Designing and evaluating a Virtual Reality training for paramedics to practice triage in complex situations

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Abstract. Paramedics are often the first to provide medical aid at mass-casualty indidents. These are complex stressful situations where the first paramedics' role is to provide rapid response and perform a triage to classify the urgency of victims needing to to hospital. As these situations do not occur frequently, Virtual Reality provides a cost-effective manner to frequently train for these incidents. We present a user-centered design approach used to design the training, which we evaluated with 32 paramedics and trainers. We integrated the design with developing a business model that we evaluated with ten training coordinators of ambulance services. The evaluation revealed that paramedics were highly motivated during the training and that they rated the training high on user-experience. Trainers indicated that the resulting training can be used in practice; not as a replacement but as an addition to current practices. To conclude, the study reveals that co-developing a VR training with paramedics and their trainers, can yield an effective platform to practice triage in complex situations. While further improvements are necessary, our study not only provides a set training, but also a roadmap for how to design VR training environments for paramedics and possibly other (medical) services.

Keywords: Mass-casualty incident training, Paramedic training, User-centered design.

1 Introduction

Providing first medical aid at mass-casualty incidents (MCIs) is hard to train, because these incidents occur infrequently, are costly to simulate in the physical world and most other methods do not offer the immersion and presence that such training would benefit from [1]. Immersion and presence are essential because they provide paramedics the experience and sensation that help them preparing well for acting effectively in such stressful situations [2]. One crucial aspect of providing emergency care at MCIs is to triage casualties to decide what first aid needs to be provided. In this paper we explain how we designed a training with VR elements and present our evaluation with professional paramedics, their trainers, and heads of training.

1.1 Challenges in preparing paramedics for MCIs

Highly complex emergency response situations have a major impact on those involved, bystanders, family members and the emergency services present. Paramedics are one of the first on the scene and must reassure victims and panicked bystanders. At the same time, medical assistance must be offered to victims and bystanders to prevent further incidents from occurring [3].

Incidents can arise from aggression and panic in highly complex situations, because of which people can act erratically and pose a danger to themselves and the environment [4]. The paramedics must have sufficient competences in these and similar situations. A commonly used training for nurses working in hospitals, mental health care, prisons, defense, rehabilitation centers and ambulance centers is simulation education and simulation training [5]. The aim of simulation education is to simulate practical situations, so that knowledge and practical skills can be translated into practice. Typically, these simulations take place in the real world. When situations occur infrequently, such as MCIs, professionals need to practice frequently how to act. Research has shown that re-training the triage at MCIs on a regular (yearly) basis improves preparedness of paramedics [6].

One of the simulation exercises is the re-enactment of major disasters, in which all emergency services are involved. The advantages of a re-enactment of disasters are practicing scenarios at different locations, collaborating with various disciplines, and taking a critical look at one's own actions by means of debriefing [7]. Practicing complex and unpredictable circumstances realistically is a costly affair and is sometimes not feasible with the resources available for education. One of the drawbacks of these practices is that they are costly in both time and resources and lotus victims rarely act like actual victims [1]. Also, not every situation can be simulated with high fidelity, which means that simulation training can feel unrealistic for the paramedic. However, fidelity of simulations plays a crucial role in effective of the training [8].

Alternatives to simulating major disasters in real-life include Virtual Simulations (VS). While VS may include simulations in VR using a headset, they more often refer to screen-based simulations [9-11]. While screen-based VS tend to be highly effective, they lack the level of immersion that can be achieved by VR headsets [12]. Various studies have investigated how VR may support training paramedics for their behavior at MCIs (e.g., [2,12-14]). Most studies focused on training of the triage, and generally found little differences in the efficacy between standard simulation training and VR simulation training [1,14]. Moreover, a meta-analysis found that VR was more effective than their controls in terms of knowledge-gain, while they performed similarly to their controls concerning skills, satisfaction, confidence, and performance time [15]. In addition, research has shown that learning in a virtual environment increases paramedics' motivation and attitude, which contributes to wanting to actively participate in training [16].

So, while these studies demonstrate that VR is an effective tool to simulate training of nurses and paramedics, the costs of carrying out a VR training is much lower than real-life training, especially with head-mounted displays becoming increasingly available [1,17]. Since VR gives users a high sense of immersion and presence during simulation, making the training feel more real, this could become a mainstream method to train paramedics. The challenge remains how to design and develop a VR training that is acceptable, effective and has high fidelity. Also, important is the question how the VR can be implemented within the organization of the ambulance care.

1.2 Didactive considerations

To design adequate education material for paramedics (or any other professional in general), it is important to have a good sense of the background and profession of the target population. Certified paramedics in the Netherlands are nurses with a bachelor’s degree in nursing or in medical assistance supplemented with a specialized training of seven months. The Dutch Individual Health Care Professions Act[1] must promote the quality of care provided by professionals. The law also intends to protect patients or clients against improper or negligent actions by healthcare providers.

