Comparative Evaluation of AR-based, VR-based, and Traditional Basic Life Support Training

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Abstract—Basic life support (BLS) is crucial in the emergency response system as sudden cardiac arrest is still a major cause of death worldwide. In the majority of cases, cardiac arrest is witnessed out-of-hospital where execution of BLS including resuscitation through by-standers becomes indispensable. However, survival rates of cardiac arrest victims could significantly increase if people were more familiar with the BLS process. In this context, technology-enhanced BLS training approaches utilizing Augmented (AR) and Virtual Reality (VR) have been proposed in recent works. However, most of these approaches are not compliant with the medical BLS guidelines or focus only on specific steps of BLS training such as resuscitation. Furthermore, most of the existing training approaches do not focus on automated assessment to enhance training effectiveness through fine-grained real-time feedback. To overcome these issues, we present a novel AR- and VR-based training environment which supports a comprehensive BLS training compliant with the medical guidelines. Our training environment combines AR-/VR-based BLS training with an interactive haptic manikin that supports automated assessment, real-time feedback, and debriefing in an integrated environment. We have conducted a usability evaluation where we analyze the training effectiveness and cognitive workload of BLS training based on our AR and VR environment against traditional BLS training. Results of the evaluation indicate that AR and VR technology have the potential to increase engagement in BLS training and reduce the cognitive workload compared to traditional training.

Index Terms—basic life support, resuscitation, augmented reality, virtual reality, usability evaluation

I. INTRODUCTION

Basic Life Support, or BLS, generally refers to the type of care that bystanders, first-responders, healthcare providers, and public safety professionals provide to anyone who is experiencing cardiac arrest, respiratory distress, or an obstructed airway [1]. BLS mainly requires knowledge and skills in cardiopulmonary resuscitation (CPR), using automated external defibrillators (AED), and relieving airway obstructions in patients of every age. In the majority of cases, cardiac arrest is witnessed out-of-hospital, but emergency medical services may not arrive at the emergency location in a short time interval. Thus, execution of BLS and including steps such as resuscitation through bystanders becomes indispensable. However, survival rates of cardiac arrest victims could majorly increase if lay resuscitation rates would be higher. Despite the importance of becoming active in BLS and starting the foreseen steps, BLS skills are usually not trained regularly among people. Regular training, for instance in schools or at regular training courses, is missing in most cases. Thus, many people are not skilled in BLS procedures. In this connection, the question remains on how to teach people BLS skills and how to motivate them to refresh their skills regularly. Even though there is a large selection of training formats available, such as local BLS training courses, online courses, or training sets including video tutorials on DVD and other materials, people may not be motivated or willing to pay for these courses or materials. Especially for younger people, who are accustomed to using modern technology gadgets, traditional teaching methods may feel outdated and may create a barrier concerning their self-motivation for training. In addition, these training formats are usually limited with regard to their capability to combine theoretical teaching of knowledge with practical skill training and assessment, such that they are suitable for independent self-training only to a limited extent.

Motivated by the need to provide access to such BLS self-training approaches for everyone, modern training formats that utilize Augmented Reality (AR) or Virtual Reality (VR) technology were proposed in recent years. While AR and VR technologies have shown great potential to enhance BLS training in general and especially cardiopulmonary resuscitation (CPR) performance, most of the existing approaches are in a rather prototypical state of implementation or do not leverage the full potential of an immersive learning environment for basic life support training. With this regard, most of the existing approaches are not fully addressing the following requirements (R) that we have identified based on a collaboration with...
medical experts. Firstly, most of the existing approaches are not compliant with standardized medical guidelines for BLS [1] or only focus on specific sub-steps of the BLS training such as CPR (R1 - Compliance with BLS Guidelines). Furthermore, existing solutions mostly do not provide mechanisms to automatically assess user actions and to provide real-time feedback during training in order to increase learning effectiveness (R2 - Automated Assessment) as well as an overview of the training results at the end of the training (R3 - Real-Time Feedback and Debriefing). As there are two major purposes of the training environment: acquisition of knowledge and practical skills, and examination of the acquired skills, the training environment should be divided into two modes of operation (R4 - Training and Exam Mode). While few approaches follow this requirement, most approaches do not provide dedicated modes for training and examination. Finally, to support an interactive and haptic learning environment, the AR- and VR-based training environment should be integrated with a haptic manikin to represent the victim who is in charge of BLS. The haptic manikin should deliver a hands-on learning experience for BLS and support the training of high-quality CPR especially with regard to compression rate and depth (R5 - Haptic Reality).

