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VReanimate II: training first aid and reanimation in virtual reality

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Abstract First aid saves lives and reanimation is an important part of it. In order to be able to perform the correct steps in emergency situations, appropriate behaviors must be learned and trained by as many people as possible. Nevertheless, easily accessible training opportunities are quite rare. We therefore developed a virtual reality (VR) application, *VReanimate*, that teaches about aspects of first aid in a controlled digital environment. In the first part of this article, we describe related work and conceptual and implementation details of our approach, that is based on a non-textual and situated training in authentic scenarios. In the second part of this article, we present an evaluation of the system, including results concerning its usability and effects on the knowledge gain of different users. Conducting a mixed methods study, we were able to observe a significant improvement in regard to knowledge about correct procedures in emergency situations and could confirm our hypothesis, that a non-textual and situated design can be helpful for this purpose.

Keywords Virtual reality · Learning · First aid · Situated learning

Motivation

Cardiopulmonary resuscitation (CPR) is a crucial part of first aid. In Germany 100,000 people suffer from arrhythmia every year (Trappe and Arntz 2011). If affected, an immediate start of heart rhythm massage and application of a

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defibrillator is essential to keep a patient alive until the ambulance arrives. Studies show that if CPR is started by the arriving emergency service, there is a 50% lower chance of full neurological recovery (Fischer et al. 2017). However, many people are too afraid to give first aid (Steen et al. 2003). This may be due to the fact that CPR training is still not mandatory on a regular basis in Europe. In countries with a mandatory training, lay reanimation is performed in 60–75% of the cases (Boettiger and Van Aken 2015). Providing more first aid manikins and training defibrillators could mitigate this issue, but they incur great investment costs. A VR setup on the other hand is considerably cheaper, more versatile and can be used in educational as well as leisure time contexts. Therefore, by using VR to deliver CPR training, we hope to enable a greater number of people to cheaply and effectively practice it, whether at home, in schools, or at medical training centers. In this way, the number of trained first responders could be drastically increased (Brooks 1999).

To reach as many potential first responders as possible, we tried to avoid possible exclusion factors, like text-based instruction or additional expensive equipment (i.e., gloves or a doll). Instead, we developed a non-textual, symbolic and situated guidance and learning approach. Thereby, we hoped to overcome possible language barriers (Shneiderman 2010) that reach far beyond mere textual localization but include issues as multifaceted as dyslexia, illiteracy, or affection arising from inter-human communication in high-stress situations. Furthermore, we tried to create a VR experience, which could be easily accessible and appealing.

In this article, we present *VReanimate*, an immersive VR application, where the user can learn about and train the correct procedures. The remainder of the text is structured as follows. In "Related work" section, we introduce common means of training reanimation and present other training procedures that are realized by using interactive VR experiences. Afterwards, in "VReanimate" section, we discuss *VReanimate* with special focus on its non-textual user guidance. In "Methodology" section, we introduce the pedagogical and technical design aspects. Finally, we present the findings of our simulation's empirical evaluation in order to shed light on its possibility to teach the targeted knowledge and usability. We conclude with a short summary and an outlook on future steps.

Related work

In Germany, first aid is usually taught by a voluntary expert in group sessions. For learning how to apply heart massage, a manikin is used (Miles 1969). However, this approach has several disadvantages: (1) One has to book and visit a course in a special facility such as a first aid center. (2) The course can be considered rather time-consuming. It typically takes at least one full day. (3) Still, sometimes not all of the participants are given an opportunity to actively practice with the manikin. As a result, acquiring or refreshing one's first aid knowledge and skills is not very accessible. In order to overcome these potential obstacles and offer an easier way for learning and training, VReanimate provides the opportunity to practice such first aid skills in VR—anyplace, anytime and without having to book any course in advance.

Training of medical procedures in VR

Using VR to teach medical-related procedures has already been suggested and evaluated in a number of different publications and studies (Ruthenbeck and Reynolds 2015). For example, Zajtchuk and Satava (1997) already recommended training first aid scenarios in VR. Furthermore, Mantovani et al. (2003) pointed out that there is a continuous stream of new medical procedures that could be trained almost instantly in VR (Zajtchuk and Satava 1997). Regarding the general use of VR in the medical field, the literature provides different examples for a successful application. Huppert et al. (2016) set out to train laparoscopy using VR. In addition to conveying the very foundational mechanisms of the operation procedure, the application exposes users to stressful scenarios. An evaluation of according operation performances was recently presented by Moussaïd et al. (2016). Multiple approaches have also been introduced in the dental health domain, where the operation can be narrowed down to a very specific environment and interaction activity, see for instance von Mammen et al. (2015). This limited scope renders this domain easily applicable to VR technology. Due to the need for gaining a spatial understanding of the subject matter, VR is deemed generally beneficial for learning about numerous medical training scenarios, see e.g., Colt et al. (2001), Seymour et al. (2002), Ruthenbeck and Reynolds (2015).

An example for teaching about cardiopulmonary resuscitation in VR was presented by the Resuscitation Council (UK) in 2017. It released a mobile VR app called *Lifesaver VR*, showing a 360° live-action movie and making the user decide on how to proceed with the treatment of the person in need (Resusciation Council UK 2017). It offers the user to select different options at several points in the video by means of gaze control. The app can be used with a smartphone and low-level VR-glasses, but is currently limited to specific smartphone models. Unfortunately, to the authors' knowledge, the effectiveness of this application was not empirically examined.

VR and situated learning

The application of immersive VR (cf. Bailenson et al. 2008), as an educational tool has recently become very popular, as, with its current state, it offers new and almost unique possibilities for teaching and learning and at the same time is reaching the mass market (Freina and Ott 2015): First of all, realistic immersive environments that can be manipulated by the user can lead to great advantages from the perspective of learning theories, like the ones associated with situated learning and constructivism. These define the process of learning as an active construction of knowledge (Moore 1995; Hedberg and Alexander 1994). Second, today's VR hardware can reach particularly high degrees of immersion, resulting in educationally valuable first-person experiences (Moore 1995). It is believed that these could be especially beneficial for learners who have difficulties with symbol-based learning activities (Winn 1993). Third, current VR systems offer the opportunity to be used not only for audiovisual learning but also for kinesthetic learning, as they allow the user to move freely in a designated area. This can be an important advantage if the learning goals are not limited to concepts or facts only, but include knowledge about processes as well. All of these developments render current VR systems a promising medium for teaching and learning.