The profession of paramedics has been formally described in the Netherlands [18] and centers around the seven CanMEDS (Canadian Medical Education Directions for Specialists [19]) –a framework that describes the core competences a paramedic should have in terms of seven CanMEDS roles: Caregiver, Communicator, Collaborative Partner, Reflective Professional, Health Promoter, Organizer and Professional and Quality Promoter. These CanMEDS roles form the foundation of the further education of paramedics, and so it is essential that these competences can be trained within our VR training module.

It is also important to realize that older adults with professional experience learn differently from younger adults because they have an already built-up frame of reference, and they developed a professional identity [20]. Adult students experience different emotions while learning and combine their studies with work and/or family. The professional identity reflects how they see themselves as professionals, what values and norms they consider are important for practicing their profession and what image they have of themselves. The frame of reference of paramedics is shaped by previous experiences in education, work, and life, which ensures a critical look at training. Training should be of added value and in line with their (future) professional practice. Apart from the critical view, learning ability plays a major role in the composition of education for the adult target group.

Illeris's [21] learning theory describes different dimensions of learning and aligns with the adult's frame of reference. The following dimensions should be considered when designing good teaching: *learning content*, *interaction*, and *incentive*. Learning content includes that which is to be learned. The interaction dimension indicates how the adult student interacts with his social and societal environment during learning. The final dimension, incentive, involves the incentives, emotions, motivation, and

[1] In Dutch: *Wet BIG*. https://www.igj.nl/onderwerpen/wetten-in-ons-toezicht/wet-big

resistance that plays a role in learning. Figure 1 provides a schematic representation of how these dimensions are connected and influence each other.

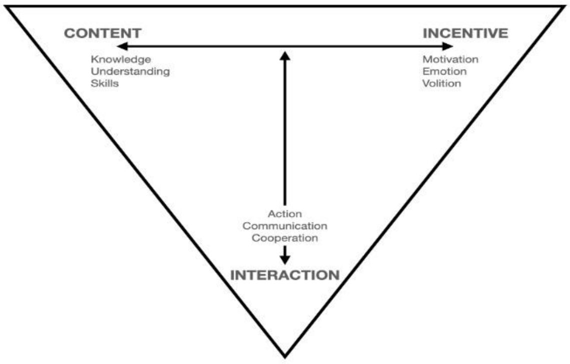

Fig. 1. Illeris' three dimensions of learning (adapted from [20]).

Besides shaping the learning content, how paramedics want to learn was examined. Knowles, Holton and Swanson's [22] model stemming from andragogy best aligns with how paramedics want to learn. Andragogy is a scientific discipline that focuses on adult education. This model indicates how the characteristics of adult learning affect the learning goals of the education offered. Knowles shifted the focus from the teacher to the student (learner). In addition, he uses learning principles that apply to adults. Self-direction or making their own choices that are in line with their experience (knowledge and skills) contribute to learning participation. Relevance, orientation and motivation are the final principles within andragogy in practice [22].

Because motivation is reflected in the learning theory of Illeris and the model of Knowles, it is important to give it a prominent place in the education to be developed. The educational model, called ARSC-model (attention, relevance, confidence, satisfaction) [23], is a learning motivation model and focuses on students' motivation and readiness [24]. The four components from the ARCS-model contribute to creating motivation.

1.3 Business perspective

To develop a VR training that can be used in practice by ambulance services, the business perspective must also be considered. Lehoux et al. [25] show the close relationship between the business model, the value proposition of an innovation and the stakeholders for whom value is created and to whom value is offered. The business and technology development processes they observed were characterized by reciprocal adjustments. Technology development and business case development go hand in hand. That is why in this project from start to finish technology development and business case development formed input for each other, with mutual adjustments being made to each other.

In the remainder of this paper, we first outline the process and results of designing the VR training. Next, we present the methods and results of our evaluation study. This is followed by a discussion and concluding remarks.

2 Designing VR training for paramedics

We took a user-centered design (USD) approach to develop a prototype for this training, following the main principles of Design Thinking [26]. To achieve this, we applied a co-creation, scrum-like design cycle in which we iterated roughly in the following four steps (Fig. 2): 1) The project team (nurse educators, USD researchers, health-care IT researchers, and IT developers) and users (paramedics and their trainers) defined a joint vision on the end-product, resulting in a roadmap. 2) The project team and users agreed on concrete actions to take in the developmental phase, yielding backlog list. 3) The project executed the developmental actions, while having multiple standups. 4) The users (i.e., paramedics and trainers) verified and (dis)approved the prototype during the sprint review.

