the classification of patients according to the severity of their injuries, is applied at the beginning of the intervention. The START triage system divides injured persons into four groups using coloured tags to mark them. This method helps to easily identify patients in need for urgent help as well as patients for whom treatment would be futile. Its advantage is particularly its speed. Since only life-saving operations are performed (airway clearance, stopping massive bleeding), even the thirtieth wounded person with massive bleeding, for example, has a chance of life. Paramedics examine the patient regarding vital parameters, namely walking ability, lethality of injury, respiratory rate, peripheral pulse, blood–bleeding spurt, and consciousness. One of the rules of triage is the equality of the different age categories. A child does not take precedence over an adult. However, there is a JumpSTART method that considers the age of the child. The change is observed mainly in breathing [17]. Virtual reality may be a feasible alternative for training emergency medical service personnel in triage during mass casualty incidents. Virtual reality provides flexible, consistent, on-demand training options while using a stable and repeatable platform that is essential for developing assessment protocols and performance standards [18]. The virtual reality environment offers several advantages over traditional methods based on the use of paper, phantom simulation or real field exercises and mass casualty assessments [19]. For example, Vincent et al. [20] measured novice students' acquisition of triage skills after being exposed to three consecutive scenarios with five simulated patients in a virtual reality environment. The hypothesis predicted that students would improve in speed, accuracy, and self-sufficiency. Novice learners were shown to have better triage and intervention performance, speed, and self-efficacy during repeated, fully immersive virtual reality triage. For future comparisons, it is intended to repeat a similar experiment and compare the results with those of professional paramedics working in the field.

Virtual reality as a technology allows users to explore and manipulate computer-generated real or artificial 3D multimedia sensory environments in real time. Using this technology, it is possible to provide active first-person learning through different levels of immersion, i.e., perceiving the digital world as real, combined with the possibility of interacting with objects or performing a series of actions in this digital environment [21–24]. The use of simulation games for regulated health professions [9] appears to be a suitable substitute for refresher training, as well as a possible part of the adaptation process or readaptation process in case of return after a long absence from the workplace due to specific reasons such as parental leave, long-term illness, etc. Using the technology, it is possible to simulate virtually any situation without significant safety and financial risks. Situational games focus on identifying and solving real-life professional problems that present specific, difficult phenomena that require committed effort and decision making. They are used in adult education to learn the skills of making good decisions in complex cases and unusual situations and to establish the desired course of action in these situations [3]. Thus, the essence of the method is to solve problems that reflect real-world realities. The main advantages are the focus on practice, the emphasis on concreteness and training in decision making [25–27]. At the same time, virtual reality offers a cost-attractive way to train medical staff, quite specifically in terms of the project and the study of paramedics, although it should be noted that good practice in this area can be transferred to other medical disciplines, considering the needs.

Educational programs designed to train paramedics have a variety of simulation resources available and can access them. However, the use of virtual reality in the educational training environment of future paramedics is rather sparse. Virtual reality is generally used for teaching anatomy (virtual dissection table, exer-gaming approach, etc.). The use of virtual reality in teaching seems to be influenced by teacher training and program resources, but the lack of data and re-flection of traditionally designed exercises using mannequins has had its influence here for a long time [28]. Traditional training of paramedic students and professional paramedics is carried out using simple intubatable mannequins or volunteer students or colleagues with a training version of the equipment that is standardly used in pre-hospital care by a medical team consisting of a doctor and a paramedic. Training is conducted on a regular basis, both in the case of professional paramedics at the base, in the case of students in a college setting, and in both cases out in the field. Scenarios are led by scenario facilitators. Facilitators are typically senior physicians/paramedics who instruct the training team and manage the scenario, patient assessment results, and simulated responses to interventions and treatment. To enhance realism, other actors are often used in the scenarios to take on the roles of bystanders, other personnel, or other integrated rescue system components (in case the relevant integrated rescue system component, i.e., police or firefighters, are not the ones requested to participate). The scenario participants are briefed and realistically introduced into the scene [28,29]. The described approach is the traditional approach to training and exercising paramedics. However, not enough attention has yet been paid to the emotional perspective of the paramedics themselves and the level of preparedness of the figurants with respect to the stress response and the level of authenticity. It is undeniable that the approach described provides a safe environment for learning, practising, and maintaining skills in prehospital emergency care. This teaching and maintenance of skills are essential to an effective prehospital trauma care system. On the other hand, they require relatively extensive logistical support and, in the case of the involvement of other components of the integrated rescue system, considerable costs, as verified in this study by the GURD exercise described below, which was exceptional precisely because of the massive involvement of all components of the integrated rescue system. Depending on the complexity of the scenario, simple scenario-based training using mannequins is feasible on a relatively large scale and, in the case of the involvement of a limited number of paramedics without the participation of other components of the integrated rescue system, has the advantage of low cost and rapid preparation. The range of scenarios here is limited by the imagination of the trainers. However, it is essential to keep in mind that sufficient effort must be made to get the trainees into the zone, i.e., into a psychological setting in which they believe they are in a real environment and treating a real patient. Only then can they get the most out of the learning module. Although this method can be used for many aspects of a paramedic's work, whether it is learning new skills, communication, and leadership, and maintaining existing skills, it is the realism of the training concept and entering the zone that tends to be problematic in many cases. The method described here is a low-tech and low-cost alternative to technologically demanding simulations that, when properly prepared and executed, can be a useful adjunct to delivering effective training. It can be considered useful for both initial and regular training of prehospital trauma care providers [29]. However, the authors of this study believe that, based on the action research conducted, it is appropriate to begin continuously supplementing the type of exercises with virtual reality modules for their benefits described above and to bridge the basic disadvantages of these mostly low-cost alternatives to technology-intensive simulations.

