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Cardiopulmonary resuscitation training for high school students using an immersive 360-degree virtual reality environment

E. Z. Barsom, R. D. Duijm, L. W. P. Dusseljee-Peute, E. B. Landman-van der Boom, E. J. vanLieshout, M. W. Jaspers and M. P. Schijven

E. Z. Barsom is a PhD-candidate with research focused on telemedicine and virtual reality in healthcare. R.D. Duijm is a medical information expert at the Amsterdam UMC. L. W. P. Dusseljee-Peute is as assistant professor at the Public Health research institute, Department of Medical Informatics of the Amsterdam UMC. E. B. Landman-van der Boom is a resuscitation counselor at the Amsterdam UMC. E. J. van Lieshout is an anesthesiologist and head of the mobile Intensive Care Unit at the Amsterdam UMC with a special interest in medical innovations. M. W. Jaspers is a professor at the department of medical informatics at the Amsterdam UMC. M. P. Schijven is Professor in surgery with a chair on Simulation, Serious Gaming and Applied Mobile Healthcare at the Amsterdam UMC. Address for correspondence: Marlies P. Schijven, Department of Surgery, Amsterdam Gastroenterology and Metabolism, Room: G4-133.1, Meibergdreef 9, 1105 AZ, Amsterdam, The Netherlands.Email: m.p.schijven@amsterdamumc.nl

Abstract

Cardiopulmonary resuscitation (CPR) is a lifesaving emergency procedure. To increase survival rates, it is recommended to increase the number of high school students who know how to perform CPR. We have developed an immersive "Virtual Reality (VR) Resuscitation Training" to train the theoretical knowledge of CPR in which trainees must save the life of the patient in a virtual environment. This paper presents a randomized controlled study with a pre-posttest design to explore whether a VR enhanced curriculum improves high school students' theoretical CPR knowledge. Forty students without previous CPR experience in the past year were randomly assigned to either the VR group or the standard group. The VR group had a significant higher increase of correct answers in comparison with the Standard group. More importantly, the gain in score on taking the correct sequence of CPR steps was significant favouring the VR-enhanced protocol over the Standard protocol. Therefore, the use of a VR training for CPR training appears to be an effective learning method for non-medical students and may be of great value skilling high school students in becoming adequate CPR providers.

Keywords: Cardiopulmonary resuscitation, virtual reality, medical education, immersive environment

Introduction

Cardiopulmonary resuscitation (CPR) is a lifesaving emergency procedure. Citizen-initiated Basic Life Support (BLS) is strongly associated with a higher chance of full neurological recovery and a better quality of life of out-of-hospital cardiac arrest survivors (Geri *et al.*, 2017). To increase survival rates, it is recommended to increase the number of skilled citizen BLS-providers who can perform CPR. High school students are an important target group because they have a highly positive attitude towards BLS-training (Kanstad, Nilsen, & Fredriksen, 2011).

Practitioner Notes

What is already known about this topic

- CPR education leads to an increase in CPR knowledge and increases trainees' willingness to initiate CPR in a real-life situation.
- Training CPR in a classroom setting has a lack of realism that bystanders experience during an actual life threatening situation. The experienced gap between the classroom and reality has a negative impact on self-confidence which is known to be an important motive to actually initiate CPR.
- Smartphone-based VR combined with immersive scenarios has the ability to engage trainees in a real-life setting using immersive interactive scenarios.

What this paper adds

- This randomized controlled trial demonstrates that a VR enhanced curriculum results in a higher increase of CPR knowledge in comparison to a standard curriculum featuring an e-learning with 2D videos.
- This study shows that participants report higher self-confidence in performing CPR.

Implications for practice and/or policy

- VR training provides opportunities to keep CPR knowledge up to date to preserve self-confidence in CPR-providers.
- VR immersive environments improve the learning experience significantly.