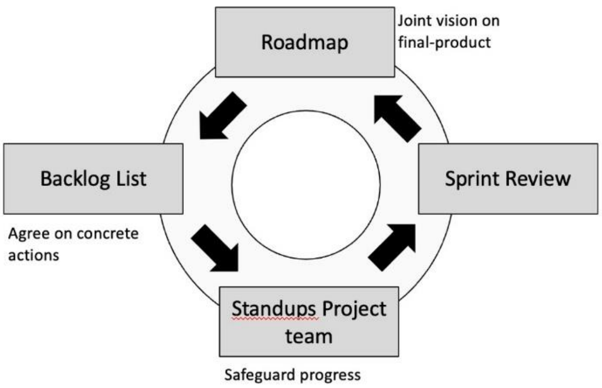

Fig. 2. The scrum-like design cycle to design the VR training for paramedics.

Because designers know that VR does not only work on the basis of literature and expert knowledge, we wanted to involve the user intensively and let their wishes be leading [27]. We took an agile approach and allowed the user to experience and test multiple prototypes. Eventually, this would save more time than the cost of an additional iteration, because it results in having the user become the owner of the decision process and the technology is thus not pushed.

It is, however, difficult for paramedics to indicate what they want when they have no expert knowledge about the possibilities in VR. Yet, building a prototype without the knowledge of what it is supposed to do is also hard. By taking time and space to develop and adjust prototypes, adding new functionality, and demonstrate these to the users, one can solve this chicken-and-egg issue faster than organizing many brainstorm sessions. The mindset of the developer should be "I'll quickly make something, so you can see …" During our design process, we realized that paramedics think in protocols, the creative industry thinks in possibilities, and developers think in tasks. These three worlds and the three languages that accompany them need to be translated. We gave ample attention to this during the development process.

We gave the users ownership of the development by asking them to direct the progress of the scrum-sprints and have the designers follow them. In the scrum-like design cycle, next steps were only taken after approval of the paramedics, yielding the end-product in five sprints of eight weeks each.

In the remainder of this section, we first detail the roadmap thus achieved, after which we explain the development of the business case, as this adds to some design requirements for the final training. We end by explaining the developed of the end-product. We mostly provide our explanations without referring to intermediate results of the individual sprints.

2.1 Constructing the roadmap

Motivating paramedics is reflected in the requirements of the users of the VR education tool. To find out what the design criteria are from the mindset of the paramedics, for the VR education tool, several interviews took place with both paramedics and their trainers (who often also work or have worked as a paramedic), resulting in our roadmap.

All paramedics interviewed indicated that current training and further education are well established. A virtual reality application would be a good addition to the current offer and should not replace the current scenario training. Virtual reality can contribute to the realistic nature of scenario training. Paramedics indicated that they find it difficult to empathize in a setting that feels *real* but is not, like in physical simulations. Interviews indicate that victims need realistic features in training, such as emotions, behavioral expressions, and facial expressions. *Realness* is important for the experience of a virtual world. However, we found that this does not necessarily mean that the world should be photorealistic. After first developing a prototype using a 360 degrees camera, paramedics felt they could not act realistically, as they could not bend over or kneel beside the victim, nor could they examine their pulse. Paramedics want to feel that they are at the location where the victim is. Ambient sounds, social interaction and haptic feedback contribute to this. Making the experience as real as possible contributes to the user's learning experience. Users need to experience the feeling of *being there* (presence) before acceptance of the virtual world as being real (suspension of disbelief) can take place. The realistic factor is what paramedics consider essential for training.

A study by Kampling [28] focusing on the role of individual learning with VR found that it can enhance learning if an immersive environment is used. The importance of environment is emphasized. Immersive environment can include the clinical image of a victim. Another systematic literature review [29] examines exercises in nursing education through human simulation. Here, the training environment is also emphasized. To make it as realistic as possible, these took place in a clinical setting, among others. This motivates students to respond to real-life situations. These outcomes support the importance of a realistic environment.

Another form of realism is returning to the method for clinical reasoning of the paramedic. The ABCDE model is a methodology used during primary assessment, focusing on life-threatening abnormalities [30], and used by Dutch paramedics. For proper primary assessment, the clinical picture of the victims is very important. A lot of information can be recalled from the clinical picture [31]. Paramedics indicated that they particularly want to see external features and symptoms that fit the clinical picture in the training. By using realistic clinical images, diagnosis can be well trained during virtual reality training.

Not all aspects of the training, however, should be realistic. Literature reveals that learning under time pressure does not benefit the mastery of new skills [32]. So, while paramedics are under a lot of time pressure in real-life situations, trainers and paramedics preferred not to have to operate within a given time while practicing.