Because of the possibility to create authentic and engaging experiences for learning, VR is a great opportunity to create situated learning experiences. According to Dawley and Dede (2014), situated learning occurs when "a student experiences and applies learning in a specific environment or setting that has its own social, physical and cultural contexts" (Dawley and Dede 2014, p. 724). Therefore, a situated design of virtual environments (desktop-based and immersive) is usually employed when domain-specific knowledge about processes or procedures is taught. There are several examples of according successful applications (Dubovi et al. 2016; Seymour et al. 2002; Lugrin et al. 2016; Muller et al. 2017; Dawley and Dede 2014). One is the project *Breaking Bad Behaviors* (Lugrin et al. 2016), which has the aim to teach knowledge about appropriate classroom management to pre-service teachers in an immersive VR training environment. In the simulation, the user is confronted with a virtual class, whose members exhibit all kinds of disruptive behaviors. The user has to react properly in order to stop the disturbances and be able to continue with his lesson. Another example is given by Muller et al. (2017) and addresses students, who study in the field of mechanical engineering. Here, the authors present an immersive virtual laboratory in which the user has to learn to maintain and control different machines. Employing VR for situated learning thereby offers various advantages. These are, for example: Enabling users to experience the situation from a first-person view and making them experiment with their actions and their consequences in a safe environment; repeating-related tasks, which would not be possible or too expensive in real life; and offering various possibilities for multimodal feedback (Dawley and Dede 2014; Huang and Liaw 2011).

These examples and affordances render the employment of VR as a situated learning environment an ideal possibility for the training of skills related to CPR. Especially, the opportunity to train the making of decisions without having to worry about harming someone, as is needed when being confronted with a multitude of possible choices in an emergency situation, seems a valuable aspect in the eyes of the authors. The simulation was therefore designed following the central aspects of situated learning theory, which will be discussed in more detail in "Pedagogical design of VReanimate" section.

VReanimate

VReanimate is a first aid simulation within a virtual environment. It enables the user to learn and practice concepts of first aid in different scenarios. It allows, for example, to learn when to apply a defibrillator, when to apply a heart massage, and when to conduct no reanimation. We developed VReanimate with four goals on our minds: (1) To show that a non-textual and situated learning approach can work for fostering knowledge about first aid; (2) To show that VR is a good option for practicing in a real world-like environment; (3) To communicate knowledge which can help in situations that require CPR; (4) And to increase the willingness to help other people in order to enhance the probability of survival in a corresponding situation. The simulation is designed as an application for the HTC Vive VR equipment (cf. Fig. 1) and consists of a tutorial for teaching related knowledge and scenarios for applying the acquired knowledge.

VReanimate I

The simulation was developed in a multi-stage process according to a user-centered design approach (Bainbridge 2004). The initial state of the system can be seen in Blome et al. (2017). We further developed the simulation based on the feedback from users in the first phase of our study (see "Evaluation"). Major changes were (1) introducing audio guidance to support the teaching phase, which changed our original approach from non-verbal to non-textual, (2) furthering the design in accordance to situated learning theory, by introducing the possibility to reflect on the trained knowledge and (3) updating and adapting the content according to the current official guidelines by the European Resuscitation Council. In the following section, we will present the result of this continued development—VReanimate II.

VReanimate II

At the beginning of the improved simulation, the user finds himself in an empty and boundless room.

Menu

From there, he can either access the included tutorials, the exercises or the more advanced training. The choice is provided by three differently colored buttons (cf. Fig. 2). At the beginning, the user is verbally advised to press the blue button to start the tutorial. The green button, starting the exercises, is suggested after the user played the tutorial. Playing the advanced training is recommended after the exercises are finished.

Fig. 1 The HTC Vive comprises two input controllers in the left and right front, a head-mounted display (HMD) that is mounted to the head of the player and two base stations called *Lighthouses*

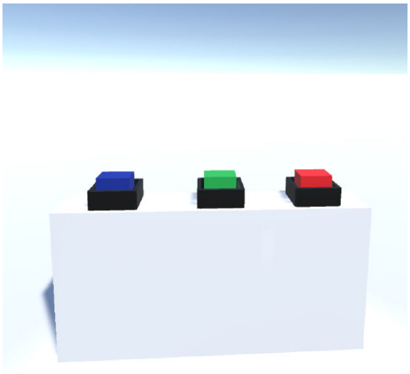


Fig. 2 Menu with a blue button to start the tutorial, a green one to step into the exercises and a red one to access the advanced training. (Color figure online)

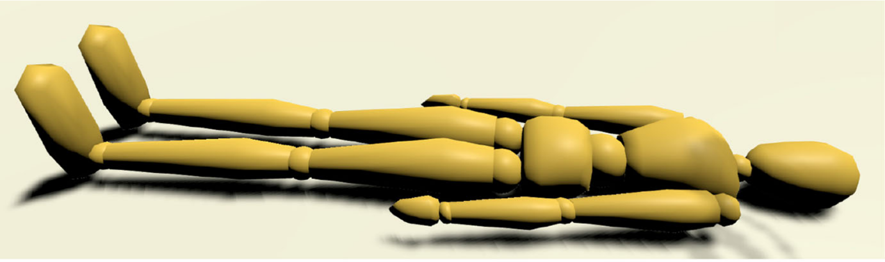
By giving the user the full control over this decision, the user has the possibility to redo the tutorial several times before continuing to the exercise scenarios. Additionally, he can decide to use the system solely for the practice of knowledge or for learning new knowledge as well.

Tutorial

The tutorial teaches the user the correct sequence of first aid interactions when confronted with an unconscious person. Hereby, the person is visualized as a three-dimensional lay figure (Fig. 3). Instead of using text or a video to convey knowledge, VReanimate uses a non-textual approach. As the user is immersed into a VR experience, he can associate renderings of green semi-transparent controllers and an according headset with the head-mounted display and controllers he is holding and wearing at the time. For this purpose, we used the visual of a headset projected into the simulation as a concrete means of self-reference. These "ghost" objects are supported by a voice (created with a voice synthesizer) explaining the necessary interaction steps in correspondence to the displayed situation and the actions performed by the user. The tutorial covers three different settings: One teaches chest compressions (since the victim has a cardiac arrest and no AED is available), one teaches using an AED (since it is available and the victim has a cardiac arrest), and the last one teaches to apply no resuscitation (since the victim does not have a cardiac arrest). After finishing all three stages of the tutorial, the user returns to the empty room and can continue with the exercises or the more advanced training.

