
Master thesis

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The effectiveness of learning to apply CPR by training in Virtual Reality

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ABSTRACT

The Human Resources Department of the Police wishes to use innovative learning methods in frequently attended training types, like Cardiopulmonary Resuscitation (CPR) training. CPR training is essential because the police are mostly the first to arrive at a victim. Virtual Reality (VR) is a promising tool since studies have shown that VR learning is an effective way to obtain CPR skills. However, the effectiveness is still subject to discussion.

This study aims to determine whether VR training with a Head-Mounted Display is a suitable alternative for standard, classroom-based, instructor-led CPR training and if there is an optimal sequence for both training types. The research question is: What is the effectiveness of learning to apply seven different CPR skills and overall CPR achievement by training in VR compared to the standard training? The sub-questions are: what is the effectiveness, and what is the influence of the sequence in which both training types are followed?

A quantitative experimental study with a cross-over design submitted respondents to both the standard training and VR training. Their CPR skills were determined before and after each training while they were randomized into two groups. The randomization determined in which order the training types were attended; VR first or standard training first.

The results show no differences in effectiveness when the training in VR and the standard training are compared regarding the skills; ECC, Compression depth, Hand position, Leaning, and Ratio. However, overall CPR achievement and breathing frequency and volume skills are learned most effectively after respondents first followed the standard training. Furthermore, the sequence of standard training first is most effective for breathing volume. Regarding the overall CPR achievement, ECC and breathing frequency show a difference in effectiveness, favoring the sequence starting with the standard training. On the other three skills, no differences were found in the effectiveness of the sequence. The question regarding the most effective sequence of types of training was not previously examined in the literature.

The recommendation is to use the VR app after the standard training, to keep the skills up to standard, and since it was the first release, to develop the VR training further. Also, this study fits the protocol used by Zheng et al. (2022) for a systematic review and meta-analysis. Therefore, it will be interesting to compare the findings of this study with those of Zheng et al. (2022) expected later this year. Lastly, there is a plea for standardizing the measurement of multiple skills.

ACKNOWLEDGEMENT

This is the thesis 'The effectiveness of learning to apply CPR by training in Virtual Reality.' The co-design and development of the VR app and subsequently the research for this thesis were carried out at the Police Services Center Rotterdam. The context was my second master's degree, this time at the University of Twente, within the Educational Science and Technology program. From June 2021 to June 2022, I have been working on the app, the research, and writing the thesis.

In coordination with my first supervisor Bas Kollöffel, my second supervisor Ilona Friso-van den Bos from the university and the external supervisor Marlous van de Brand-Revier and project managers Jeroen van den Heuvel and Ronald Tieman from the Rotterdam Police, I formulated the research questions. Furthermore, the design of the VR app, standard training, and research data collection took place in continuous coordination with Sander van Goor of the National Resuscitation Council. Finally, after extensive quantitative research, I could answer the research questions.

A second master's is expensive; I was able to follow this study with the help of a teacher grant and financial support from my employer, the Hogeschool van Arnhem en Nijmegen, made possible by Petra Jagtman and Eemke Euverman-Schaeffer.

I want to thank everyone for their guidance and support during this process. I would also like to thank all the respondents who participated in this research. They have committed themselves in times of Covid-19 restrictions, contributing to research and developing themselves. As a result, all 50 of them are now certified in the application of CPR.

I would also like to thank my best research methods and data analysis teacher, Judy, for all the lessons and wise advice. I have always been able to spar with her effectively about my research. I have also received my family and friends' patience and moral support during the writing process. Finally, I would like particularly thank my partner Jan, my children Thijmen, Berrit, and Rein, and my sister Jenny, who taught me the art of trusting the good outcome.

Sheila Baas.

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INTRODUCTION

In the Internal Strategic Plan 2025, 'Politie van Overmorgen', the police organization in the Netherlands articulates five guiding statements to remain constantly vigilant and subservient to the values of the constitutional state. One of the statements is 'We accelerate our technological and intelligence developments'. The plan is applied company-wide, in all ten regional units, a National Unit, three Centers for police services, and the corps leadership.