Another requirement for use is that it is user-friendliness, or in other words no complicated instructions for use. From a didactic point of view, people indicate that it should match their skill-level, so setting a difficulty level is desirable. Also the possibility of using the VR training tool for multiple purposes (individual, in duos or classroom) was considered important.

Paramedics indicated that they want to know why they need to learn something, understanding of importance is a key driver. Briefing the paramedic about the training and their learning goals –as set by the trainer, often in consultation with the trainee– is therefore instrumental to achieve this. Receiving effective and regular feedback is crucial to learning, encourages self-reflection, and stimulates the learner in their learning process [33]. Feedback can be given during the VR practice, but the question was how frequent this should happen. Tests revealed that this distracted the trainee when this occurred after each classification of a virtual patient. Showing feedback immediately after the final victim was classified was judged better, but in the implemented version this included visiting all victims again, which the paramedics did not like in the end. It was therefore decided to provide feedback after the session in VR is finished, together with an opportunity for self-reflection and consulting with the trainer if so desired.

2.2 Developing the business case

In this study we investigated which factors contribute to the implementation and long-term use of VR training by ambulance services for their employees. At the start we held interviews with five heads of learning & development departments of ambulance services. We developed a questionnaire with 20 open questions based on the S(service)T(echnology)O(rganization)F(inance) model [34] in combination with phases of technology development for eHealth, the eHix [36]. The interviews were recorded and then analyzed by placing relevant comments and statements in the CANVAS business model [36].

Regarding the value proposition, respondents think that use of VR can contribute to the organizations' vision on ambulance care training. They strive for practice-based, personified, teacher-independent, blended learning, learning together and ownership to the learner. Practice based learning means learning in a realistic learning environment and going through the cycle of doing, experiencing, reflecting and feedback. Respondents would like to see that the VR training focuses on components that now receive less attention and situations that cannot easily be trained with other means, such as soft skills, rare situations, and upscaling. They also find dealing with distracting and dangerous circumstances extremely suitable for VR. Respondents find it important that the VR training can be embedded in working processes and linked to IT systems. Both in terms of terminology and in terms of content, the VR training must fit with professional requirements and tasks, the CanMEDS roles and learning objectives. It must be provided with teaching materials and lesson plan. For accreditation, it should be possible to automatically register the credits and training hours of employees. Insights and procedures are changing rapidly in the world of ambulance care, which means that maintenance and organization of updates will have to be a major part of the service.

Regarding the business case, a distinction should be made between individual, duo and team use. In the case of individual or duo (couple of nurse and ambulance driver) use, scarce ambulance personnel need to be scheduled less for training days, making them more employable. During the service, individuals or duos can train independently at times when no effort is required, even during evening, night, or weekend shifts. In the case of team use, savings can be made if it leads to substitution of more expensive training courses. With VR it should be possible to get more out of or save on expensive large-scale simulation exercises on location. It provides the opportunity for preparation, practice and repetition of all roles, thereby increasing learning outcomes. In addition, the respondents refer to the shortage of personnel. Learning with the help of new technology such as VR appeals to young people. This is strategically important in times of high staff shortages.

2.3 The design of the VR training

The design process resulted after five iterations in a prototype training that not only involved an immersive VR experience, but also a learning environment that facilitates a briefing and debriefing of the training that runs on a laptop computer or PC (Fig. 3). This system is designed such that 1) a trainee can take a lesson, 2) a trainer can provide feedback, and 3) a trainer can design a lesson. Lessons can be taken and designed for a single trainee, a duo, or a group of trainees. In the latter two cases, communication, observation, and group-based feedback can become a major part of the learning goals. To facilitate all this, the VR-experience relates to an online database containing the design of the lesson and a history of performance that is constructed during the VR-experience. This database thus takes input from the trainer and provides output for the debriefing.

Fig. 3. The three phases in training.

The briefing module can be accessed with a personal account. Once inside, the trainee can choose a lesson, (re-)read feedback, rehearse the triage protocols, and gets informed about the lesson itself. The trainer can, prior to the trainee accessing the system, write feedback about the previous lesson, prepare a new lesson for the trainee, and write questions to be answered during debriefing. To develop a training, the following parameters can be set in the database:

- the specific environment (currently indoors/outdoors),
- the number of victims (1-6),
- type of symptoms per victim (heart rate, bleeding wounds, breathing, etc.),
- the number of bystanders (numeric),
- background noise from environment (on/off),
- background noise from sirens (on/off),
- background noise and visual images from an overhanging helicopter (on/off),
- presence of fog (on/off – outdoors only).

These settings are typically set by the trainer based on the trainee's skill level. The trainer can also specify the learning objectives, and whether the training is carried out by an individual, a duo or a group. The briefing module informs the trainee about the learning objectives.