Based on the above-mentioned requirements, the following research questions (RQs) can be raised:

RQ1: How can we exploit AR/VR technology to support engaging, effective, and comprehensive BLS training?

RQ2: How does AR-/VR-based BLS self-training perform in comparison to traditional training in terms of training effectiveness and cognitive workload?

To answer the research questions, our contributions in this paper are as follows: Firstly, we introduce a novel AR- and VR-based BLS training environment which tackles all the above-mentioned requirements. Our training environment consists of a generic training application kernel that can be instantiated for AR and VR usage scenarios. Furthermore, it integrates a custom build haptic manikin which supports an interactive training where AR/VR technology is combined with haptics. Apart from the constructive approach, we have conducted a usability evaluation where we analyze the usability, effectiveness, and cognitive workload of BLS training based on our AR and VR environment against traditional BLS training. In addition to that, we have analyzed the feeling of presence between the AR- and VR-based BLS training environments.

The rest of the paper is structured as follows. In Section II, we present and discuss the related work. In Section III, we describe the conceptual solution and implementation of our AR- and VR-based BLS training environment. In Section IV, we present and discuss the main results of the usability evaluation. In Section V, we conclude the paper and give an outlook for future work.

II. RELATED WORK

Several approaches for AR- and VR-based training in the medical domain have been proposed in recent years [2]. Improvements in modern AR and VR technology make researchers gain increasing interest in using this technology for medical education, including resuscitation training ([3], [4]).

A. AR-based approaches

Strada et al. [5] propose an AR-based self-training and self-evaluation tool for Basic Life Support and Defibrillation called Holo-BLSD. It utilizes Microsoft HoloLens to create a first aid emergency scenario consisting of holograms of interactable objects as well as non-player characters (NPCs) that can be given instructions to. The system offers different modes of operation for learning, rehearsing, and examining basic life support skills. An included automated assessment evaluates the correctness of the executed steps. System usability and ISO 9241-400 ergonomics of the proposed system have been demonstrated in a subsequent usability study [6]. Balian et al. [7] go one step further in terms of visual augmentations and show a model of the human circulatory system next to the training manikin, providing direct feedback to the user by changing the visual blood flow proportionally to the rate of chest compressions applied. HoloCPR by Johnson et al. [8] focuses on simple visualizations, such as arrows, circles, texts, and animations, in order to give instructions to the trainee and guide the trainee’s attention towards points of interest. Experimental results demonstrate the effectiveness of the proposed application and indicate reduced initial reaction times and faster action as compared to traditional 2D instructions.

A common problem with these approaches is their limited ability to provide a comprehensive assessment of the trainee’s CPR performance, as they exclusively rely on the technical capabilities of the HoloLens. However, training systems with a more sophisticated CPR quality assessment have been proposed in the past [9] [10]. Here, the physical training manikin is equipped with a dedicated sensor kit consisting of several pressure sensors, allowing precise CPR measurements in terms of compression location, depth, and frequency. Pretto et al. [11] demonstrate the applicability of AR concepts for life support training without the use of modern AR hardware. Here, visual augmentations (wounds, injuries, facial expressions, etc.) are projected onto the training manikin, reflecting the state of the virtual patient. Cardiac or pulmonary sounds played via speakers installed in the back of the manikin’s neck enable the trainees to autonomously assess the patient’s consciousness. The authors conclude that their system improves accuracy and objectivity as well as the trainees’ autonomy during training.