3. Methods Used

The study used action research. Action research is usually used for research on social phenomena [30], and it was quite suitable for the purpose of the author's team. In it, the researchers entered a real situation in order to gain knowledge and improve the state of the phenomenon. The action research model works with actual data and applies the scientific method of research and problem solving. It represents both a specific approach to problem solving, i.e., a model, a paradigm, and a problem-solving process [31]. Thus, based on the implementation of action research in its basic well-being, the aim is to propose an appropriate action, in this case a new approach or method for training paramedics for the needs of mass casualties. Hence, the practical objective is to change the training methodology in the sense of incorporating sub-complementary elements. The research problem arose from the evaluation of the implemented training Rozvadov 2018 to which other actions within the nature of action research responded and followed up.

In the first phase of the research, a large tactical training of all components of the integrated rescue system was prepared and implemented within the framework of the GURD project, which is described below. The aim of this exercise was not only to test the preparedness for a mass casualty event, one of the most challenging situations that tests the readiness of not only the paramedics, but also to obtain data in terms of the readiness of the mannequins for their role in the plane of experience, as well as data on the experience and immersion in the zone by the practising paramedics. For this purpose, a questionnaire survey was conducted after the exercise among the respondents by the mannequins and semi-structured interviews with the participants–paramedics. The preparation of the exercise itself took more than one calendar year regarding the necessary permits in terms of occupation of the area, scenario preparation based on the analysis of the most serious mass casualty incident, coordination of all participants and other related logistical processes. A conference was held a few months later, which was attended by all the components of the integrated rescue system that were part of the training. During the conference, the advantages and disadvantages of the training were discussed, the individual units evaluated the effectiveness of the intervention and reflected on tools to strengthen preparedness for mass casualty incidents in the future. The authors' team established cooperation with experts from the medical rescue services of the Pilsen Region, the Karlovy Vary Region and the Hradec Králové Region, with whom they consulted regarding the needs of training for medical rescuers in the context of the prepared scenario, i.e., a car accident. These individuals (in total five of them) were used as consultants and validators of the virtual reality module, which the authors intend to build on the results of the action research and use it as a supplement for the traditional form of training in the context of the acquisition of the most essential competencies by the practising paramedics in follow-up measurements. Since an analysis of mass casualty incidents and the concept of a car accident had already been elaborated in the preparation of the tactical training described below in the framework of the GURD project, it was retained as being the most necessary not only in terms of the frequency of actual interventions of paramedics, but especially after discussion with doctors and paramedics in terms of the difficulty of the simulation of the situation and problematic immersion of the trainee in the field.

The car crash module, which was designed for the needs of training paramedics in preparation for mass casualty interventions, reflects and transfers into a simulation virtual and fully immersive environment the realistic form of a car crash in which six to nine participants are injured. The student arrives at the scene of the accident in an ambulance where he/she learns the details of the scene. Upon reaching the scene, his/her main task is to report to dispatch, and triage and secure the affected persons. Effective use of virtual reality in regular training practice requires effective and intuitive methods of designing complex interactive scenarios [32]. In the example of the car accident, it is a semi-structured scenario because the student does not have a clearly predetermined course of action and can influence it himself. The module was prepared based on the experience from the Rozvadov 2018 training, based on which a needs study was conducted among paramedics who are part of the Medical Rescue Service of the Pilsen Region and the Faculty of Health Care Studies of the University of West Bohemia. The need to focus on the initial parts of the intervention, especially triage and basic pre-hospital emergency care, emerged from this study. Mass casualty was confirmed as an exposed topic; however, compared to the Rozvadov training, the need for a realistic scenario in terms of possible frequency with a lower number of casualties was highlighted, to which the scenario was adapted.