After the briefing, the trainee experiences the VR exercise with the aim to correctly triage all victims and communicate this to the emergency center through a virtual transceiver, which is recorded in the database so trainees can listen to their own communication afterwards. When practicing in a duo or a group, communication may support collaboration. Prior to starting the practical exercise in VR, trainees can carry out a VR tutorial to learn about the controls, how to navigate the environment and how to perform the activities for carrying out the triage. This tutorial is essential for onboarding the trainees and can be done multiple times until the trainees is confident to practice. We also built in a start check to verify whether the trainee still masters the necessary skills in VR before they start their exercise.

To carry out the exercise, the trainee moves through the environment (either walking or using the joystick) searching for victims (Fig. 4). When a victim is found, the trainee can examine the victim by sight (visual injuries shown as bleeding wounds), by measuring the pulse (a vibration in the controller signals heartbeats when the wrist or neck is touched and a wristwatch indicates time; Fig. 5), or examining breathing (heard when ear is near the victim's mouth or seen by movements in the victim's chest). Based on this examination, the trainee decides whether a direct medical response should be taken (e.g. placing a tourniquet to stop bleeding or performing a chin lift to open the victim's airway), and what triage classification should be provided by placing the appropriate wristband or 'slapwrap' (choice between red/T1 –urgent to hospital, yellow/T2 –not urgent but to hospital, green/T3 –wounded but not to hospital, and white –death). After that, the trainee should communicate the location and classification through the transponder and move on to find the next victim.

Fig. 4. A 360 degrees view of the virtual indoor environment.

Fig. 5. A paramedic examining the heart rate by 'touching' the victim's wrist, and feeling the controller vibrate with the heart rate's frequency while timing using his wristwatch.

When a bystander is visible, the paramedic can signal it to come over and stay with the victim. We decided against verbal communication to and from the virtual characters to avoid technical issues in natural language processing –something that various paramedics regretted. Instead they could "point and direct" bystanders to help, a solution we found after numerous iterations and which paramedics appreciated. Once the trainee believes all victims were triaged, they could stop the VR-experience.

After the exercise, the trainee would take the debriefing on the laptop. Here they receive feedback from the system about the correctness of the triage. They can also listen to their own voice recordings, see the victim with classification, answer questions posed by the trainer, and provide a written self-reflection. Based on the written feedback, the trainer can provide additional feedback.

A didactive learning cycle is constructed that allows the trainee to redo the VR-experience in case they feel not yet competent. Paramedics considered it extremely important that trainers could only see their performance of the final practices after their own approval—trainees are in the lead of their training. However, the trainer can decide that the trainee should redo the training or decide to move on to a next level.

3 Evaluation Methods

The resulting VR training has been evaluated among professional paramedics and trainers from several ambulance service centers throughout the Netherlands. For this evaluation, we have set up one single lesson with 6 victims in an indoor setting. All noises were turned on, except the helicopter's sound. In addition, we evaluated our business model with training program representatives of different ambulance services. In this section, we describe the evaluation methods.

3.1 Participants

We recruited 32 paramedics (12 females) from five different regional ambulance services in the Netherlands to evaluate our training with VR elements (briefing, VR experience and debriefing). Five participants were also a trainer in their regional service organization. In total, four discontinued their training due to motion sickness. The remaining 28 participants completed the entire training and provided input for our evaluation.

3.2 Materials

To evaluate the training, we asked all participants to fill out a questionnaire composed of the Reduced Instructional Materials Motivation Survey (RIMMS) [37] and the short User Experience Questionnaire (UEQ-s) [38] on a 5-point scale (Cronbach alpha's > 0.72 for all categories). Additional questions probed for participants' behavioral intention and to provide free text comments.

The reason for using these tools was to obtain a good indication about the way paramedics were engaged in the training: the RIMMS is particularly suited to measure motivation that participants feel, and the UEQ measures the user-experience (UX) of working through the training. The RIMMS contains questions concerning the four different dimensions of the ARCS model, which formed the didactic basis of the training, to evaluate the participants' motivation in the training activity [23,24].

The UEQ-s contains questions about five different dimensions (attractiveness, efficiency, novelty, perspicuity, and stimulation) that, combined, indicate how well users rate the application's use and feel. When the training has a positive UX, the motivation to engage in the training is high and helps to focus on the training itself rather than having to focus on how to use the application. High scores of both tools suggest that users are highly engaged with the training, which in turn tends to contribute to effective learning [21-23].

Trainer perspective

. To evaluate the trainer's perspective, we held semi-structured interviews with the five trainers that participated in this evaluation. These interviews were carried out using an interview-guide including questions about how trainers experienced the training method we developed; to what extent they would want to incorporate this training in their institute, and to what extent this training should become part of the standard training for paramedics.