Effective CPR acquires both theoretical knowledge as the ability to physically perform CPR. The first is often trained by eLearning, the latter is an instructor-led training in a face-to-face setting. CPR education leads to an increase in knowledge and increases trainees' willingness to initiate CPR in a real-life situation (Cho *et al*., 2010). However, one concern is that CPR in a classroom setting has a lack of realism that bystanders experience during an actual life threatening situation (Everett-Thomas *et al*., 2016). The experienced gap between the classroom and reality has a negative impact on self-confidence which is known to be an important motive to actually initiate CPR (Ro *et al*., 2016). Virtual Reality (VR) combined with 360 degree scenarios has the ability to engage trainees in a real-life setting using immersive interactive scenarios. In order to fully immerse into the scenario, a 360-degree environment allows the trainee to explore the environment in any direction (Chang *et al*, 2020). Because related real-world tasks are practiced in a virtual immersive environment, it is believed that VR improves students' confidence and efficacy (Youngblood *et al*., 2007). Therefore, the goal of using VR in CPR training is to bridge the gap between reality and a training environment, in order to increase bystander response during a cardiac arrest.

We have developed a 360-degree VR environment "VR Resuscitation Training" to train the theoretical knowledge of CPR in which trainees must save the life of patient in a virtual environment. The learning objective is to learn the correct step-wise sequence of actions on how to administer CPR correctly. Although most authors focus on the ability to perform the technical skills of CPR (Leary *et al*., 2019), we focused on teaching the theoretical knowledge because students can use the VR environment without requiring physical study material (eg, mannequin) other than a VR viewer.

This VR environment can be used in preparation for instructor-led skills training but most importantly can be used as a refresher course to maintain CPR knowledge.

Although promising, new educational tools in the medical domain require scientific validation before they may gain credibility and support for wide implementation (Barsom, Graafland, &

Schijven, 2016; Robertson, Wong, Brady, & Subramanian, 2016). Therefore, the aim of this study was to (1) develop and offer a VR environment for CPR education purposes to high school students, (2) to compare the outcomes with current teaching strategies and (3) to assess the self-confidence of the trainees.

Literature review

Various VR training modalities have been developed for CPR training purposes (Aksoy, 2019; Bench, Winter, & Francis, 2019; Cerezo Espinosa *et al.*, 2019; Creutzfeldt, Hedman, Medin, Stengard, & Fellander-Tsai, 2009; Keys, Luctkar-Flude, Tyerman, Sears, & Woo, 2020; Khanal *et al.*, 2014; Leary *et al.*, 2019; Nas *et al.*, 2020; Rushton, Drumm, Campion, & O'Hare, 2020; Semeraro *et al.*, 2019; Youngblood *et al.*, 2007) The purpose of these modalities can be categorized into "increasing knowledge," "training skill performances" and "increasing self-confidence."

Increasing knowledge

Bystander's preparedness to start CPR is dependent on the knowledge of the subject, hence training bystanders has a positive effect on the outcome of victims (Berger *et al.*, 2019; Pivac, Gradisek, & Skela-Savic, 2020). Semeraro and colleagues found an improvement of CPR knowledge in 73% of the students as represented by an increase in the MCQ score ($p < .001$) (Semeraro *et al.*, 2017). Creutzfeldt reported a steep proficiency gain in CPR knowledge when using VR for pre-training and repetitive training (Creutzfeldt, Hedman, & Fellander-Tsai, 2012). Another study reported a beneficial effect of VR on CPR knowledge when compared to a tablet-based serious game. Although there was a significant difference between pre- and posttest results in both groups ($p = .001$), the increase in knowledge was significantly higher in the VR group (Aksoy, 2019).

Skill performances

An important requirement for effective CPR is the physical ability to perform CPR with the right compression rate and compression depth. In order to increase CPR skills, hands-on practice is needed (Neumar *et al.*, 2015). VR is considered a promising technique to enable technology-enhanced skill mastery processes in CPR education (Taplin & McConigley, 2015). This, because students can practice repetitive at a time that suits them. Repetitive practice reinforces synaptic connections, making use of memory and conditioning for certain actions (Siddaiah-Subramanya, Smith, & Lonie, 2017). Ultimately improving responder skills through repeated exposure to clinical scenarios (Rushton *et al.*, 2020).