4. Tactical Exercise Rozvadov 2018—Limits and Restrictions

The Rozvadov 2018 tactical exercise is considered one of the largest and most logistically demanding exercises of the Czech Republic's integrated rescue system in cooperation with a cross-border partner. The scenario of the training was a large traffic accident of a truck, three cars in a place of gathering of people with a larger number of people, when the total number of participants in the gathering was 250. Of these, 170 people were injured and the remaining 80 suffered psychological trauma. Specifically, 15 persons died, 30 persons were affected by failure of basic life functions (priority 1), 35 persons were severely affected (priority 2a), 25 persons were moderately affected (priority 2b) and 65 persons were slightly affected (priority 3).

The exercise took place on the area behind the rest area in the cadastral area of the border crossing Rozvadov–Waidhaus, cadastral area Střeble, where an unspecified gathering of 250 people took place. Figure 1 shows the location of the event.

Figure 1. Location of the emergency within the framework of the implemented exercise Rozvadov 2018.

A lorry drove at high speed into the people gathered at the scene, veering off its route and colliding with three cars travelling along the area of the waiting area in front of the gathering. The vehicles were fully occupied by passengers. The cause of the accident was the medical indisposition of the truck driver, who suffered a myocardial infarction and ran the truck off its route. Monitoring of the reported event took place at the scene as part of the security measures of the reported event, patrols from the District Police Department and the anti-conflict team were present. Medical assistance was provided by the Medical Rescue Service of the Pilsen Region.

The description of the event itself shows how demanding the exercise was, especially on human resources. A total of 250 participants were deployed at the scene in the role of mannequins, i.e., including mannequins simulating truck drivers, crews of three cars (four persons/car), three mannequins were placed in the nearest forest stand for tracking practice. The total number of mannequinswas supplemented by 10 film mannequins simulating devastating mechanical injuries incompatible with life. The mannequins were students of the Faculty of Health Care Studies of the University of West Bohemia in Pilsen, who were professionally masked and instructed about their disability, including symptoms and their manifestations, they were marked with orientation cards with fictitious identification data, description of injuries, values of basic life functions in Czech and German. A total of 170 mannequins, who simulated injuries, were realistically moved to predetermined medical facilities. A total of 80 participants simulating psychological trauma were provided with psychological intervention services at the exercise site by the psychological intervention teams of the individual components of the integrated rescue system.

The aim of the exercise specifically for the Medical Rescue Service of the Pilsen Region was to test the activation and functionality of the Traumatology Plan of the Medical Rescue Service of the Pilsen Region. In connection with the verification of the procedure according to the plan, it was specifically about the division into individual teams, the development of individual stations, primary re-sorting, secondary medical sorting, the organization of routing and removal of the injured and registration of the injured–deceased. In this context, the submission of the first information from the accident scene to the health operations centre and the triage of casualties were identified as key activities to the virtual reality training. A detailed description of the activities and activities within the training is described, including a timeline, in Table 1.

Table 1. Exercise schedule Rozvadov 2018.

Time Period	Activity	Activity of Practitioners
7:00–12:30	Preparation of the exercise site, masking of the mannequins, instruction of the mannequins, meeting of the evaluators.	Masking of the mannequins, meeting of the evaluators, lessons learned. Placing the figurants on the event scene no later than 12:30 p.m.
12:00	Assembly of integrated rescue system equipment at the meeting point.	Meeting point: components of the integrated rescue system
13:00	Occurrence of an emergency, reporting to the Regional Operations and Information Centre of the Fire Rescue Service of the Pilsen Region, transfer of information to other operations centres of the integrated rescue system	The slightly injured are in an acute stress reaction at the scene
13:03	Arrival of the first components of the integrated rescue system	Arrival on site, initiation of intervention, organisation of the intervention site
13:03–16:00	Carrying out rescue work in connection with the occurrence of an emergency	Rescuing, re-sorting, transport to the medical rescue service station, treatment of persons, their transport to the target medical facility, actions associated with the investigation of the emergency, ensuring public order, identification of victims and injured, providing first psychological aid to participants in the emergency
16:00–16:30	Completion of the exercise at the scene of the emergency	Evaluation of the exercise, packing of the material