3.3 Procedure

Trainee test procedure

. Participating paramedics were mostly visited at their own organization-unit, but three of them visited our location. After obtaining informed consent, participants were asked to fill in a short survey about prior experiences with using VR and with carrying out triage in complex situations, and they were given some information about the procedure. After this, they started the briefing part of the training. Following this, we provided them with the VR headset and hand controllers and helped to start a short manual explaining them how to carry out the different elements withing VR. During this introduction, paramedics could ask all kinds of questions. When they finished the manual, they could start the VR experience part of the training. To provide all participants with the same situation, we had set the environment to indoors, the number of casualties to six and having six dynamic (i.e. moving) bystanders.

We instructed the participants to continue the training until they believed they have classified all six casualties in the building. They could also stop their training whenever they wanted, for example in case they would experience motion sickness. Once they finished the VR experience, they were asked to complete the training by going through the debriefing module.

Finally, after the entire training was completed, participants were asked to fill out the survey, consisting of the RIMMS, UEQ-s and behavioral intention surveys.

Trainer procedure

. The five trainers received an additional demonstration of the entire module prior to experience the VR training themselves. This demonstration included a presentation concerning the objective of the training tool and what kind of features the tool included, focusing especially on how the trainers can use them in their own practice. This also contained a hands-on practice to set up a training session for a random trainee.

After this demonstration, the trainers received the same training as described in the trainee procedure, including filling out the survey. Finally, this was followed by the semi-structured interview.

3.4 Evaluation business model

The VR-training was also evaluated from the business perspective. Based on the prototype, an estimate of financial costs and benefits was drawn up from a business perspective and interviews were conducted with ten program representatives individually after demonstration of the prototype. During the interviews, questions were asked about strengths and weaknesses of the VR training, and opportunities and threats for application within ambulance services. The business case was submitted for verification. Finally, questions were asked about implementation. This provided input for a 'definitive' business case and implementation roadmap.

4 Evaluation Results

4.1 Survey results

Participants were highly motivated: on average, they scored high on all constructs in the RIMMS (Fig. 6, left), demonstrating that the participants felt that the experience raised their attention and confidence in the training, which they rated as being relevant and satisfactory. The scores for each construct were equal around 4 with standard deviations smaller than 1. This shows that participants rate the training higher than what would be expected at random.
Participants scored similarly high on the UEQ-s (Fig. 6, right), showing that they found the experience attractive, efficient, novel, perspicuous and stimulating. Here too, all participants scored around 4 on all constructs with standard deviations smaller than 1. We see a little bit more variation in the scores with novelty scoring highest and perspicuity lowest. However, these differences are not statistically significant.

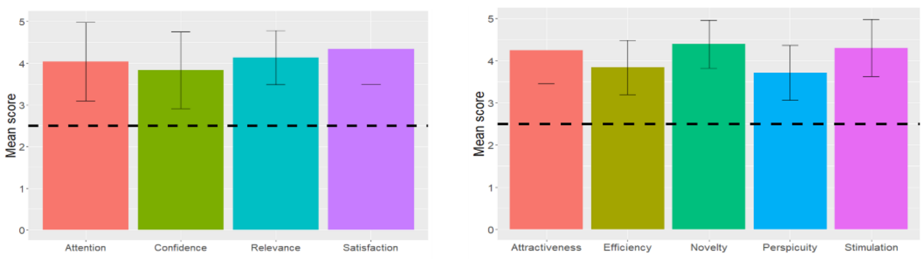

Fig. 6. Barplots showing the mean scores for each construct of the RIMMS questionnaire (left) and the UEQ-s (right). Error-bars indicate standard deviations.

On average, participants rated the behavioral intention questions whether they would like to take the training again with 4.1 and whether they would recommend the training tool to colleagues with 4.2. This confirms their overall interest in using this tool to improve their triaging skills.

Responses to the final open-ended question confirmed these findings, highlighting that most paramedics perceived the training likeable, innovative, and instructive. Some stressed the importance of being guided by human trainers, while at the same time stressing the added value. As one respondent wrote "Very nice to do but decent guidance is necessary… according to me [this training] has an added value to the schooling within the ambulance care." Other participants indicated possible future improvements, such as adding more variability in ways to examine the virtual casualties and symptoms they can have. One example for improvement is the inclusion of verbal communication, as this allows the paramedic to examine whether the victim is conscious and communicative. Finally, one respondent who completed the training indicated to suffer from motion sickness, "so this [training] is totally not for me."

4.2 Trainer's views

Semi-structured interviews with trainers further confirmed the potential of this approach. They confirmed that the training is highly realistic, motivation inducing and instructive for learning the appropriate triage skills. This would be useful to train how to act in MCIs. They indicated that they would use it; not (yet) in replacement of practicing in the physical world, but as an additional format that can be utilized more frequently to keep up and improve their skills. In the physical world, you can for instance practice with a lotus subject or a manikin, which makes certain activities more realistic.