Exercises

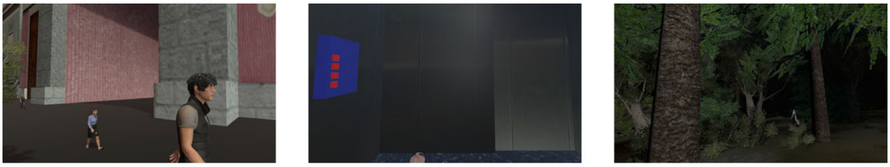
In addition to the tutorial, the users can test and train their acquired knowledge in three exercise scenarios. This time, there are no ghost objects to guide the user. By means of these exercises, the user can consolidate the learned concepts of first aid. The three included scenarios are: Finding a person in a busy street (see Fig. 4a), in an elevator (see Fig. 4b), and in a forest at twilight (see Fig. 4c).



(a) Manikin in the tutorial.

(b) Manikin in the exercise.

Fig. 3 The different manikins in VReanimate



(a) (b) (c)

Fig. 4 The three training scenarios in VReanimate: **a** A busy street scene, pedestrians that pass by the user can be stopped to call an ambulance by touching them with the controller. **b** The elevator training scenario. **c** The forest scene at night, lit by spotlights from a car driving by. This scene contains trees, an animated heron and animated spiders

In every scene, the users have to start with trying to wake up the person lying on the floor, cleaning the airways, checking the breath and calling an ambulance by a phone lying somewhere around him. In the street scene, where the patient needs to be treated by means of the defibrillator, an ambulance can also be called by touching a passing pedestrian. In the elevator scenario, the person does not need any reanimation and in the forest scenario a heart massage needs to be performed.

If the user calls the ambulance, it appears with flashing blue lights and sirens after 50 s and a paramedic approaches the player. If the user does not call the ambulance, it is suggested to check the reactions and to call an ambulance after 100 s. If the user still does not call the ambulance, the paramedic appears without an ambulance after 3 minutes.

When the paramedic arrives, she asks the user about registered symptoms and performed actions. The user answers by clicking on the displayed symbols and is either told that he treated the person correctly or is told the expected treatment and receives the recommendation to refresh one's knowledge.

Advanced exercises

After successfully completing the exercise scenes, the user can continue with more intense scenarios by clicking on the red button. This time, no advice is given to call an ambulance. Furthermore, if the ambulance is not called, neither the ambulance, nor the paramedic will arrive. Additionally, a patient simulation based on a finite-state-machine (FSM), described in "Simulation of patients" section, is connected to the feedback of the paramedic. If the user reports the correct symptoms and reactions but treated the patient incorrectly, the paramedic still suggests to strengthen one's first aid knowledge. In this way, the health state of the patient is indirectly reported to the player. We decided on this indirect way to circumvent possible negative effects from telling the player that the patient died.

Methodology

This chapter is split into five sections: The first section focuses on the pedagogical design of the simulation. The next one depicts the sensory, auditive and visible feedback and the implementation of the included patient, using multiple extended FSM and health values. The last section of this chapter describes our approach to creating a non-textual environment.

Pedagogical design of VReanimate

As discussed in "Related work" section, we decided to design the system as a situated learning environment and therefore followed central design aspects of situated learning theory. Researchers who mainly contributed to forming this theory, were for example Jean Lave, Etienne Wenger and James Greeno, building upon the work of (educational) scientists like Dewey or Piaget (Klauer 1999). From the perspective of situated learning theory, knowledge must be presented and applied in authentic settings and relevant situations to be properly understood (Huang and Liaw 2011; Klauer 1999). The theoretical approach is closely linked to didactic methods such as anchored instruction or cognitive apprenticeship (Klauer 1999). According to Herrington and Oliver (1995), this leads to the following design goals:

- Provide authentic contexts that reflect the way the acquired knowledge will be used in real life;
- Provide authentic activities;
- Provide access to expert performances and the modeling of processes;
- Provide multiple roles and perspectives;
- Support the collaborative construction of knowledge;

- Provide coaching and scaffolding at critical times;
- Promote reflections to enable the formation of the abstractions;
- Promote articulation to enable tacit knowledge to be made explicit; and
- Provide for integrated assessment of learning within the tasks.

When designing VReanimate, we tried to fulfill as many aspects of the presented listing as possible to create a pedagogically sound learning experience. In order to achieve a presentation in authentic contexts, the situations for the training of the acquired knowledge were chosen according to prominent situations in which people could be confronted with finding a person in need (i.e., next to a road, in the forest or in the elevator). To provide authentic activities, typical tasks and behaviors, like calling the ambulance, giving a heart massage, or moving one's head towards the head of the patient to hear him breathing, were included. The modeling of processes is realized in the tutorials by employing the ghost controllers presented in "VReanimate" section. In order to provide multiple perspectives, the training has to be performed in different contexts and presents several different states of the patient and possible actions for the user. By including repeated audio guidance when the user does not proceed during the tutorial, we tried to provide scaffolding when needed. To make the users reflect on their performances, a paramedic was included, which asks them about their activities. The knowledge is made explicit by the need of pushing the buttons on the tablet of the paramedic, which yields according reactions. Finally, assessment was integrated by sound feedback on individual actions during the tutorial as well as by means of general oral feedback given by the paramedic. The only aspect which was disregarded was the collaborative construction of knowledge, as this seemed too complex to realize and was expected to become an obstacle for simple deployment situations such as at home.

The decision to design the system in accordance with situated learning theory also resulted in some contradictions in regard to prominent design guidelines from the perspective of usability. For example, Shneiderman's popular eight golden rules for designing user interfaces recommend for interactive systems to offer informative feedback for every operation of the user (Rule 3) (Shneiderman and Plaisant 2004). As continuous prompts would have disturbed the creation of an authentic experience, these were avoided if possible. Furthermore, the authors suggest to provide possibilities for the users to reverse their action (Rule 6) (Shneiderman and Plaisant 2004). This again would have led to a decrease in the authenticity of the learning situation, as there is no undo button in real life either. Possible effects on the users were investigated in the evaluation of the system by examining the knowledge gain as well as the usability (cf. "Evaluation" section).

Content design

In the following, we go through the individual steps based on the latest suggestions by the European Resuscitation Council (ERC) from the year 2015 (Perkins et al. 2015). We also elaborate on their background and demonstrate their realization in the training environment. Please note that the training focuses mainly on the sequence of steps that have to be taken in the case of an cardiac arrest and does not reflect all the possible scenarios described in the ERC guidelines. Especially VReanimate focuses on the process that should be applied if a single person treats a cardiac arrest. In the tutorial, each step is visualized through the movement of the ghost controllers and the headset. The sequence of actions is depicted in Fig. 5.