To assess the readiness of the components of the integrated rescue system, a conference was held as well as semi-structured interviews with training participants. From the point of view of the head of the medical component, the cooperation in the integrated rescue system and in the headquarters of the intervention commander, the function of the assistant to the head of the medical component, the constant overview of the available forces and resources, keeping an overview of the situation and communication with the representative of the Medical Rescue Service of the Pilsen Region in the headquarters of the intervention commander can be evaluated as positive. Potential for improvement was seen in the use of Bavarian Red Cross forces and resources in the initial phase of the intervention and in the level of communication between the head of the medical unit and the person in charge of the Bavarian Red Cross during the intervention. From the point of view of the chief physician, the delegation of the paramedical health worker to the organization of the pre-hospital emergency care group unit can be positively evaluated. Potential for improvement can be seen in the overview of what is happening at the pre-hospital emergency care group unit by the senior doctor, the legibility of the records on the identification and triage cards and the placing of the wounded in sectors were also problematic. The actual use of figurants also had its limits.

A questionnaire survey was carried out among the mannequins, the return rate was 144 questionnaires, and one questionnaire was incompletely completed. Out of 144 (100%) respondents, 115 (80%) respondents participated in the training for the first time, and 29 (20%) respondents participated in the training for the second time. One of the questions was designed to determine respondents' satisfaction with the organisation and on-site provision of the tactical exercise. Only five (4%) respondents gave an excellent rating, 33 (23%) gave a very good rating, 53 (37%) gave a good rating, 38 (26%) gave an unsatisfactory rating and 15 (10%) were not satisfied at all. One respondent did not answer this question. In the on-site evaluation of the organisation, a larger number of respondents were dissatisfied and even in their comments on the whole exercise they described this fact. Similarly, the satisfaction of the participants with the facilities at the tactical exercise site was also assessed. Only two (1%) of the respondents rated it as excellent, 28 (20%) rated it as very good, 36 (25%) rated it as good, the largest number of respondents rated it as satisfactory, 48 (33%) rated it as unsatisfactory, 30 (21%) rated it as unsatisfactory. The questionnaire survey had one (1%) respondent categorized as black, 25 (17%) respondents representing red, 37 (26%) respondents representing green, the highest number of respondents were 41 (28%) respondents in the yellow category and 40 (28%) respondents were categorized as compars of the tactical exercise. A large proportion of respondents were very negative about the provision of refreshments for the figures, believing that the opportunity to drink and refresh after the training was very undervalued. The mannequins were informed that refreshments would be adequately provided, and in their opinion, this was not the case after the training. Another frequent comment was the lack of organisation during the arrival of the figurants, but especially during the departure of the figurants, especially those who were not transported to hospitals. The interviews conducted with the training participants showed that many of the participants were their classmates or colleagues, which, despite the realistic disguise, ensured a greater comfort and sense of safety during the exercise. The 12 interviews conducted show that only three participants subjectively targeted under pressure and stress, six participants described experiencing moderate stress, which for some was due to the concept of the training as a competition, and for others to the presence of other components of the integrated rescue system, i.e., professional police officers and firefighters. Three participants even stated that they felt minimal or no stress at all.

It is the use of figurants and the demanding organisation that are very challenging in exercises of this type. It can be assumed that parts of the exercises could be transferred to a virtual reality environment, where these exercises could to some extent reduce the frequency of real-time organisation of exercises, intensify the training of paramedics and at the same time increase their readiness for real-time exercises, and thus also make the costs more efficient. At the same time, an easier transition to the "zone", i.e., the required immersion in the actual training of paramedics, can be assumed. For this purpose, the teaching module "Car Accident" was designed as the first of the planned modules and following its design, measurements, and comparisons of values with real-time exercises will be carried out.

5. Virtual Scenario "Car Accident"

In addition to the Rozvadov 2018 exercise, several other real-life scenarios were the inspiration for the creation of the environment for the paramedic exercise, which enhance the experience and immersion for the individual user. Information about the structure of these exercises was obtained through semi-structured interviews with paramedics and representatives of the middle management of the Medical Rescue Service of the Pilsen Region, who are responsible for the preparation and implementation of the training. The design of the application is created in such a way that the user can run the module without external help. The reason for creating this module was so that anyone can run the training part and go through the training at any time. They do not need further assistance and it is up to them when and how many times they try the module. Now, the car crash module is fully prepared for further testing and later implementation into the training of paramedics and refresher training of professional paramedics. The introductory environment is also used as a transitional environment where the user has the space to adjust their goggles and begin to fully focus on virtual reality and their future training. It is, therefore, important that no pressure is put on the user, no distractions are introduced, and that the user has sufficient time to prepare for future training. The control scene environment is shown in Figure 2.