B. VR-based approaches

Bucher et al. [12] create a VR training system for non-verbal guidance in virtual first aid scenarios. The non-verbal approach allows the authors to avoid the trainees having to read and interpret texts during the training, facilitating the creation of fast-paced, uninterrupted scenarios. In ViTAWiN, Schild et al. [13] augment the virtual training with a physical training manikin in such a way that the manikin provides a direct
physical reference for the virtual manikin, thus allowing precise haptic feedback. Semeraro et al. [14] enhance traditional CPR training with VR using a sophisticated setup consisting of a VR headset, a CPR training manikin, data gloves, and tracking devices, putting the user into a first-person perspective cardiac arrest simulation. A refined prototype VR CPR standard manikin training system with hand tracking and handsfree Kinect motion detection was presented in their follow-up work [15]. Experimental results indicate that compression rate and depth data collected with the developed system are comparable to a professional CPR training manikin such as Resusci Anne. Further efforts have been made recently to compare traditional training and VR-based training. For instance, in a recent study Issleib et al. [16] describe an immersive VR BLS training environment and compare the effectiveness of VR-based BLS training with a traditional training course. They conclude that traditional training is best for teaching technical skills, while VR-based training has a higher overall learning gain. Emphasizing the importance of early and repeated BLS training, Vaughan et al. [17] demonstrate a VR CPR training system specifically for schools. Further, the integration of gamification features into first aid training systems has been explored by a few approaches in the past [18] [19]. By including gamification features such as progressive difficulty, leader boards, and competition with other trainees, these approaches aim to provide a gamified learning environment that keeps the training exciting and engaging, thus encouraging repeated training and preventing degradation of CPR skills over time.

C. Discussion

None of the proposed systems described above is fully compliant with the ERC basic life support guidelines [1] in terms of the taught methods, techniques, and procedures. Since properly executed CPR is one of the most important steps in life support, the majority of works proposed in the past, focus on this topic rather than encompassing the full BLS procedure. Another important limitation of the considered approaches is the lack of an included debriefing feature. While some of the considered works do have a logging feature included that records the trainee’s actions [5][19], an actual debriefing session is never part of the AR or VR application as such.

Recent comparative studies between VR-based and traditional BLS training exist [16]. However, it is important to note that to the best of our knowledge there is no existing work that provides a detailed comparative analysis to identify the benefits and limitations of both AR- and VR-based solutions for BLS training in terms of usability, training effectiveness, and cognitive workload compared with traditional methods.

III. CONCEPT AND IMPLEMENTATION

To address the first research question RQ1 motivated in Section 1, we have designed and developed a novel AR- and VR-based BLS training environment which tackles the described requirements R1-R5 using the Unity\footnote{https://unity.com/} game engine. The following sections give an overview of the concepts and technologies we used to realize the applications. A more detailed insight into the implementation can be obtained from our accompanying technical report [20].

A. Software

As in AR applications the users still see their environment, we decided to create a scenario close to real resuscitation training. The user is in a safe place (e.g. a training center or an office) and stands in front of a resuscitation manikin simulating the victim. We then use augmented reality to explain what to do and give feedback on the executed steps. Everything shown to the user should be correctly placed around the manikin. So, we use the manikin as an anchor to synchronize the position of the virtual objects with the real world. The AR application was developed for the Microsoft HoloLens\footnote{https://www.microsoft.com/en-us/hololens}. We were using Unity version 2019.4.3f1 together with the Mixed Reality Toolkit (MRTK)\footnote{https://github.com/Microsoft/MixedRealityToolkit-Unity} version 2.4.0 and the Vuforia Engine\footnote{https://developer.vuforia.com/} version 9.4.6. The MRTK provides various tools and pre-built elements to simplify AR development whereas we use Vuforia Engine for image recognition to align the virtual with the real world. To do so, a QR code needs to be placed on the manikin’s belly and scanned once with the HoloLens. Then the application adjusts to fit the real world.