In literature, some findings suggest that VR-based CPR training modalities are able to teach trainees the correct compression rate and -depth. In a longitudinal, prospective study, high school students were trained by playing the serious game "Relive." Both the compression rate- and depth were positively affected by VR. In contrast to the compressions rate, the application of the correct compression depth remained after 3 months (Semeraro *et al.*, 2017). Khanal showed that their study participants could keep a compression rate between 95 and 104 where the goal was to reach 100 (Khanal *et al.*, 2014). In another study, the VR-group outperformed the control group on both the compression rate (97.5 (9.7) vs. 80.9 (7.7)) and –depth (34.0 (6.5) vs. 27.9 (4.9)) (Cerezo Espinosa *et al.*, 2019).

However, other authors did not find a satisfactory outcome in terms of compression rate and -depth when compared to face-to-face training (Nas *et al.*, 2020). Leary and colleagues compared a VR CPR app with a standard CPR app in a randomized controlled trial. The Standard group

(44 ± 13 mm) outperformed the VR group (38 ± 15) in terms of compression depth ($p = .05$) but there was no significant difference in the compression rate (Leary *et al.*, 2019).

Self-confidence

If the acquired knowledge and skills, in fact, lead to a higher willingness to perform CPR when an actual cardiac arrest occurs is highly dependent on the self-confidence of a bystander towards performing CPR. A bystander who believes he or she is capable of performing CPR is, indeed, more likely to perform CPR when needed (Liaw *et al.*, 2020). As the prompt initiation of bystander CPR is of paramount importance, increasing self-confidence is an important subject of modern CPR training modalities. Moreover, using VR in an immersive environment has unique engaging potential, optimizing the learning experience of the trainee. This, by adding emotional and psychological aspects to CPR training, while offering close to real-world experience in a virtual environment in which you can make mistakes without real-world consequences.

Judd and Young studied confidence in medical students after using a VR teaching scenario in comparison with textbook learning, video training, course training and a blended teaching method (textbook, video and course training). Students were asked to rank their confidence towards performing CPR steps, their enjoyment and their confidence to perform CPR in a real-life setting. Students who used the VR training, had more confidence to use their skills in clinical practice ($p = .045$) compared to all other teaching methods (Judd, 2018).

Although several VR training modalities have been described in the literature, not all have been subject to validation studies yet. Hence, evidence regarding the effectiveness of VR for CPR purposes remains limited. Although VR training is considered more enjoyable than standard training modalities, if VR will be used for skills training purposes, several training modalities should be developed further in order to achieve sufficient outcomes. Moreover, several authors claim that VR training for CPR skills purposes should be considered as a supplement to traditional methods instead of replacing them (Keys *et al.*, 2020).

Methods

Participants and randomization

A randomized controlled trial was conducted comparing the VR Resuscitation Training (VR group) with a standardized e-learning (Standard group). High school students were asked to participate on a voluntary basis. Participants were randomly assigned to either the VR group or the Standard group. Because CPR skills deteriorate significantly within one year post-training, participants with CPR training experience less than a year ago were excluded from participation (Yeung, Okamoto, Soar, & Perkins, 2011).

Study protocol

All participants completed a standard online CPR pretest using a 10-item multiple-choice questionnaire (supplementary file 1). The pretest was administered in order to establish the baseline level of CPR knowledge and correct sequencing of CPR steps. The same test was used to assess the increase of knowledge during the posttest setting, with the questions asked in a different order to avoid order memorization benefits. The Standard group was offered an online e-learning module (Expertcollege^{TM}) including 2D videos explaining the right sequence of steps in CPR. After each chapter of the e-learning, a video followed presenting each step of CPR. The VR group was offered the same online e-learning module, with the alteration of having the 2D video replaced with the VR Resuscitation Training. Figure 1 illustrates the study protocol. Both groups performed the full