(1) *Check response* First, the helper is encouraged to check the responsiveness of the victim by touching the shoulders and asking “Are you okay?”. In the tutorial, this is represented by a ghost controller, which is moving to the shoulder of the victim. If the helper performs the maneuver correctly, the real controller vibrates to give haptic feedback according to the contact.

(2) *Open airways* If the victim does not answer (which is always the case in this simulation), the helper’s task is to clear the airways of the victim. Like before, we used a verbal explanation and a symbolic gesture of the ghost controller which has to be followed by the helper. Again, the controller vibrates at contact with the victim.

(3) *Check breathing* The next step is to find out whether the victim is breathing. To explain this to the user, speech is combined with a ghost headset (cf. Fig. 6) moving near the face of the victim. The user has to move the head in a similar position. If the patient is indeed breathing, the helper hears a breathing sound through the headphones, otherwise nothing can be heard.

(4) *Emergency call* If the victim is not breathing, the helper has to call *112* (the emergency telephone number in the European Union and several other countries) on a smartphone. To facilitate the use of a virtual phone by means

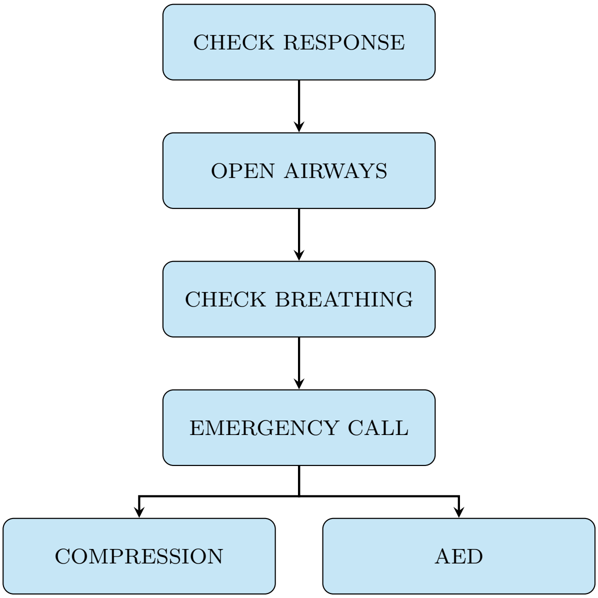


Fig. 5 The resuscitation workflow based on the ERC 2015 Guidelines (Perkins et al. 2015) taught by VReanimate

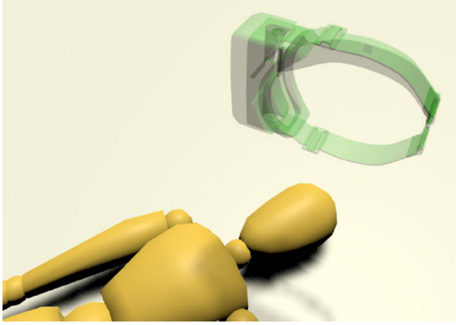


Fig. 6 Green *ghost headset* moving towards the head of the tutorial manikin. This movement guides the user to follow with ones head and check the breath of the patient. (Color figure online)

of the input controller, it is scaled up to approximately ten times its normal size as soon as the controller comes close to it. The calling procedure is directly copied from the standard phone usage: It is carried out by dialing the number (typos can be corrected) and pressing the green phone button. In case of success, the phone answers that an ambulance is on the way to the accident location.

(5a) *Automated external defibrillator (AED)* In this step, we assume that an AED is available for the helper. He is encouraged to follow the instructions that the AED gives. Here, it is the placement of the electrode pads on the breast of the victim (cf. Fig. 7) and the pressing of the shock button.

(5b) In the case where no AED is available, the helper has to give chest compressions. This is again explained verbally and by a ghost controller that moves up and down on the chest of the victim which has to be replicated.[1]

(6) At the end of the situation, a paramedic appears and the user has to describe the performed actions by clicking on the displayed symbols (cf. Fig. 8). After finishing, an *equation of symbols* appears on the canvas. If the answer was correct, the paramedic thanks the user and tells him that she is taking care of the patient, if not, she suggests to update the user's knowledge on first aid.

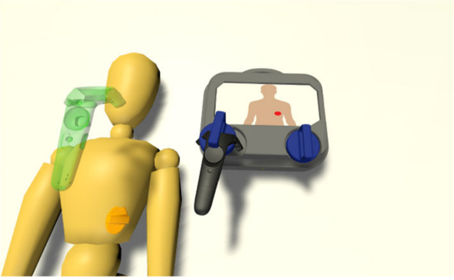


Fig. 7 Green *ghost controller* moving towards the corresponding attachment point of the lay figure. This movement guides the users to follow with their controller and attach the right defibrillator pad. (Color figure online)

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[1] Please notice that VReanimate focuses on *untrained people* and therefore we omit the rescue breath following the ERC suggestions.

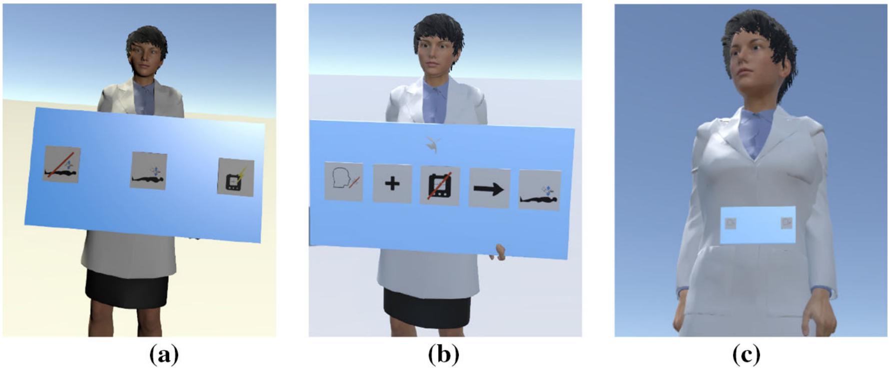


Fig. 8 The paramedic in VReanimate. **a** The response plane held by the paramedic to inquire about the user's knowledge, **b** enlarges, when the user's controller touches the plane or paramedic. **c** The paramedic responds after the user input

Presence

Following the terminology by Slater and Wilbur (1997), we understand immersion as a technology's capacity to reproduce the sensory perception of the real world. The notion of presence complements this technological perspective by the subjective experience of an immersed person. Generally, presence is felt by the user, if he forgets about the technical origin of the experience and is perceiving it as real (Schuemie et al. 2001). In VReanimate, we establish the sense of presence by utilizing haptic, auditive and visual feedback. Concerning the latter, the visual sense in our simulation has been addressed by using the software provided for VR equipment, which ensures a stereoscopic, tracked three-dimensional experience.