The VR application was built with Unity 2019.1.7f1 in combination with ValveVR\footnote{https://valvesoftware.github.io/steamvr} version 2.3.2. SteamVR manages the communication between the applications and various kinds of VR systems and provides some basic components to simplify the development. In our case, we used the Valve Index\footnote{https://www.valvesoftware.com/en/index} VR headset as a target platform for the VR application. Whereas we use a real-life manikin as the victim in the AR application, we need a virtual victim for the VR variant. For that, we use a 3D model of a human lying on the ground.

Figure 1 shows an overview of the BLS training architecture that is described in the following.

1) Task Management: To allow the application to keep track of which steps the user executed, and how well it was done, we developed a Task Management which works on tasks derived from the ERC guidelines for BLS [1] (R1). For every step of the guidelines, we created a task with all corresponding subtasks. With that, we can track the state of the user in the training. We can also record how well a task was executed, and automatically assess the user’s performance (R2).

2) Building Blocks: As the task management only knows the basic logic of the process, we created several Building Blocks which can be activated by a task and are aware of the user’s interaction with the applications.

Text/Audio: We needed a possibility to display static information to the user. We created Texts describing the current step, how to execute it, and why it needs to be executed. These texts have been derived from the ERC guidelines for

\begin{figure}[h]
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\caption{Overview of the BLS training architecture.}
\end{figure}
BLS. As it can be tiring for a user to only read text, and to simulate a trainer explaining the content, we provide Audio files of the text being read. We decided to record the texts in high quality rather than using a text-to-speech system to increase the immersion and better simulate real-life training. In the case users missed something or have problems understanding the language, we additionally show the text itself and corresponding images depicting the task. In order to provide a better overview of the current, previous, and next steps in the BLS sequence, we show a checklist and a breadcrumb-like overview of the tasks during the whole procedure (Figure 2).

Animations: Until now, we adapted techniques used in real life so we can use them in our application. But as we are in a digital environment we can control, we also created Animations showing how the described steps are executed. With that, a user can walk around and watch the animation from the spot they like to fully understand how to execute a step properly. To show the user Animations about what to do, we first needed a possibility to create them. As it is very time-consuming to create all animations by hand, we utilized the HoloLens' head, hand, and finger tracking capabilities in order to record the movement of the head, the hands, and the fingers by saving their position and rotation in fixed time intervals. Those animations are used in the AR and VR applications.

(Interactable) Objects: In real accidents, multiple helpers are likely to be present at the accident scene. Thus it is also important that users learn how to communicate with them and where tasks can be delegated to someone else. For that, we provide an avatar representing other helpers. As the users cannot directly interact with it, we call it a Static Object. Additionally, we need Interactable Objects the user can directly interact with. For our BLS training, we created broken glasses, a mobile phone, and a defibrillator with its electrode pads.

Voice Commands: In order to evaluate whether a user correctly communicated with bystanding helpers, we integrated the possibility to recognize Voice Commands, i.e. specific keyphrases that users have to say which can be recognized by the application.

Manikin/CPR simulator: Chest compressions are a central aspect of the BLS sequence. To increase immersion and realism, we created a haptic Manikin/CPR Simulator. In Section III-C, we explain the simulator's hardware setup in more detail.

Position Trigger: When interacting with the manikin, the user’s head or hands need to be in a specific position. For example, when ventilating the victim, the user’s head is right above the victim’s head. To retrieve that information, we created Position Triggers which raise an event after the correct position is reached.

In order to inform users about their current performance, we give them real-time feedback (R3) while they execute the training. Whenever a task was executed correctly, the user gets notified by a sound cue. In addition, during CPR, we also display the current compression depth and rate.

With that, we described our concept for the training part of the application where we offer explanations, descriptions, and guidance through the training. In addition to that, we developed an exam mode (R4). In the exam mode, explanations and guiding elements are omitted so the users have to execute the training on their own.