Multiple trainers stress the ability to train in small groups and for training during the waiting times between two responses, which makes the training more flexible. As one respondent said "It is just a new opportunity… [T]he nice thing is that you can now also practice in your own waiting times. You can then do this with two or three persons."

The advantage of training in duos or groups is stressed multiple times, because this way you can learn from each other. Although it is possible to see what the person doing the VR-experience sees through an external monitor, it is in the current product not possible to experience the VR part of the training by acting in a team. One trainer suggested that "[i]t would be nice if you could do this as a team. That you can see each other and that you can complement each other, because that is daily practice."

The trainers were also considering how they would incorporate this training into the education within their ambulance care service. "If I would apply this in our schooling, … I would train the scenarios in the morning … with a video monitor so [other trainees] can see how one reacts [in VR] … and then change [who works with VR]. Than you would have a very nice training."

The trainers also very much like the debriefing module. The fact that you receive effective feedback on performance and that you can listen to your own communication is much appreciated. However, one trainer indicated that not everyone is open to self-reflection. Some are very open and willing to improve, others are reluctant and not open to self-reflection, especially older paramedics as they have little experience and say ‘we used to do this without self-reflection, so why should I bother’. One trainer also liked the ability to repeat the training before reporting back to the trainer: “Even if you train 100 times and only report back once, then you have trained 100 times … so you have spent many hours training. And that is the final goal, of course.”

They do see some downsides. For instance, not every paramedic can participate due to motion sickness. Some functionalities do not work smoothly, such as the chin lift, which is hard to achieve and has no appropriate follow up procedure. Also, the number of possible symptoms and medical treatments that often occur in practice is somewhat limited, though the most essential functions are there. For example, there is no possibility for reanimation or asking bystanders to help doing this. As one trainer mentioned: “Nice that there are bystanders, but it should also be possible to talk to them and give instructions (for example to help with reanimating victims, something that happens in practice)”.

4.3 Business case evaluation

By providing input for the development of the VR training from a business perspective, it was possible (with greater certainty) to respond to the vision and views of training managers about the (future) training of ambulance service providers. desired concepts in this context, such as flexible learning, personalized learning, blended learning, work-based learning, learning in a professional context, ownership by learners, more attention to 'soft' competences and training of rare situations that are otherwise difficult to simulate, were very recognizable in the chosen design. The possibility to deploy the training individually, as well as in duos and groups, was much appreciated and gives the opportunity to tailor the training to the organization.

Wishes collected at the beginning of the project were largely recognized in the prototype. After seeing the prototype, not only did they realize that the application fits their vision of learning, but also that the application can be an attractive means to give concrete shape to their vision of learning in practice. It is not always easy to break through existing ideas about learning and replace them with new ones. Applications that respond to changing vision can offer added value for decision makers.

It is also important that the effort can be raised from the budgets reserved for training. Substituting other, more costly forms of education, using downtime hours, saving on extra expenses such as travel and accommodation costs and obtaining extra resources or subsidies (e.g. in the context of innovation) can offer solace here. However, the managers have different view on the possibilities of saving costs through VR training. For example, not every manager sees much room to save on downtime hours.

For the purpose of implementation, it is also important, given the high costs and impact, to convince and align all stakeholders with regard to purchasing decisions: management, financial department/purchasing, ICT department and, very importantly, the trainers who have to work with it and to motivate their students. The trainers are key-users, and they must be enthusiastic, otherwise it has little chance of success. It is also important to embed VR training in training policy and program.

In addition, having a link to a Learning Management System and availability within one platform with other eLearning tools is desirable. Technically it should just work, too many hitches are disastrous for use. It should also require little preparation before working with it. Proper setup and testing at the place where it is used is therefore important.

5 Discussion

5.1 User-centered approach

We designed the training using a user-centered approach in a scrum-like manner with five design cycles that lasted eight weeks each. However, we did not focus too much on the users, but more on the collaborative aspect of the process. To achieve this, we gave the end-users, training coordinators, trainers and paramedics, the lead in our scrum-sessions. In our opinion, this facilitated deciding what was interesting to develop, and what were the necessary and desirable ingredients that the training should have. We as researchers and designers took a subordinate role in the scrum sessions to avoid directing the design too much. Moreover, we believe that visiting them at their ambulance care services, rather than asking them to visit our premises, was important to allow them to show their work and have them feel at ease during the design process, something they are not accustomed to.