From the tutorial scenes to the exercises, VReanimate establishes the visual sense of presence step by step. We took this step-wise approach as to render first aid as accessible to the user as possible and to avoid any kind of obstruction which otherwise might build up: The tutorial uses a lay figure representation of the patient. In the other scenes, a manikin represents the patient. These representations are inanimate as patients suffering from irregular heartbeat do not move. In the scenarios, we added realistic graphical effects to the scene. Concerning the interaction with the environment, we highlighted items with which the user can interact to provide quick feedback and to minimize the user's cognitive load. This also allows the user to ease into the virtual experience much quicker.

Auditive feedback is provided when the user moves the head towards the head of the patient and a sound recording of a human breathing is played. A consistent use of unobtrusive sounds can be intuitively understood and does not jeopardize the experience either, especially since playing these sounds is always associated with the change of a scene as well. Finally, we deployed haptic feedback by the use of the vibrators built into the 3D input controllers of the HTC Vive system. This feedback is used to communicate that the patient has been touched, for example when the user compresses the chest of the patient during the heart massage. In combination with the pictographic feedback during the tutorial, this compensates, to some extent, the lack of proper haptic feedback.

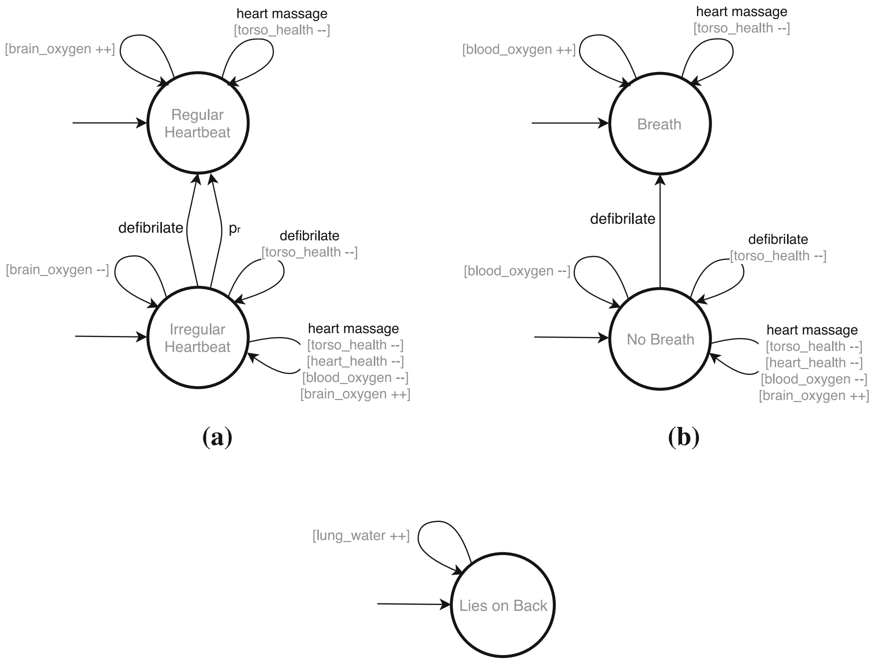
Simulation of patients

The casualty can be in different health conditions. This is internally represented by three finite state machines (FSM) depicted in Fig. 9. The casualty's overall condition is described by all three FSM at the same time, i.e., different aspects of his/her condition are described by three different health (sub-)states. Depending on the simulated scenario, the initial states of the FSM may vary, as indicated by the horizontal arrows in Fig. 9a, b marking the entry points of the FSM. Transitions between states are triggered by the user's interaction in combination with the casualty's internal health parameters. These parameters include a *torso health* value, the *blood oxygen level*, the *brain oxygen level*, the *amount of water in the lungs* and a *heart health* value. These parameters are represented as floating point numbers and are increased (++) or decreased (–) depending on the casualty's health state and the user's intervention as seen in Fig. 9. For instance, a heart massage causes a decrease of the *torso health* value, a slight decrease of the *blood oxygen level* but a slight increase of the *brain oxygen level*. If one of the values exceeds a given threshold, the virtual patient dies, e.g., when there is too little oxygen in the brain, too much water in the lungs, or the torso has suffered too much damage. For training purposes, we limited the state transitions to those with high probability, e.g., that a regular heart beat can only be recovered by chance (probability p_r) or by applying the defibrillator.

At the beginning of each scene, a subset of all conditions is chosen. By having more than one FSM affecting the patient, we achieve a parallel execution of the FSM impacting the patient's health, which implies that the user's input may have different outcomes in different situations. Considering interdependencies among states, the condition *irregular heartbeat*, for example, affects the *brain oxygen level*, as the circulatory system does not work properly any longer. We also added stochasticity to the FSM's respective state transitions in accordance with the corresponding literature. In addition, the *irregular heartbeat* state has a small chance of recovery at each iteration. If the patient recovers from this condition, it switches to the *regular heartbeat* state and the health parameters are not affected negatively any longer. Considering the user's interaction with the patient, the activation of the defibrillator, for instance, recovers the patient from the state *irregular heartbeat* with a certain probability. But activating the defibrillator also negatively affects the health parameter *heart health*. This transition gives credit to the high voltage passing through and damaging the body and the heart of the patient.

To provide the user with an environment in which he can learn and practice first aid more efficiently, we decided to exclude incurable conditions like *vomiting* patients.

As the greatest challenge in first aid is to have bystanders respond at all, we designed the simulation to be rather forgiving if the patient is not treated absolutely correct. To this end, we increased the odds of recovery for specific treatments and let the model disregard the occasional medically adverse interaction. The patient's



(a) **(b)**

(c)

Fig. 9 The casualty's health condition is simulated by means of three state machines that model the heart's state (**a**), the breathing condition (**b**), and the effect of the casualty lying on the ground (**c**)

death, as the drastic result of wrong treatment or lack of engagement, occurs within a short time frame of 50 s in the advanced exercises. This puts pressure on the user, but it also alleviates the need of sustained heart massage over a long period of time, which is exhausting even without proper haptic feedback.

The simulation does not differentiate between the symptom and different causes for the symptom. If required in the future, this information could be added to the FSM in order to enable a more differentiated analysis of the patient state.