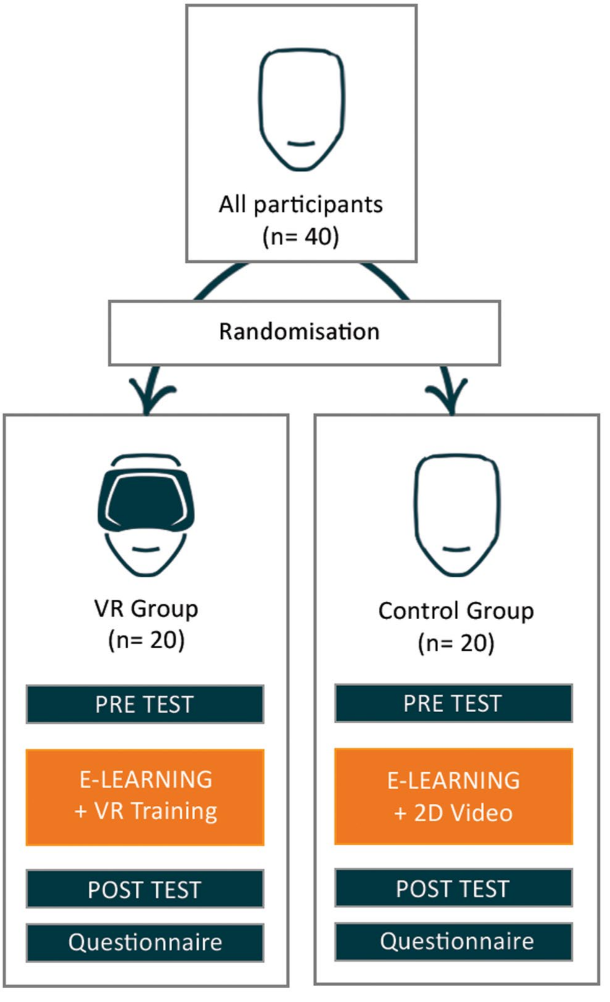

Figure 1: A schematic presentation of the study protocol [Colour figure can be viewed at wileyonlinelibrary.com]

learning course at the same time in a quiet studying room and spent 30 to 45 minutes completing the e-learning and 10 minutes watching the videos/VR Training.

The VR resuscitation training

The VR Resuscitation Training contains a 360-degree virtual environment. The learning objective is to learn the correct step-wise sequence of actions on how to administer CPR correctly in a playful manner. The educational content is based on the most recent guideline on CPR resuscitation (Reanimatieraad, 2015). The training can be played on a smartphone in combination with a standard VR viewer such as Google Cardboard or Samsung Gear VR. For this study, the Samsung Gear VR was chosen (Samsung co., The Netherlands). Figure 2 shows a screenshot of the scenario. The 360-degree virtual environment enables the trainee to look around to explore the environment. Per video fragment, various choices for actions are presented to the viewer. The player must choose a presented option in the correct sequence to proceed in the training scenario. The chosen option or action is highlighted when the player looks at it and is subsequently