3) Debriefing: When a training session (exam mode) has finished, the system presents an overview of the training results. Results show the list of tasks in combination with their completion result, i.e. whether the task has been completed correctly or not. Further, the system provides hints for improvement where appropriate, such as when a task has been completed successfully, but a time constraint associated with the corresponding task has been exceeded. In addition to the real-time feedback during the execution, results for CPR (average compression rate and depth and whether the chest was always fully released) are presented during the debriefing. The application can also give specific improvement suggestions, for instance when the compression rate could be optimized in one or the other direction. To not overwhelm the user, we implemented two levels of detail for debriefing, one providing an overview of all the tasks and one providing a more detailed insight into single tasks.
B. Training Application

Using the building blocks as described above, we created the whole training application which guides the users through the BLS sequence. Figure 2 shows one step in each application. In Figure 2a, the trainees need to remove all dangerous objects (the broken glasses), whereas, in Figure 2b, they need to use the defibrillator on the victim.

C. Hardware

As working on/with the victim is an essential part of BLS, we need some kind of hardware to train that. That is especially important for performing chest compressions. Without real-life hardware, the users would perform compressions in the air or on the ground without realistic resistance. In addition to that, we could not precisely assess the rate and depth of the compressions. For conventional training, there are resuscitation manikins available to buy which allow chest compression and ventilation. But, as our goal is to evaluate the rate and depth of the compressions automatically, we need sensors to be integrated into the manikin.

Manikins with sensors are also commercially available, such as the Laerdal Resusci Anne\(^7\). They are mostly used to train medical professionals and thus consist of many complex sensors. As these commercially available professional manikins are usually closely tied to their own companion tools and apps, accessing their sensor data is not easily possible. Thus, we have explored an alternative solution where we created our own CPR manikin, which is equipped with only those sensors we need for our application (R5). Figure 3 shows the custom manikin we used. Figure 3a depicts the schematic used to create the manikin whereas the final result is shown in Figure 3b. To give real-time feedback for the chest compressions in the application, there are two elements to consider. First, we have the compression rate, and second the compression depth. The manikin measures how far the chest is pushed multiple times every second and sends those values with a timestamp to the application. Here, we compute the rate and depth of the CPR. Since in AR applications the users’ real environment is perceivable, we utilize a real manikin for the training. As a starting point, we employed a plastic manikin and inserted springs into the chest to allow compressions. We installed sensors in both the manikin’s chest and head. These are used for measuring compression depth during CPR and for recognizing a head tilt during airway clearance.

For VR, the compression simulation can be simpler. As the users do not see the real world, we do not need a correct representation of a resuscitation manikin. In addition, every user interaction happens in the virtual environment, so we do not need a realistic manikin. Instead, for the VR hardware, we use the same technique and sensors, but they were not embedded into a manikin. We created a simpler version with a wooden board on the top.

IV. Evaluation

We have conducted a usability evaluation to analyze the training effectiveness and cognitive workload of our AR- and VR-based BLS training environment compared to traditional training methods. In Section IV-A, we describe the used setup and procedure. Following that, we present our participants and their background in Section IV-B. We display the results we gathered during our usability experiment in Section IV-C. Those results are discussed in Section IV-D. Finally, in Section IV-E, we describe the threats to the validity of our study.

A. Setup and Procedure

To answer RQ2, we conducted a user study that targets comparing our AR and VR training with real-life (R) training. For the R training, the trainer explained the tasks on the manikin and the trainee performed them afterward. In this context, please note that we had no certified trainer, but

\(^7\)https://laerdal.com/us/products/simulation-training/emergency-care-trauma/resusci-anne-simulator/
rather an expert familiar with the BLS training process. The content was the same as in the digital trainings, i.e. the trainer described the same steps and used similar descriptions as the AR and the VR application. For the usability experiment, we followed the following process. First, the users completed their assigned training. Next, they were asked to answer a questionnaire. We used the SUS questionnaire [21] to get insight into the systems’ overall usability, the NASA TLX score [22] to evaluate the workload, and the presence questionnaire by Usoh et al. [23]. Here, we adjusted the questions so that they fit our scenario.