The Rotterdam Center for police services, known as Politie Diensten Centrum (PDC) Rotterdam, manages Police operations, such as finance, ICT, communication, and human resources (HR), to give officers more time for actual police work (*Organisatie Politie | Politie | Rijksoverheid.Nl*, n.d.). Being in charge of the Learning and Development of personnel, HR investigates possibilities of using innovative techniques to bring their services to police employees in a practical, more interactive, and faster way.

So, whenever corporate education or vocational training have to be organized, HR is interested in the best ways to organize time and cost-effectively place independent learning, giving employees more freedom in their working schedule. In addition, project managers of the HR department, Learning and Development, want to know what technical learning tools are available to facilitate learning so employees will learn efficiently and effectively while taking good care of themselves and serving society optimally.

This wish to use innovative learning methods is especially interesting for frequently attended training types, like the training for Cardiopulmonary Resuscitation (CPR) skills. Most cardiac arrests occur out of hospitals, and in most incidences, the police are quicker to the place of the incident than the ambulance is (Sayre et al., 2005). Therefore, it is of the greatest importance that police employees are skilled in providing CPR to the victim directly after they collapse. For this reason, HR organizes CPR training frequently. The police are especially interested in Virtual Reality (VR) as a training tool to train CPR to their employees since studies have shown that VR learning appears to be a quick and promising way to obtain CPR skills (Nas et al., 2020). With the assistance of an external bureau and the commitment of the Dutch resuscitation council, known as the Nederlandse Reanimatie Raad (NRR), a VR app was developed for the Head Mounted Display (HMD) of Oculus Quest 2.

Although Nas et al. (2020) found that VR can enhance training CPR skills, the effectiveness compared to other training types, for instance, in-person training, is still subject to discussion (Zheng et al., 2022). This study seeks to research the effectiveness of learning to apply CPR using VR training. Therefore, the current study aims to determine whether VR training is a suitable alternative to classroom-based and instructor-led CPR training. Additionally, it will be determined if an optimal sequence in which both training types can be given to achieve optimal CPR skills. To determine the effectiveness of both training forms, several crucial skills that a skilled resuscitator needs to perform are measured.

Furthermore, the overall CPR achievement of the trainees is compared between the training types and several parameters that give insights into the CPR skills of the trainee. To test which order of both training types, either VR first and then the standard training or first the standard training and then the VR training, leads to the best results, a repeated measures design was chosen. First, a pre-test was performed, and the test was repeated after each training session. Using a cross-over design, this quantitative experimental research gives insight into the extent to which the VR training leads to the ability to apply CPR skills effectively.

In the upcoming chapters of this document, first, a theoretical framework on CPR, suitable training types to learn CPR, and the use of VR to train CPR are presented. Then, in the methods chapter, the study design, the participants, the interventions, and the statistical data analyses are discussed, followed by the results of the study. Finally, in the discussion and conclusion, the results of the current study are compared to findings from the literature. The relevance and limitations are discussed, resulting in a conclusion and recommendations on using VR as a training tool for CPR within the police department in the Netherlands.

THEORETICAL FRAMEWORK

In this section, CPR is described, how it is trained, and how VR could be used in CPR training. Then follow the differences between standard training and VR training and the effects of the sequence of the types of training, after which the research questions are articulated.

CPR

The right and timely application of CPR by laypersons in an out-of-hospital cardiac arrest situation can increase the chance of survival of a person having a Sudden Cardiac Arrest. Sudden cardiac death is a major health issue in Western countries, causing up to 20% of deaths yearly (Wong et al., 2019). Laypersons are bystanders, not medically trained, who are the first at the scene before the arrival of professional medical assistance.