Symbolic speech

Using a text-based approach did not seem suitable for first aid to us: First of all, first aid should be applied almost instantly, without having to transfer abstract knowledge into movement. The correct procedures, therefore, must be witnessed or performed, not only read. Additionally, relying on texts as a medium creates a limitation for potential users. For example, young children or people with reading difficulties would be inhibited by a text-based approach. Instead of text, the simulation uses graphic symbols combined with ghost controllers and buttons to form an easily understandable environment (Shneiderman 2010). These graphical symbols should be universally recognizable. In order to guide the user's movement, we chose to project a *green semi-transparent ghost controller* and an according *headset* into the virtual space. These ghost projections can be augmented by additional pictographs. Given a specific context, the resulting combinations carry certain meanings. For instance, we tried to ask the user whether the patient is breathing, which is seen in Fig. 8.

Evaluation

In the previous paragraphs, we described the design process and the final application *VReanimate*. As presented, this was heavily based on theoretical and empirical findings. In order to arrive at a high quality, appropriate and conducive application, we furthermore decided to conduct a formative evaluation of our prototype. The formative evaluation has the aim to improve the quality of a program or product continuously while it is developed. This approach facilitates iterative adjustments which increase the prospect of successfully achieving the defined objectives (Brown and Gerhard 2006). It was therefore the main purpose of the evaluation to provide data on potentially critical or conducive aspects of the application in relation to its suitability for learning about appropriate procedures in first aid situations related to CPR. This research procedure contrasts with the common approach of a summative evaluation, which analyzes the effectiveness when the program or product is completed. The former approach enabled us to continuously improve our application according to the feedback of potential users. To evaluate the suitability of *VReanimate* and its non-textual and situated approach for teaching first aid and reanimation, we therefore chose to conduct a two-step mixed methods triangulation study, following the procedures of a multilevel model (Creswell and Plano 2007). On a first level, this included a qualitative approach with 8 semi-structured interviews at the beginning to evaluate the initial state of the simulation with a focus on the subjective user perspective. On a second level, this was followed by a quantitative approach with an experimental pretest-intervention-post-test procedure ($N = 22$) to analyze its suitability for knowledge gain. During the pre-post-test, a structured qualitative non-participant observation ($N = 22$) was conducted, assessing the revised version with a focus on an objective usability perspective on a third level. The former thus allowed us to revise critical elements or design problems which existed from the subjective perspective of users at first. After revising these elements, the latter confirmed the suitability of the system to teach the targeted knowledge from a more objective point of view by using knowledge tests and participant observation. The subjective perspective was taken into consideration because of the strong influence of personally perceived attitudes and skills of the user on his or her successful use of a medium for learning (see for example Shroff et al. (2011)). The objective point of view ensured that there is no contradiction in the perceived use and the related learning gain compared to the actual use and the related learning gain. Analyzing these three perspectives one after another made it possible to continuously improve our application, while at the same time following an economical research procedure. Furthermore, employing a quantitative approach in the beginning would have given us less hints for improvement as it would not provide detailed and unexpected information. In the following sections, we will give a brief overview about the study and the related procedures, including the selection and characteristics of the participants, the employed instruments and, of course, the results.

Semi-structured interviews

This survey method was chosen, because we wanted to learn more about the specific impressions by the users, like how they felt when playing the simulation or which thoughts it triggered. We felt that otherwise it would not have been possible to properly investigate how well the approach of non-textual and symbolic guidance worked out for our presented aim to learn about appropriate behavior in first aid situations or if there were particular crucial points that we had not anticipated. Furthermore, it seemed to be more suitable to assess other important points like the role of authenticity or questions concerning its usability. Such questions might not have been answered by other methods such as questionnaire-based inquiries due to their lack of flexibility in communicating subjective experiences and solely including questions regarding aspects which the researchers were expecting. By means of the interviews, we hoped to find answers to the following questions:

- How was the user’s overall impression of the simulation?
- How did the users experience the non-verbal and pictographic guidance approach?
- Which knowledge gain did the user experience by playing the simulation?
- How did the users perceive the realistic scenarios?

Participants

In order to create a test group as heterogeneous as possible, we focused on the three criteria age, experience with VR and prior knowledge in first aid. The age criterion seemed necessary to us, as a training of first aid skills affects almost everyone and thus needs to be suitable for as many people as possible. As the system needs to be usable by users unexperienced in VR as well, we also included the criterion “experience with VR.” Last but not least, we included the aspect of prior knowledge in first aid, as it is the goal of the system to be valuable for a broad range of people with different conditions and, as shown by Müller et al. (2014), this aspect had significant effects in similar studies related to teaching reanimation. The final sample consisted of eight participants between 18 and 54 years old. It included participants, who *never had a first aid course* (2 ×), *had only one first aid course* (5 ×) or were *medical professional medicals (graduated nurse)* (1 ×). Additionally, they had different levels of experience with the medium VR, varying between *didn’t know anything about the medium VR* to *plays VR games on a regular basis.*

Data collection

The participants took part in the study separately. At the beginning, they were told about the simulation and its purpose. Then we introduced the participants to the setup and started VReanimate. During the simulation, the only advice that was given when needed was that participants struggling to continue should *look around*, and that *there are two buttons they can interact with*. After the simulation was finished, the participants took part in the interview, which was guided by a rough guideline. These interviews were recorded. After conducting all interviews, they were transcribed and a qualitative content analysis in accordance with Mayring (2015) was performed. This method was chosen as it is one of the most prominent methods for the analysis of interviews, because it offers a very systematic and standardized procedure including detailed step-by-step models and analytical rules (see ibid.). For the presented research questions, we followed the model of a summarizing content analysis, including the following steps: (1) Determination of the units of analysis; (2) Paraphrasing of content bearing text passages; (3) Determining the envisaged level of abstraction, generalization of paraphrases below this level of abstraction; (4) First reduction through selection, erasure of semantically identical paraphrases; (5) Second reduction through binding, construction, integration of paraphrases on the envisaged level of abstraction; (6) Collation of the new statements as a category system; (7) Retesting of the new statements as a category system (cf. Mayring 2015).

Results

Regarding the overall impression, the participants' feedback was rather positive, although also including some negative responses. One participant added that the *simulation is uncomfortable almost like in the real world*. Another one said that by *caring for the patient, the environment faded in the background*. However, from the perspective of our theoretical foundations for the design of the simulation, the negative feedback corresponds with our goal to create an authentic way for the training of the acquired knowledge. As situations which request the provision of first aid are usually perceived as uncomfortable, according to situated learning theory, it must be a goal to provide such similarities in the simulation as well.