Finally, the users performed an exam. That means they have to perform the whole BLS sequence without any help. We measured the time and noted whenever a user completed a step, so we know in which order the tasks were executed and how long it took. Additionally, we recorded the sensor values of the manikin to analyze the compression rate and depth. We then calculate a score that indicates how well the sequence was executed. Note that we do not consider the duration here.

To compare the execution of the BLS sequence, we introduced a simple scoring system. Every time the user executes an activity correctly, they get the corresponding score (Figure 4). The score distribution was implemented in a similar way to Strada et al. [5].

| Task name                      | Score |
|-------------------------------|-------|
| Ensure Safety                 | 2     |
| Check Response                | 1     |
| Open Airways                  | 1     |
| Make an emergency call        | 2     |
| Send somebody to get an AED   | 2     |
| Perform compressions          | 0-4   |
| Ventilate                     | 2     |
| Place AED pads                | 1 for each pad |
| Make people stand back        | 1     |
| Trigger shock                 | 1     |

Fig. 4: Scores

For the compressions, the average rate (compressions per minute) and the average depth (in cm) are evaluated. The average rate points have the following intervals. 95<avg. rate<125: 2 points, 80<avg. rate<95: 1 point, 125<avg. rate<140: 1 point, all other values: 0 points. For the average depth, 5<avg. depth<6 results in 2 points, all other values result in 0 points.

By adding the points for executing the tasks, we get an intermediate score. As the correct execution order is important for most tasks, we weigh the score. For that, we count the number of tasks that were executed at the correct time (i.e. the task the user executed before the current task is also its predecessor in the activity diagram). If the order is 100% correct, the user gets the full score, if the order is 0% correct, the user gets 50% of the intermediate score. All values in between are mapped accordingly.

B. Participants

For our user study, we had 21 participants, with ages ranging from 22 to 54. We had 5 female and 16 male participants. The participants were distributed evenly on the training types so that 7 participants each performed the AR, VR, and R training. 19 participants had done first aid training before, but for most of them, the last training was 5 or more years ago. Only two persons regularly participate in first aid training every two years. Most AR participants had no to little experience with AR, whereas most VR participants had at least a little experience with VR applications.

C. Results

Figure 5a shows the SUS scores for the AR and VR training applications. The mean scores are 80.36 for the AR and with 83.57 slightly higher for the VR training. But considering the median values, the AR application is rated higher (87.5) than the VR application (82.5). It is also worth noting that the scores for the AR training are broader distributed on the scale, whereas the scores for the VR training are close together. Figure 5b shows the results of the NASA-TLX [22] questionnaire. Here, we can see that, on average, the workloads of the AR (29.88) and the VR training (30.12) are almost the same. A small difference can be seen at the median which is 30 for the AR and 26.67 for the VR application. Again, the values for the AR application are more distributed than the
E. Threats to Validity

For our study, we had 21 participants and, accordingly, 7 participants in each training type. Especially when comparing the AR and VR versions the results are close to each other and we could not see whether one is significantly better than the other. Also, the participants had no time to get familiar with the AR and VR application before the performance evaluation. This means that the participants may not have had enough time to become proficient in the use of the technology. Furthermore, some participants may have had difficulty understanding how the technology works and how to use it properly. We could not verify that all hand and finger movements were 100% correct. Due to the limited possibility and reliability in recognizing gestures or movement of e.g. the hands, the applications could yield more convincing results.