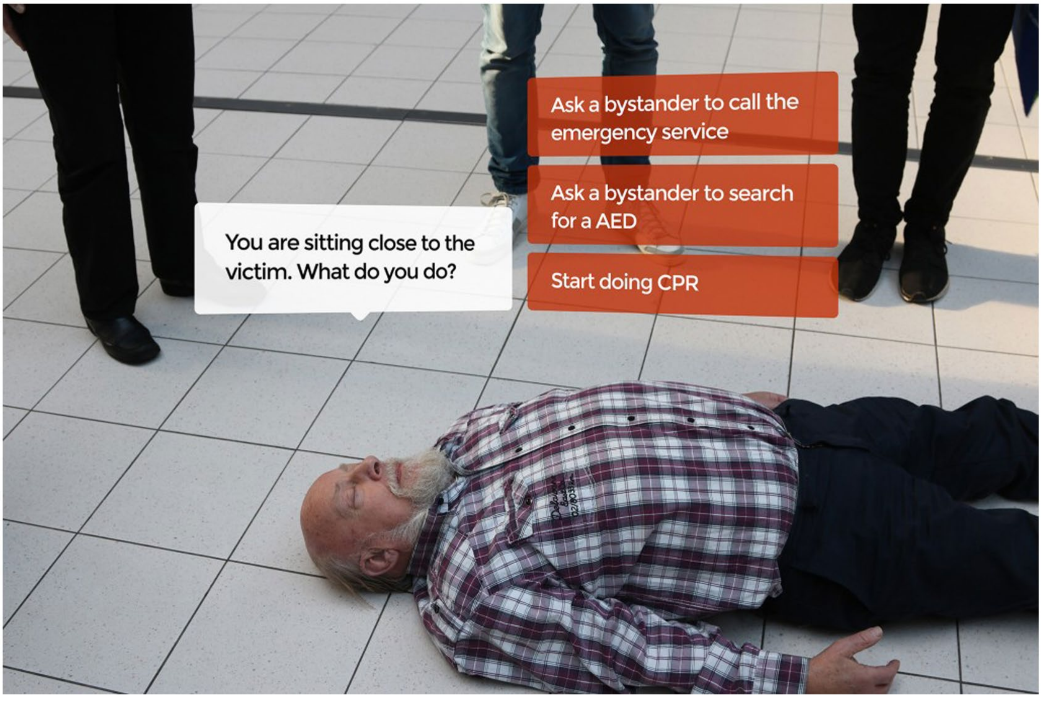

Figure 2: The VR resuscitation training. The player is immersed in a scenario in which the player is asked to choose the best option to save the patient
[Colour figure can be viewed at wileyonlinelibrary.com]

selected by maintaining the option in the center of the user's vision for two seconds. A time limit of 10 seconds was set for every question to encourage the user into prompt decision making. If no choice was made during these 10 seconds, the trainee had to start over. In total, the training has a maximum duration of two minutes and thirty seconds to complete. This, in order to remind the user that, in addition to following the protocol correctly, time is of uttermost importance in performing CPR. The user is challenged to replay the scenario taking various pathways or actions until he/she has completed the CPR protocol correctly, following the game-play principle of offering players a "sandbox- scenario" and learning from trial-by-error. When incorrect choices are made, the user is informed and is challenged to try again (learning by experience). Upon each attempt, the trainee is rewarded with up to five stars, to add a scoring component, which is based on the number of incorrect choices and their impact in real-life. At the end of the training, the number of earned stars (high score) is displayed.

Questionnaire on learning course

A questionnaire concerning statements on usability, self-confidence, content and overall quality of the learning course was administered among all participants after the posttest. Self-confidence was measured to explore factors that most likely will lead to the initiation of CPR or not. The questionnaire contained 18 items. The statements could be rated on a five-point Likert scale, in which 1 related to "fully disagree," 3 to "neutral" and 5 to "fully agree." A median value of more than 3 was considered as a positive evaluation of the statement, a mean value of less than 3 as a negative evaluation.

Statistical analysis

Data are presented by their means and standard deviations when normally distributed, or by their median and interquartile range (IQR) in case of a non-normal distribution. Categorical data are presented in frequencies and proportions. A Mann-Whitney *U* test was used to determine if the variation between the pre- and posttest scores differed significantly between the two groups. A Wilcoxon signed rank test was used to assess possible within-group differences. Statistical significance was considered when the calculated probability (p) was smaller than 5% ($p < .05$). IBM SPSS version 25 was used for statistical analyses (IBM corp., Almond, NY, USA).

Results

Participants characteristics

Forty participating students were randomized into either the Standard group ($n = 20$) or the VR group ($n = 20$). No participants were lost to follow-up. There were no significant differences in baseline characteristics between the two groups. All participants completed the learning course (Table 1).