Figure 2. Control scene.

The garage for the ambulance was chosen as the basic scene (see Figure 2). The individual module buttons are positioned in a corner on the wall to make them easily visible and clear. The simulation is controlled using standard controllers. The term “button” refers to the button on the corresponding controller that the paramedic presses. On the right side there is an avatar that gives information about the selected module. This type was chosen as a neutral ground for paramedics, where they have enough peace of mind to orient themselves in the environment and fully focus on virtual reality training. The option to select a module is shown in Figure 3.

Figure 3. Option to select a module.

The only interactive elements are the ones in the corner that are used to select the project. Other models like the ambulance, gate, table, and rescue bag are inserted here for aesthetic reasons. They are meant to bring the users as close as possible to the environment they are in and to indicate what they are about to encounter. The user, by putting their hand with the controller and pressing the confirmation button, selects the module he wants to go through. This launches the basic information about the module. The selected module, in this case car accident, is coloured green so that the user knows which part he/she has selected. An avatar (see Figure 4), designed as a paramedic, guides the user through the training part. This is a virtual trainer who helps the user through the training, warns him/her which parts to watch out for and, when a mistake is made, advises him/her on how to perform the procedure correctly. For this type of scene, the avatar acts as a mentor in scene selection. After the user selects a module, the avatar will announce all the information about the selected training. It also outlines the situation and the setting to which the user will be transferred. The last part of the scene selection is the start button (see Figure 5), which is opposite the avatar from the layout view (i.e., to the right of the module selection). Again, it is inserted on the wall at eye level to be clearly visible to the user. In terms of more prominent handling, the green colour was chosen to ensure that the start button does not blend in with the wall. This step ends the possible module selection, and the user is already moved to the selected situation together with the avatar.

Figure 4. Avatar.

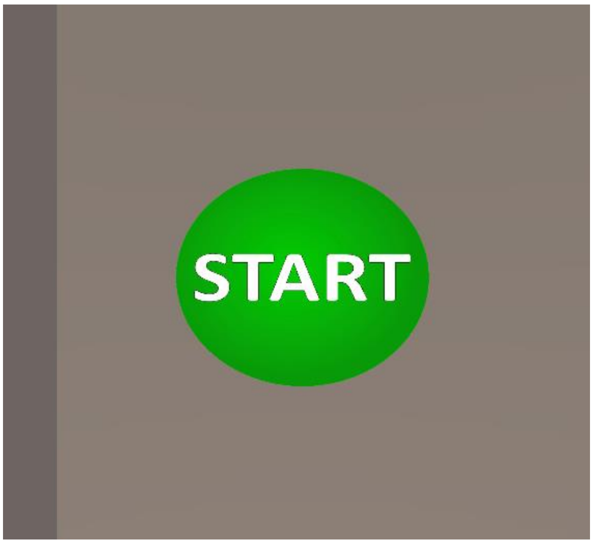

Figure 5. START button to start the module.

The prepared module focuses on a car accident scenario. The scene is set in the suburbs in the evening. The layout of the accident and the injured people is such that a maximum space of 3x3 m is needed. The evening hours were chosen to simulate degraded visibility conditions and thus create a more challenging decision-making situation. The module is designed for a two-car accident at a given time (see Figure 6). The scene itself is supplemented with sounds such as screams and cries of the injured, as well as ambulance and engine sounds. The aim is to create as synergistic an experience as possible, so that users can experience complex situations and practise their knowledge of how to handle them using this technology.

Figure 6. Vehicle deployment in a car accident

In this method, training is carried out in two basic methods: the METHANE and the START triage. In terms of METHANE, it is about reporting an accident to the dispatcher by radio, for these training applications the radio has been replaced by a tablet where the user selects the correct answers according to each letter. METHANE is a mnemonic tool whose individual letters represent the following: M—major incident declaration, E—exact location, i.e., the exact location of the incident, T—type of incident, i.e., the nature of the incident, including the number of vehicles, buildings, etc., H—hazards, both present and potential, A—access, i.e., the best route for the emergency services to access the site, or obstacles and bottlenecks to avoid, N—numbers, i.e., the number of casualties, deaths and injuries at the scene, E—emergency services, i.e., an indication of the emergency services already on site and still required [33]. For the training part, the letters are separated by name and the user can only select the correct option. For the test version, a generator is designed that randomly scatters the letters, and in addition to the correct answer selected, it also checks in which order the user started reporting the accident. The already selected buttons are underlined for the user to have a better overview. This helping function can be switched off. In addition, the tablet serves as a confirmation signal, as the crew must announce that they have arrived at the scene.