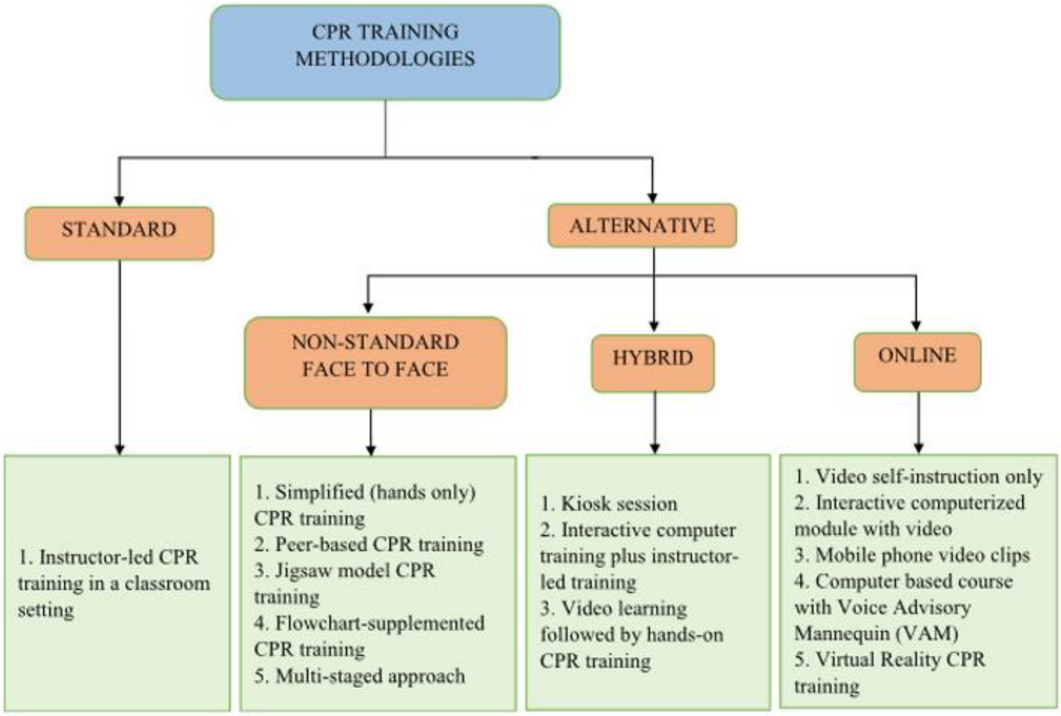
The Dutch Resuscitation Council defines CPR as 'the set of actions for restoring spontaneous circulation and breathing' (Van den Berg, 2021). These guidelines are based on the recommendations of the European Resuscitation Council, which were revised in 2021 (Olasveengen et al., 2021), and form the basis for each CPR training, regardless of the type of training that is used. Being able to give CPR is an essential part of Basic Life support. Six essential actions are described to perform CPR effectively regarding Basic Life Support (Olasveengen et al., 2021). These actions are: (1) (notice that the person is) unresponsive with absent or abnormal breathing, (2) call emergency services, (3) give 30 chest compressions, (4) give two rescue breaths, (5) continue CPR 30-2 and, (6) as soon as an automated external defibrillator (AED) arrives – switch it on and follow the instructions.

CPR TRAINING

To increase the chances of survival after a cardiac arrest, it is crucial that as many laypersons as possible are trained. Zheng et al. (2022) reported that the standard training method to learn CPR is face-to-face teaching in a classroom, instructor-led, and using a mannikin as a proxy for a patient. However, the standard training is time-consuming and, due to time- and place dependencies, just reaching a fraction of interested laypersons. Also, since the COVID-19 pandemic, the number of standard training and attendees per training had to be reduced, as the usual close contact method was no longer practicable or allowed. Therefore, various CPR training types have been developed, especially after the pandemic's start. The urgency to improve CPR training by deploying new technology became paramount (Zheng et al., 2022). A systematic literature review (Ali et al., 2021) of studies comparing the learning outcomes of standard training with alternative training methods that were conducted between 1995 and 2020, divided the CPR training types into four categories (figure 1): standard training, alternative training Non-Standard face-to-face, alternative training Hybrid and alternative training Online.

Figure 1:

Comparison of the mode of delivery of different CPR training methodologies (Ali et al., 2021)



Each category consisted of different training methodologies. This overview shows the vast variety of CPR training types and methodologies.