Theoretical knowledge

All participants completed the pre- and posttest on CPR knowledge. The percentage of correct answers on the pretest comparing the Standard group with the VR group appeared not to differ significantly (Mann-Whitney *U* test, $p = .064$), reflective of same base-line knowledge of CPR and on steps to be taken to perform CPR correctly before training (Mann-Whitney *U* test, $p = .335$). Both groups benefit significantly from their respective training protocol; as within-group scores on CPR and on choosing the correct sequence of steps in the CPR protocol are significantly higher after completion of either type of offered training.

The overall gain in score on CPR knowledge is, however, significantly higher in the VR group than in the Standard group (Mann-Whitney *U* test, $p = .035$). More importantly, the gain in score on taking the correct sequence of CPR steps is also significant (Mann-Whitney *U* test, $p = .006$) favoring the VR-enhanced protocol over the Standard protocol. The outcome of the pre- and posttests is presented in Table 2.

Questionnaire on learning course

All students completed the questionnaire. Participants' opinions of the learning course were uniformly positive, both in the Standard group and the VR group (Supplementary file 1). Perceived competence towards performing CPR was rated equally in both groups (Figure 3). Higher self-confidence was reported in the VR group concerning an increase in self-confidence to perform CPR (85% vs. 55%), readiness to perform CPR 65% vs. 45%) and willingness to perform CPR (80% vs. 75%) (Figure 4).

Table 1: Demographic characteristics of the study population

Demographic characteristics		*VR group N = 20*	*Standard group N = 20*	*p-value (Chi Square Test)*
Gender	Male	12	8	0.206
	Female	8	12	
Age	Median (IQR)	16 (16-16)	16 (16-16)	0.953

Abbreviation: IQR, interquartile range.

Table 2: Participants' performance in terms of correct answers in percentages on the pretest and posttest on CPR knowledge and score on taking the correct sequence of CPR steps within and between groups

Test scores	*Pretest (Median, IQR)*	*Posttest (Median, IQR)*	*Difference Pre-posttest (Median, IQR)*	*p-value within groups (Wilcoxon signed rank test)*
Pretest score CPR knowledge				
Standard group (N = 20)	56 (47-58)	79 (72-82)	25 (15-30)	0.000*
VR group (N = 20)	49 (42-55)	82 (75-91)	32 (22-42)	0.000*
p-value between groups (Mann-Whitney U test)	0.064	0.186	0.035*	
Score on taking the correct sequence of CPR steps				
Standard group (*N* = 20)	29 (14-42)	43 (32-71)	14 (14-39)	0.003*
VR group (*N* = 20)	21 (14-29)	86 (61-100)	57 (32-71)	0.000*
p-value between groups (Mann-Whitney *U* test)	0.335	0.008*	0.006*	

Abbreviations: CPR steps, the right sequence of actions to be taken in administering Cardiopulmonary resuscitation correctly; IQR, Interquartile range.
*$p < .05$.

Discussion

This randomized controlled trial demonstrates that a VR enhanced curriculum results in a higher increase of CPR knowledge in comparison with a Standard group receiving e-learning and 2D videos among high school students. More importantly, trainees perform the CPR steps significantly more often in the correct sequence, a key element in training CPR. In addition, this study suggests that training CPR in a VR environment results in higher self-confidence of the trainees.

The results of this study concur with the positive impact and usefulness of VR on knowledge (Aksoy, 2019; Creutzfeldt *et al.*, 2009; Semeraro *et al.*, 2019) and self-confidence reported by colleagues (Judd, 2018). Keys and colleagues underline the use of VR as a valuable adjunct to traditional classes (Keys *et al.*, 2020). The aim of this VR environment was, indeed, to complement instructor led courses prior to- and after physical classes in order to gain preserve the most CPR knowledge from their educational experience.