Working with a multi-disciplinary design team involving nurse educators, user-centered design researchers, health-care IT researchers, and IT developers made that we could communicate well with the different stakeholders and translate the language from the world of paramedics to the world of VR design and back. To achieve the latter, we often rapidly designed some prototypical features to demonstrate what could be done in VR and what the consequence of certain design decisions would be in VR. This way, paramedics and their trainers not familiar with VR became aware of the possibilities and limitations of the VR technology.

5.2 Evaluation findings

Results indicate that paramedics rate our VR training very high on motivation factors measured by the RIMMS and on user-experience measured by the UEQ-s. This may be surprising, but it is not because the training was carefully designed in a process where the users took the lead in what it should contain. Furthermore, we based our design for motivation in training on the ARCS model [23], which is also the basis for the RIMMS questionnaire [37]. Moreover, during the design we had iterations with rapid prototyping to demonstrate and test the look and feel of the training, focusing on the needs and desires of the paramedics and trainers involved in the process, which gave rise to the high user-experience rating. While this makes sense, some caution is in place, because for most participants in the evaluation, experience in VR –and our VR training in particular— was new. As a result, the high ratings might be caused by the novelty effect [39], and it is important to investigate whether similarly high rates are achieved when evaluating the training over multiple sessions. The reason we did not do this was a lack of resources from both the research team and the ambulance services.

We decided not to evaluate the training on achieving effectiveness in learning, because there is a lot of variation in experience and skills within the ambulance services that facilitated our evaluation study. While some studies demonstrated the potential of high learning gain using VR, these typically involved student paramedics in comparison to live training in classrooms [1,14]. Koutitas and colleagues [13] found that VR training among professional paramedics improved their accuracy in first respondence and speed in executing tasks considerably in a real-world simulation training. Although we did not measure effectiveness, we are optimistic that our training is effective for improving the trained skills. The reason for this optimism is the didactic approach we took stimulating, among others, students' intrinsic motivations based on the ARCS model that was rated highly in the evaluation. However, a verification would be desirable in a future study, which should also involve evaluating the effectiveness on the long run with paramedics engaging in the training multiple times.

Paramedics and trainers were very enthusiastic about the training and indicated they would want to use it in practice but provided some suggestions for improvement. These focused on including more functionalities in terms of medical examination, improvements of existing functions like the hard-to-use chin lift, and the ability to communicate verbally with victims and bystanders. Trainers offered ideas how to incorporate the VR training in practice. One possibility would be that paramedics can practice the triage during waiting hours between calls. This would allow them to train for many hours, which would improve their skills. However, a potential downside is that immersion in VR may cause cybersickness or after-effects in the perceptuomotor system that could influence how well a person acts after their VR-experience [40,41]. Such after-effects could prevent paramedics from acting effectively when called to an emergency during the VR-experience. Further research is required to investigate to what extent such after-effects of using VR would influence urgent responses in the real-world and how to remedy these, if possible. Allowing for dedicated training time –e.g., as part of the standard schooling– is therefore recommended for the moment.

5.3 Towards a business case

Simultaneously with the development of the VR application, we have started investigating the requirements from the business perspective so that this can serve as input for the development. This interactive method means that the implementation issue is still evolving. Important issue in the short term is ownership of the application and in the long-term multiplayer opportunities with other first responders such as police and firefighters.

As far as follow-up is concerned, it seems to be difficult to find a party that wants to continue the 'proof on concept' to a 'minimal viable product'. We are also dealing with the 'valley of death' phenomenon: the gap between academic-based innovations and their commercial application in the marketplace [42]. Ambulance services and partnerships between them do not see further development, maintenance, expansion, and associated services as their 'core business'. They naturally want to remain closely involved in further development. Ambulance services would therefore like to see a party that is already familiar with and already has a platform for digital learning resources within the industry as the 'publisher/supplier' of the product. Several innovative ambulance services could play a pioneering role in further development. Respondents suggest that the regional 'GHOR' (the Dutch ‘Medical Assistance Organization in the Region’) might want to contribute to investments if this would benefit large-scale medical assistance in disasters.

6 Conclusions

In this paper, we present a design study for developing and evaluating a training with VR elements for paramedics to practice triage in complex situations as occur in mass-casualty incidents. The system is designed such that trainers can construct training program personalized to individual paramedics. The development took a user-centered design approach with a multi-disciplinary team where the users (paramedics and trainers) took the lead in design during our scrum-like session with researchers, nurse educators, IT specialists and business developers took a more subordinate role in these sessions.

The evaluation of the training was received well by the users and other stakeholders, such as training coordinators and managers, both concerning the training itself and the business case around it. The training is rated high on motivation and user-experience. Although we did not measure effectiveness, these findings indicate a high potential for effective training. Moreover, our business model provides a framework for implementation in the professional education within the ambulance case services.

While further improvements are necessary, our study not only provides a set training, but also a roadmap for how to design VR training environments for paramedics and possibly other (medical) services.

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