When triaging according to the START method, the user controls the basic functions by which the patient is sorted into one of four basic colours. These functions include heart rate, respiration, and capillary test. In terms of real testing, haptics and touch with the patient are important for these measurements, so smartwatches were used for virtual training to represent the measurement of these functions and give the values. The display of this value has a lifetime (it is displayed for a given amount of time) because of the more realistic simulation of the real process where rescuers must calculate and remember it. This watch indicates by familiar pictures what type of measurement it is. The capillary measurement is simulated using an image that shows a detail of the nail (this principle was used because it is a very detailed measurement that would be simulated on the injured person poorly in terms of virtual reality capabilities). Measurements are taken by holding the hand at selected points for the time shown on the watch (see Figure 7). The JUMP-START method is used to treat children and teenagers to ensure that the paramedic attends to them among the first injured. To perform the application, this means that it is monitored whether children have been treated urgently.

Figure 7. Injured person with visible points for measuring basic functions.

Visual management was used to ensure correct placement of objects, with locations highlighted in pink (see Figure 8). The objects that the user uses to provide first aid can be found in the rescue bag. Places where to place objects or tape are highlighted in pink. The pink colour was chosen so as not to be confused with the colours that are used and to be very distinctive. Areas where basic functions can be measured have been highlighted with green dots. For the training version these points were not shown. Movement over longer distances was solved by teleportation. The places where one can teleport to are shown by a light blue object and are only shown when the user presses the interactive relocation button on the controller.

Figure 8. Highlighted place for bandage placement.

A database is used for the injured person models. The next thing that can be done with the patient is to clear the airway. Here again, two areas are shown using visual management that can be manipulated. These are, for example, the correct head posture during prone positioning. From the point of view of the testing section, all visual elements are off, some patients have a life span (limited time) and therefore it is possible that they may die if neglected. Time is also measured as well as treatment progress, patient selection by importance (which patient is checked first) and correct triage according to the START method.

The main objective is that the student can reliably secure and coordinate a crisis in a serious car accident. Among the sub-objectives, it can be mentioned that the student knows the sequences of actions at the accident scene, can report to the dispatcher according to the METHANE method. The student can sort and prioritize his/her attention to patients according to the START and JumpSTART method and can control the amount of time he/she pays attention to patients with different diagnoses.

For this type of development, a total of two basic types of learning were used. These were active learning and didactic games [34–38]. The car crash module reflects and translates into a simulation virtual and fully immersive environment a real car crash in which six to nine participants are involved. The student arrives at the scene of the accident in an ambulance, where information about the details of the accident scene is obtained. After reaching the site, their main task is to report to the dispatcher, sort and medically secure the injured persons. This is a semi-structured scenario, as the student does not have a clearly predetermined course of action and can influence it himself. The student enters the plot of the simulation using a headset. His avatar finds himself inside the ambulance where he watches the prepared animation. After getting out of the ambulance, the student starts to interact with the environment and the situation further unfolds according to his actions. In case the student is successful in his/her solution of the situation, the simulation ends by securing all those involved in the accident. During each activity, the student should follow the rules and principles he/she already knows from previous studies and practice. The starting points for successful coping are mastering the METHANE method, mastering the START and JumpSTART methods, and mastering the basic procedures for securing persons with various injuries. Basic procedures for securing persons with various disabilities include stopping massive external bleeding, clearing the airway, and placing the casualty in a stable position. The possible situations included in the simulation are shown in Table 2.

Table 2. Situations derived from student activities.

Possible Situation	Consequence
The participant spends more than 1 min 15s with one casualty.	Sudden deterioration in another casualty.
The participant misclassifies the injured. If he/she labels a "red" injured person as "yellow"/ "green"	Death of the injured.
The participant first pays attention to the injured with a lower priority or the unsalvageable.	A critically injured person dies.
Ineffective in stopping massive external bleeding.	Death of the injured.
Late airway obstruction, circulatory arrest occurs within 5 min of airway obstruction.	Death of the injured.