For this study, the Gear VR was used. Some authors question the limited level of interaction because the trainee cannot manipulate the environment too much. Others have demonstrated its effective use for education purposes (Moro, Stromberga, & Stirling, 2017). We believe the Gear VR, or even a more simplified VR viewer, is well suited for the aim of the VR environment. The low costs make it available for students to follow the VR training course remotely. In addition, low-cost VR equipment is well received by students (Birt, Stirling, Cowling, & Moro, 2018). Most authors focus on the ability to perform the technical skills of CPR (Leary *et al.*, 2019). The aim of this study was to increase the theoretical knowledge of CPR. To focus solely on teaching the

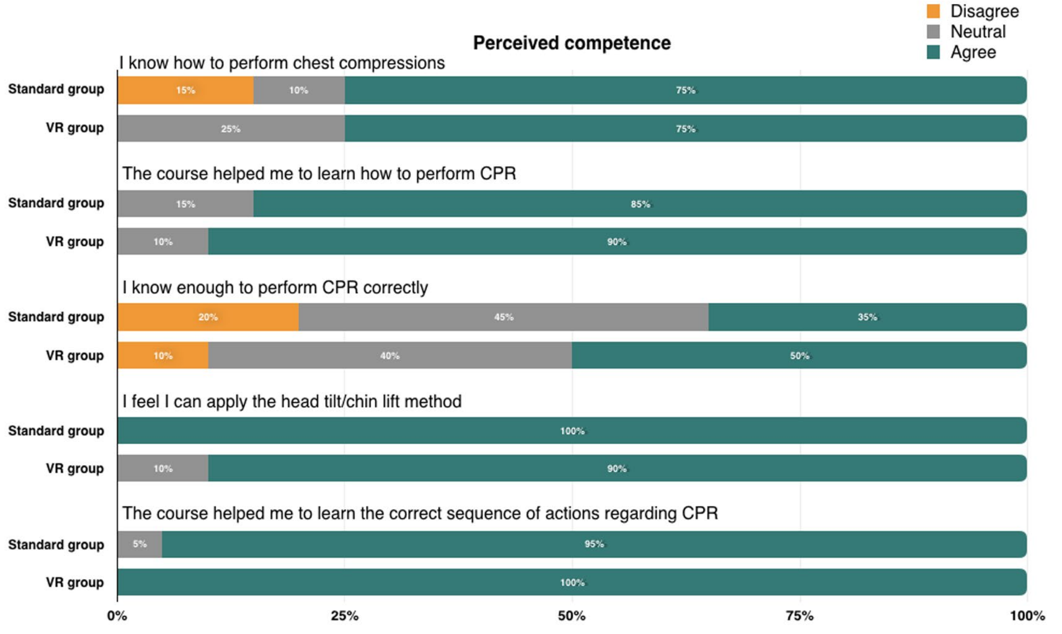

Figure 3: Results of the questionnaire items measuring perceived competence. Answers were provided on a 5-point Likert scale. Categories "Totally agree" and "Agree" were dichotomized, as were "Totally disagree" and "Disagree" [Colour figure can be viewed at wileyonlinelibrary.com]

theoretical knowledge of BLS can, indeed, a valuable addition to the current BLS course due to the acquired information on CPR (Teague & Riley, 2006).

The Red Cross Society has started a petition in June 2019 to make CPR training standard practice in secondary schools in the Netherlands. They state that only 17% of the high school students know how to perform CPR although 91% thinks CPR training should be mandatory (Cross, 2019). High school students are willing to provide help but often the fear of being incompetent plays an important role in their motivation to act (Kanstad *et al.*, 2011). Thus, on one hand, the number of skilled high school students should be increased by providing more training opportunities. On the other hand efforts should be made to maintain CPR competence preserving confidence in performing CPR by offering refresher courses. A VR environment has showed to be an effective learning method and increases self-confidence (Creutzfeldt *et al.*, 2009). If this is merely because of exposure to CPR training or if VR specifically is accountable for this increase in self-confidence requires additional research (Lynch & Einspruch, 2010). This study carefully illustrates a favorable outcome on behalf of VR, however, future studies are needed which ultimately measure confidence in real-life situations. As 78% of the Dutch population in 2018 is schooled to the level of our study group, the VR training may be of great use of great value skilling high school students in becoming adequate CPR providers (Nederland, 2020).