Concerning the user guidance and interaction with the system, the participants were quite positive: Five testers categorized it as *very understandable*, two as *understandable* and one as unintelligible. The green transparent ghost headset and controller animations were understood by every tester, and half of them specifically mentioned them positively. Selecting the correct answer about the patient's health by pressing symbolic buttons worked for most of the participants as well. Nevertheless, there were also some negative aspects related to guidance and interaction. Three people mentioned that they *missed some sort of verbal guidance*, which was not included at that time (see "VReanimate I" section). Furthermore, two participants had problems with understanding the buttons. Finally, three people felt there was a lack of information about wrong decisions: When they use the wrong treatment, they would like to get more information on *how to do it right* or *what did I do wrong*.

When asked about acquired knowledge, five of the eight testers remembered the trained procedures correctly. Six participants told the interviewer that they had the feeling they *knew what to do* and tried to act accordingly. Only one participant missed information about *why a treatment should be applied*.

Concerning the authenticity and immersive character of scenarios, most participants expressed that they were realistic for them. Six of the eight testers experienced the scenarios as *close to reality*. One user mentioned that some of the scenarios are *not realistic scenarios for the country the tester lives in*. One tester experienced the scenarios as unrealistic. Five of the participants did not feel distracted by these scenarios. They *only focused on treating the patient and did not focus on the environment* around the patient. The other three participants got distracted from the environment and experienced a *pressing, urgent* feeling.

In conclusion, the data gained in the interviews confirmed our hypothesis that the pictographic approach can be used to transport and reassess knowledge. Nevertheless, we discovered that a completely non-verbal approach is not easy to understand for everyone and thus was changed to a non-textual approach in the revision (see "VReanimate I"). Concerning the opportunity to learn first aid in VR, the interviews confirmed that this medium can be used successfully and effectively. However, the design and guidance aspects of the system once more turned out to be crucial factors in this context. Especially, the distraction of the participants seemed an important aspect for revision. Based on the results of the interviews, *VReanimate* was further developed and a new version was created. The changes can be seen in "VReanimate" section.

Pre-post-experiment

In order to examine the suitability of the revised system for teaching first aid procedures, a pre-post-experiment was administered next. This included two questionnaires, a knowledge test and a standardized non-participant observation while testing the simulation. With the questionnaires, we wanted to gain empirical data relevant for the question "Can VReanimate II lead to a significant increase of knowledge about correct procedures related to first aid and reanimation?". The goals of the observation were twofold. First, it should provide additional insights in remaining guidance and design issues in the simulation which were not perceived by the users or stated in the interviews. Second, it was included to analyze differences in the performance within the simulation compared to the performance in the knowledge test afterwards. We did not conduct an experimental study with a control group, as media comparisons tend to be linked to a multitude of problems and are therefore regarded as problematic and ineffective according to meta-analyses (Warnick and Burbules 2007). One major reason for this claim is that not the media themselves make the difference, but, if at all, the methods and presentational modes enabled by the characteristics of the media. Therefore, the success of the use of different media depends on the pursued goals and how well these can be fostered by the offered methods and modes. Comparing, for example, a VR application with common methods of training like watching videos would therefore not provide the desired comparative insight as they offer completely different possibilities, similar to comparing a text to a video and wondering why the user does not have the correct picture on his or her mind. Furthermore, a multitude of meta-analyses have empirically confirmed that media formats alone often do not make a difference in the learning results (see for example Tamim et al. (2011)). In the latter, a second-order meta-analysis was conducted which showed no significant difference in the learning achievements when using digital media formats compared to other formats. These findings support the assumption that it is not the format alone, but rather the implemented design and method. Consequently, we concentrated on the way how to present the learning content and how the characteristics of VR could be used for a novel, effective learning experience.

Instruments

The pretest included a questionnaire with questions on demographic data (age, gender), prior knowledge and experience (first aid, using a VR-headset) and a multiple-choice knowledge test. The questionnaire was constructed by using items which were employed in other studies related to the training of first aid and reanimation (Müller et al. 2014; Cheung et al. 2003; Wanke et al. 2018) and adding certain items which were not covered but are usually employed when analyzing the effects of training with educational technology (for example experience with the media format). It thus mainly relied on other validated instruments. The additionally included knowledge test for pre-post-comparison was created by the authors, based on the guidelines for resuscitation by the European Resuscitation Council. The main goal of the knowledge test was to assess whether the participants explicitly knew which steps have to be applied in situations with unconscious persons (and which not) and the related correct sequence of these steps. The procedural knowledge was assessed by observing the participant.

The post-test included a questionnaire to measure the perceived presence of the user and the same knowledge test. Additionally, a possibility to give general feedback on the simulation was given to create once again an opportunity to gain subjective feedback. The six items for the measurement of presence were developed by Frank (2014) with acceptable internal consistency rates. The choice of the given scale lies in the fact that it was created in the language of the participants and therefore prevented errors or changes in the consistency values that could have originated by translation. A presence-questionnaire was included due to empirical findings pointing to the fact that obtained values for presence can also imply the expectable performance after using virtual simulation-based trainings (Stevens and Kincaid 2015; Youngblut and Huie 2003). To pretest the instruments after discussing them in the team, we did two thinking-aloud interviews (Collins 2003). The observation sheet included sections to note the correct or wrong behavior of the participant in the scenarios, as well as two columns for technical issues during the testing and unintended or unexpected behavior by the user.

Participants

An invitation for voluntary participation in the study was distributed via different channels at the two universities involved. The final sample consisted out of $N = 22$ persons, 17 males and 5 females with an age ranging from 20 to 33 years. Six testers (27%) had never used a VR-Headset before, seven (32%) use a VR-Headset less than once a month, seven (32%) use it once a month but less than once a week and two (9%) use it once a week but not on a daily basis. Only one tester did not have any prior training in first aid and reanimation. The remainder had either had a course in *immediate life-saving measures* or *first aid*, which are two popular half-day or one-day courses in Germany and are needed for getting a driver's license. Additionally, one tester indicated that he was also a trained paramedic in active duty. We furthermore asked about when the testers had their last training. The results showed that 18 testers had their training more than two years ago, 3 had it during the last one or two years. Additionally, 15 testers indicated that they did not know the current ERC guidelines for resuscitation. Seven had the feeling that they knew parts of it.

Data collection

Each participant was tested separately with a standardized procedure. At the beginning, he was introduced to the setting, procedures, and aims of the study. Afterwards, the examiner gave a brief standardized introduction into using the HTC Vive, the possible ways to interact in the simulation and the possibility to abort the simulation at any time. The participant was then asked to fill out the knowledge test and the questionnaire on demographic data and experience, before being invited to test the complete system. During the simulation, the examiner was allowed to answer questions related to the user's orientation if urgently needed. Furthermore, he had to observe the user's behavior and fill in the observation sheet. After one complete run, the participant was asked to complete the presence-questionnaire and again the knowledge test.