Participants in the module are evaluated based on observation of their performance by the practitioner, by their peers in group interviews/focus groups and by themselves (self-reflection). A suitable aid for self-assessment is to watch a video recording of one's own performance, which is preferably provided to students and always available to module participants. Evaluating one's own performance is an important self-reflection activity for the student during the training. Self-evaluation is primarily based on the student's own experience, observation of others, feedback received and the current state of their skills.

6. Discussion

In many professions, especially those in which an employee's mistake can lead to fatal consequences, professional simulators are already used for training, which make it possible to acquire, develop or update knowledge and practical skills in a safe environment. Thus, these professional simulators are used in the healthcare sector, as well as in the military, in air traffic control, and in emergency management training [39–41]. The use of virtual reality appears to be useful in the case of paramedics, especially in preparation for intervention in situations with low frequency of occurrence but high risk, for which standard training is usually insufficient. Using virtual reality applications, paramedics can not only practise the necessary skills, but can also receive feedback in relation to their performance, can repeat the intervention as needed, and all in a safe environment [42,43]. The trained worker (paramedic) enters the virtual setting alone and must deal with a given situation, for example, a mass casualty situation. He/she solves the given situation, and the virtual environment reacts to his/her intervention. In the form of training, it gives him/her practical advice, while in the form of testing, it evaluates the handling of the situation. Trainers, of which there are a limited number, regularly visit Integrated Rescue System centres in a fixed schedule about once a year and conduct training for groups of Integrated Rescue System members in the number of 5–20 participants. In the case that a member of the Integrated Rescue System cannot attend (work duties, illness, etc.), he/she goes to the training the following year or arranges for training at another centre. In the case of large-scale training, the administrative and financial aspect is very important, and such training faces several limitations, which were evident and named in the evaluation of the Rozvadov 2018 training. The programmed virtual setting credibly simulates the real situation in which a member of the integrated rescue system is trained. Information is transmitted using virtual reality goggles and controllers that act as hands to grasp objects.

The simulation targets the Htc Vive Pro 2 Head Mounted Display. In this case, the authors have chosen a cutting-edge technology that is not mobile, and it is necessary to consider the increased purchase cost of not only the Head Mounted Display, but also a VR ready computer with a powerful graphics card. The reason the authors chose this approach is that, thanks to this chosen hardware, they can display, for example, very demanding particle effects such as blood spatter. Equally, they can represent, for example, challenging reflections etc. This makes the whole situation more believable and at the same time more nerve-provoking, a requirement that emerged from the initial stages of the action research conducted, when a weakness was revealed in the level of authenticity and immersion of the trainees.

After the members of the integrated rescue system have been trained, training takes place in real situations for which the member of the integrated rescue system has been trained. They are then evaluated in terms of mastering the correct procedures, but also in terms of speed of response, which is very important in these situations.

In each activity, the student should follow the rules and principles he/she already knows from previous studies. The prerequisites for successful mastery are (1) mastery of the METHANE method, (2) mastery of START and JumpSTART, and (3) mastery of basic procedures for securing persons with various injuries. These mentioned and discussed below starting points can be related and, in the end, influence the student's evaluation and thus his/her success in training. To master the METHANE method, the student must mention his/her call sign (M—major incident), the exact location of the accident site (E—exact location), the type (T—type of incident), the possible hazards at the scene (H—hazards), the access routes (A—access to scene), the number and type of post-incident casualties (N—number of casualties) and the medical resources present and needed (E—emergency services). In the case of the START and JumpSTART methods, the student must be familiar with the triage procedure.

Basic procedures for securing persons with various injuries include stopping massive external bleeding, clearing the airway, and placing the casualty in a stable position. In the case of stopping massive external bleeding, the individual entering the virtual environment has several options—finger pressure in the wound, pressure dressing, pressure points, and tourniquet. In each scenario, the use of a tourniquet is necessary if a particular case generates a casualty with amputation or crushing of a limb. In doing so, the tourniquet must be at least 5 centimetres wide, always placed over the casualty's clothing, inserted between the wound and the heart, as close to the wound as possible, always placed at the site of the bone—on the arm, on the thigh. The tourniquet is never loosened, and it is always necessary to write the time of strangulation on the affected part of the body. The strangulated part of the body is always raised higher. The airway is cleared by head position or, in case of suspected spinal/spinal cord injury, initially only by advancing the jaw. Placement in a stable position is performed in unconscious persons with normal respiratory activity without suspicion of possible spinal/spinal cord injury, i.e., without an injury mechanism, which is not an appropriate procedure in the event of a road traffic accident.