Future studies should explore the retention of knowledge and self-confidence after time. First, we wanted to establish efficacy of the VR environment. The next step is to research the effects on the long run. It is interesting to optimize the learning environment of our study further, offering different scenarios in such a way that it prequels the current VR scenario optimally in a future version of the VR Resuscitation Training. It would be interesting to further explore if the use of different pathways with discontinuation if a wrong answer is provided, is a better learning

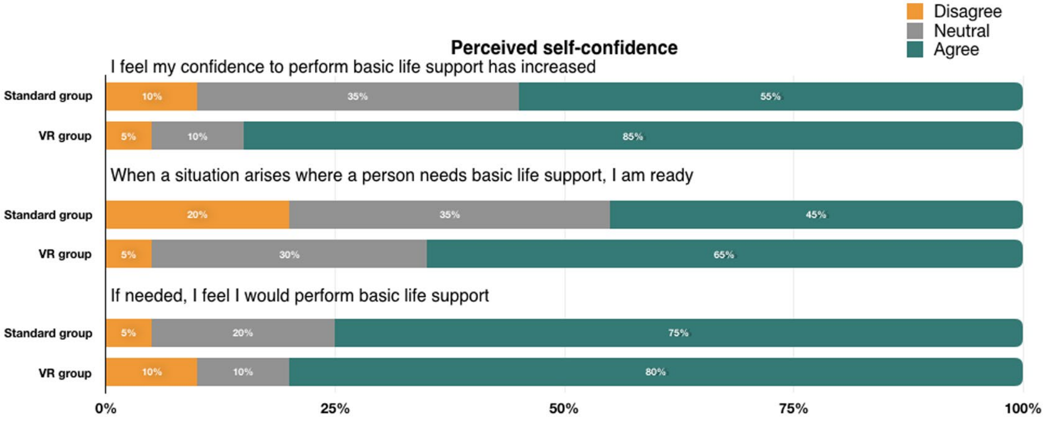

Figure 4: Results of the questionnaire items measuring perceived self-confidence. Answers were provided on a 5-point Likert scale. Categories "Totally agree" and "Agree" were dichotomized, as were "Totally disagree" and "Disagree"
[Colour figure can be viewed at wileyonlinelibrary.com]

method than when feedback is provided simultaneously. Hence, in order to increase survival rates, CPR-training modalities should provide opportunities to keep CPR knowledge up to date to preserve self-confidence in CPR-providers.

In addition, it would be valuable for trainees to practice their skills next to CPR knowledge. Although validating the use of VR for compression rate and depth seems more difficult to establish, it would be interesting to explore opportunities for skills training to enrich our VR training. This way, next to training cognitive and psychosocial skills, the VR training could offer a total package preparing trainees most optimally to perform CPR.

Conclusion

This study shows that the use of the VR Resuscitation Training is an effective learning method regarding knowledge and increasing self-confidence for high school student trainees. Further studies are required to determine retention of knowledge, the value of using VR environments as a refresher course and the impact on self-confidence and to explore the willingness of educators to accept VR environments as an adjunct or pre-post learning tool.

Limitations

Some aspects of this study are ought to be considered when interpreting its findings. Although the strength of this study is the randomized controlled design, a limitation is the number of students included. Although the number of included students was formally based on a power analysis, a higher number of inclusions might lead to a more reliable sample. Furthermore, the questionnaire used within this study was not validated, making the questionnaire on the learning course more of a subjective assessment than a standardized assessment.

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Statements on open data, ethics and conflict of interest

Additional data are available on request.

This study was conducted in accordance with the Declaration of Helsinki Ethical Principles and Good Clinical Practices and was approved by an independent local ethics committee.

The authors declare no conflicts of interest.

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Supporting Information

Additional supporting information may be found online in the Supporting Information section at the end of the article.