Results

A statistical analysis was performed with SPSS. To analyze the learning gain and its significance, we conducted a Wilcoxon signed ranked test, after checking for normality by the use of the Shapiro-Wilk-Test and missing normality in the post-sample with $p < 0.05$ (pretest: $p = 0.240$; post-test: $p = 0.023$). The latter was employed because of its better suitability for small sample sizes (Razali and Yap 2011). The results are seen in Tables 1 and 2.

They show a significant increase in the knowledge of the testers with $Z = -3.788$ and $p = 0.000$ ($\alpha < 0.05$). The results match with the high rate of correct performances in the simulation. According to the data in the observation sheet, the testers exhibited correct behavior and response to the paramedic in 78% of the cases during the exercises and advanced training.

Table 1 Scores in pre- and post-test

	N	Total score	M (score)	SD (score)
Pretest	22	49	25	6.9
Post-test	22	49	35	4.6

Table 2 Differences in scores

	(Score)	Knowledge gain	Z	Sign.
Pretest to post-test	+ 10	+ 20%	− 3.788	0.000

Table 3 Perceived presence

	Min	Max	M	SD
Overall score for presence	2.0	5.3	4.0	0.82

Table 3 shows the obtained scores for presence (Cronbach's alpha = 0.81). The mean average is $M = 4.0$ on a scale from one (*does not apply at all*) to six (*fully applies*).

Possible reasons for these comparably low scores could be found in the non-participant observation and the general feedback in the questionnaire. Both indicated, either by behavior or by explicit feedback, that some realistic aspects were missing, such as being able to push the elevator button for help. Furthermore, some users noted in the open-coded feedback questionnaire that the relative sizes between the houses and the people in the street scenario were not realistic. Others indicated by their behavior that the integrated time span for waiting for the ambulance to arrive seemed to be to long, as several testers started to play around with their controller or the virtual environment.

Concerning the usability and user guidance of the system, both, the open-coded feedback in the questionnaire and the observed behavior in the system, indicated that most of the users had no problems with understanding the symbols or interacting with the system in the intended way. Regarding possible improvement, however, some users expressed that they would have liked to know what they did wrong or why the paramedic did tell them to proceed differently.

Overall, the users expressed a positive view of the system. Some of them mentioned it to be more effective than their previously experienced first aid training. Others highlighted the fact that they were able to perform the steps instead of hearing about them and thus gained a better understanding.

Discussion

The results of the pre-post-experiment showed a significant increase of the participants' results in the knowledge-test about the correct procedures related to first aid and reanimation. This supports our hypothesis that VReanimate II could be a suitable approach for the fostering of knowledge about first aid. Nevertheless, the authors can of course not exclude the possibility that there were also other additional reasons for the knowledge gain of the participants. For example, the results of the pretest also indicated that there was a high amount of prior knowledge in our sample, leading only to minor increases. The use of VReanimate could thus have stimulated already existing knowledge instead of teaching and training new knowledge. Furthermore, there still remained some unclear points, as none of our testers was able to achieve the highest possible score. However, in regard to the overall correct procedure of the steps, there was a very high increase from 18% correct answers in the pretest to 77% in the post-test. This indicates that the teaching of the appropriate reaction in the corresponding situations was less successful than the improvements in the knowledge about the procedural sequence of steps. A more detailed statistical analysis of moderating factors like gender, prior knowledge, or prior experience in VR was, unfortunately, not possible due to the size and structure of our test sample. Hence, we can not say if there were influences on the results caused by these aspects. However, the authors regarded the heterogenous sample structure as beneficial, as the system aims for a diverse target group. The scores for the perceived presence were acceptable, although they showed that there is still room for improvement. The data of the observation sheet and the feedback on the system in the questionnaire point to different aspects, which resulted in distractions and thus still need to be revised. A statistical comparison of the results of the knowledge test and the observed performance seemed inappropriate to us, as the task completion in the system differed to much from the style of the knowledge test. However, the observed high performance in the scenarios in relation to the high performance in the knowledge tests indicate that the taught knowledge is not bound to the situational performance, but can be remembered explicitly.

Overall, our study not only shows how situated learning can be systematically transferred to the VR media format, but also shows the possible associated training success. Clearly, a comparison to other pre-post-studies on the teaching of first aid knowledge would be of great interest, but at this point, despite of our best efforts, we did not find according, comparable scientific resources. As pointed out in "Related work" section, VR simulations are assumed to be helpful for the training of medical-related procedures. The results of our research corresponded with this assumption, but furthermore extended the current state of research in regard to a new possible field of application. Additionally, in the second part of this section, we also discussed potential benefits of VR for situated learning. Especially, the results of the interviews empirically support this claim. This could for example be seen by the perceived uncomfortable feeling of the user, which reminded him or her of a real situation.

Conclusion

This article presented VReanimate, an immersive VR application, which has the aim to teach applicable procedural knowledge related to first aid and reanimation by means of a situated and non-textual design approach. Our empirical evaluation of VReanimate II showed that it could potentially achieve this goal. It furthermore indicates that a non-textual and situated approach can work for this purpose.

The main contribution of this work is the systematic connection of the situated learning and the VR media format. To realize this contribution, we devised an according, innovative VR training application in an interdisciplinary, iterative development approach. As part of this work, certain conflicts such as the need for continuous feedback mechanisms, as postulated by Shneiderman and Plaisant (2004), and the need for authenticity of the learning situation as required by the theory of situated learning (Dawley and Dede 2014) became obvious. We also gave empirical support of the learning potential of a situated-VR approach. Our results indicate that the situated-VR approach lends itself better to entrain sequences of actions rather than declarative knowledge. However, the exact emergence of this preliminary result needs to be further investigated.

There remain certain limitations based on the sample size and structure of the study. For example, we were not able to examine influences related to gender or prior experience with VR. Additionally, to gain more solid data about the effectiveness for a broader range of possible users, a bigger sample size of diverse potential users is needed. Finally, it can not be excluded that the observed knowledge gain was exclusively caused by the use of the system. The observed high prior knowledge could for example also have influenced the results to a large extend.

It is the goal of the authors to continue with the development of VReanimate in order to create an appropriate, broadly accessible and engaging possibility to train first aid and reanimation for everybody, anytime and anyplace. Our current state and results make us confident that this goal can be achieved.

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