D. Discussion

A major aspect when comparing the results of the trainings to each other is how well the users could interact with the technology. Considering the SUS score (Figure 5a), we can see a wide range of scores. But during the study, we noticed that the participants who gave the application a low SUS score had problems understanding how the technology works and how to use it properly. Whereas the participants who could work with it well gave a high rating. The same aspect can be seen for the TLX score (Figure 5b). The participants who could work well with the technology felt a smaller workload than users who had problems. Concerning the workload, we can see a great potential of utilizing AR and VR for BLS training. On average, the TLX score for the AR- and VR-based BLS training environment was around 30 and much better than the real-life training that received a TLX score over 40. This shows that independent self-training of the BLS procedure can be eased through an interactive and immersive training environment. A big difference between AR and VR can be seen for the presence score (Figure 5c), here the VR application received significantly better scores. The reason is that using Virtual Reality, we could immerse the users in another place so that it felt more like being at an accident. In AR, they could see the office room they were in the whole time. As the field of view for virtual objects is quite small on the HoloLens 2 and we cannot access high computing power, it is hard to immerse the users in another environment.

Figure 6 shows the scores the users got when executing the training and the exam. Figures 6a and 6b. We can see that the scores for AR and VR are always close to each other. For the training, their scores are very high. That is because the application only allows the user to continue with the next step after the previous was fully executed. Only the performance of the CPR can change the results. If a user executes a step incorrectly in the real-life training, the trainer can correct it afterward, but it was executed incorrectly in the first place. But considering the exam scores, users with real-life training had better results than the others. Thus, the 1:1 interaction with the trainer and the trainer’s corrections still yield a better remembering of the tasks. Further results, including efficiency evaluation in terms of training/exam duration as well as CPR rate and depth analysis, can be found in our technical report [20].

We analyzed the training effectiveness by comparing the scores users reached in the trainings and exams (Figures 6a and 6b). We can see that the scores for AR and VR are always close to each other. For the training, their scores are very high. That is because the application only allows the user to continue with the next step after the previous was fully executed. Only the performance of the CPR can change the results. If a user executes a step incorrectly in the real-life training, the trainer can correct it afterward, but it was executed incorrectly in the first place. But considering the exam scores, users with real-life training had better results than the others. Thus, the 1:1 interaction with the trainer and the trainer’s corrections still yield a better remembering of the tasks. Further results, including efficiency evaluation in terms of training/exam duration as well as CPR rate and depth analysis, can be found in our technical report [20].

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Due to the limited possibility and reliability in recognizing gestures or movement of e.g. the hands, the applications could not verify that all hand and finger movements were 100%
accurate. Thus, it may happen that the application recognizes a step as executed correctly whereas a real trainer could correct even small mistakes.

In regular first aid training, the trainers are mostly experienced paramedics who not only explain the steps of the BLS sequence but give additional information when needed and enrich the training with personal stories and experiences. We did not integrate such additional content into our trainings, but the user’s attention and thus their performance could be increased if they get some context about how the learned techniques really save lives.

V. CONCLUSION AND OUTLOOK

In the event of cardiac arrest, early bystander basic life support (BLS) is vital for increased survival chances. Regular training of BLS procedures among people is required. While AR- and VR-based approaches have been promoted to enhance BLS training in an interactive and practical way, current existing approaches are usually not fully compliant with the medical BLS guidelines or focus only on specific steps of BLS training such as resuscitation. Furthermore, most of the existing training approaches do not focus on automated assessment to enhance training effectiveness through fine-grained real-time feedback and integrated debriefing. To overcome these issues, we have designed and implemented an immersive BLS training environment that supports AR as well as VR training with an interactive and haptic manikin. The main results of our usability evaluation show that AR and VR technology have the potential to increase engagement in BLS training in practice and reduce the cognitive workload compared to traditional training with a personal instructor.

In future work, we plan to expand our evaluation to include a more comprehensive user study and in-depth data analysis. Further, we plan to extend our BLS training environment to also support Advanced Life Support (ALS). While the scope of this work considers independent self-training only, multi-user training becomes more and more important, particularly for Advanced Life Support. Since learning how to work in a team of several people is a significant part of the training, we plan to extend our training environment to include such collaboration features.

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