For acquisition, verification, consolidation and revision of knowledge and skills, a basic training for paramedics was prepared in the context of the car accident module. This is training that does not fall under emergency situations but is very important from the point of view of the functioning of integrated rescue services. The developed training set is designed specifically for the medical components of the rescue system. These are the basic types that they will encounter even in a normal call-out (which does not fall under an emergency). The module is divided into 3 parts. The first part contains two basic modules that train new candidates on the equipment of the rescue vehicle (ambulance) and the use of the portable defibrillator (AED). The second part focuses on the use of the pulmonary ventilator, which has become widely used in recent years due to the COVID-19 pandemic. This application should make the job easier for new paramedics who meet a pulmonary ventilator and are unsure how to proceed. The last part is a supporting database for previous models to arrange their diversity. It is a database of 3D models of people and children, which are categorized into four basic groups according to the START (Jump-Start) method. The development of this database involved working with regional emergency services to define the most common injuries and symptoms patients would have for a given diagnosis. As a result, of this input, a database of 80 models was created, containing 20 children and 60 adults evenly distributed in groups according to the colours of the START method. Each model has a pre-defined pulse, respiratory rate and force, capillary colouration and a critical time that determines how long it takes for its condition to deteriorate. Critical time is crucial for patients who must be among the first to be treated by emergency services. It simulates real-life situations where rescuers must decide within moments who to save as a priority. The database was created to allow for rotation of casualties in each module and to mandate wide scalability of testing for new and current members of the emergency services. Thanks to this database, it is not possible to accurately prepare for the module execution procedure. On the contrary, the database supports the necessity and importance of the user's decisions in the virtual setting.

Participants in the module are evaluated based on observation of their performance by the practitioner, by their classmates in group discussion/focus groups and by themselves (self-reflection). A suitable aid for self-assessment is to watch a video recording of one's own performance, which is preferably provided to students and always available to module participants. Evaluating one's own performance is an important self-reflective activity for the student during practice. Self-evaluation is-based primarily on the student's own experience, observation of others, feedback received from the audience, and the current state of their skills. To monitor the progressive development of the student's skills, all assessments are recorded in evaluation questionnaires and surveys. In the context of this paper, a survey refers to a means of self-evaluation of a research participant's performance, and a questionnaire refers to a means of evaluation of a participant's performance by an expert.

7. Conclusions

The training of paramedics is an integral part of not only their professional training within the study of the relevant field, but also a tool for updating information and practising skills in common situations, but also those that are rare. It is because of this that they are challenging for a rescuer, as he/she is not frequently exposed to them in real practice, encounters some of them only rarely, and therefore in a situation where he/she will intervene in the case of, for example, mass disability of persons, with which he/she has neither direct nor sufficient training experience in the past, it can be assumed that his/her performance will be affected. The authors of this article do not believe that regular paramedic exercises can be fully replaced by virtual reality modules; however, they believe that virtual reality environments are so flexible, adaptable to the paramedic's reactions in a given situation, that they can become an important complement to standard exercises and at the same time a tool for more intensive training, as the paramedic can work with the module regardless of time and space constraints.

The authors' team carried out action research, in the initial phase of which the described training of all integrated emergency services was prepared. The training given was seen as an opportunity to reflect on the logistical demands of training, but also as an environment that has the potential to reveal the shortcomings of the experienced approach of training paramedics using models and mannequins. Based on observation, evaluation of the conference discussion, a questionnaire survey of mannequins and interviews with participants, problematic variables in this training approach were evaluated and collaboration with external consultants from the medical and paramedic communities was established. Based on the analysis of mass casualty incidents, it was decided that a module for training paramedics in a virtual reality environment would be developed and subsequently programmed. The development of the module was based on the expert group, which was composed of experts from several disciplines. Now, the module is fully ready for further testing and implementation. In relation to future development, the authors' team plans to use real smartwatches for biometric data capture and semi-structured interviews with two groups of probands, one undergoing a traditional training model and the other undergoing training in a virtual reality environment, with the scenario and requirements being correlated for both groups. In addition, the preparation of two more modules is being considered. These modules would serve as a virtual tool for paramedics (and with minor specific modifications also potentially the whole integrated rescue system) to train professionals in a safe environment, considering the cost-effectiveness of this method and approach in comparison with the organisation of extensive training in a real environment.

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