DIFFERENCES IN EFFECTIVENESS OF THE DIFFERENT TYPES OF TRAINING

The systematic review of Ali et al. (2021) gives insight into the differences in effectiveness between all training methodologies. Standard training appeared to be more effective in learning the correct hand positioning and compression depth. Alternative training types were more effective at teaching trainees the ratio (compressions/breathings), breathing volume, ECC, and handoff time. They concluded that alternative training methods of CPR training provide an effective alternative to the standard training for large-scale public training. A more extensive overview of the findings can be found in Appendix A.

Differences between the outcomes of standard training and alternative training methods can be attributed to several causes. For one, there is a lot of variation between the instructional methods used in the different forms of standard training and alternative training. Also, within the standard training, the content of the training types showed differences. And although all types of standard training were based on official guidelines, the same level of variation was found in the content within the alternative forms of training. Standard training and alternative training also appeared to differ in training time. Standard training varied from 20 minutes to six hours, whereas alternative training took between one minute and three hours. Ali et al. (2021) found that some alternative training forms were better at training several specific skills than the standard training. They suggested that these training types were more effective because they used the advantages of the standard training and combined it with new technology. Also, the alternative forms of training were improved multiple times before they were carried out. Standard training, however, appeared also strong in teaching several skills. For instance, few technologies have been available to train and monitor compression depth until now (Ali et al., 2021).

HOW ARE CPR SKILLS TYPICALLY MEASURED?

During CPR training, a training manikin of AMBU (AMBU, 2022) is used (see Figure 2). Training manikins of AMBU are patient simulators capable of specific measurements in complex training situations (Paradis et al., 2007).

Figure 2:

AmbuMan® Wireless

Several skills must be mastered to perform four of the six actions CPR consists of. Using a training manikin allows those skills to be measured by the built-in software parameters (appendix B). The optimal performance per skill is shown in table 1. The following skills that belong to the 'give 30 chest compressions' action that the manikin can measure are (Ambu, n.d.):

- ECC rate. This is the number of eligible calculated compressions per minute. Compressions with the correct hand position and with five to six centimeters of depth are eligible. The optimal range is 100-120 compressions per minute.
- Compression depth, compressions of five to six centimeters deep

- Hand position is listed as the number of compressions with the hands placed in the middle of the chest.
- Leaning is the number of compressions applied by the trainee, leaning over the patient's chest, with straight elbows and shoulders placed above their hands

The measurable parameters that are related to the 'give 2 rescue breaths' action are:

- Breathing frequency is the number of ventilations with a volume of 0.35 to 0.5 liter per minute. The optimal range is 3-6 breathings per minute.
- Breathing volume is the amount of air blown per minute during rescue breaths. The optimal range is 1,5-3,2 liter per minute.

The measurable skill within 'continue CPR 30 - 2' is:

- Ratio is the number of compressions compared to the number of breathings.

In addition to the measurements of the actions mentioned above, the software can also display an overall CPR achievement score based on all the action measurements of the trainee together.

- Overall Achievement is measured as the percentage of the quality of the CPR based on all skills by use of an algorithm. The algorithm is included in appendix A.

The CPR skills measured in the studies included in the systematic review of Ali et al. (2021) vary considerably, though most research on CPR training types is limited to measuring compression rate and compression depth. By measuring only these two skills, just one of the six actions of BLS is taken into account, namely 'give 30 chest compressions'. These skills are most commonly measured because they strongly correlate with patient outcomes (Considine et al., 2020). If these are mastered during the training, the training attendees will be able to contribute to rescuing lives. Secondary is the measurements of Overall Achievement, full chest relaxation, leaning and the time spent on the ratio compression/breathings (Zheng et al., 2022). The least measured in scientific studies are the other actions, for instance, the check for responsiveness, the call for help, giving rescue breaths, the continuation of CPR, and the application of the AED.

As mentioned before, CPR skills are commonly measured via software in manikins. Widely used are manikins of Laerdal or AMBU. These manikins gather data that, later on, can be uploaded from the manikin to a laptop for further analysis. In addition, other types of manikins are recently being developed, which resemble the haptic experience of applying CPR more closely and give feedback to the trainee on their CPR performance (Semeraro et al., 2019). This is sometimes even possible when using VR techniques built in the manikin (Issleib et al., 2021), enabling the trainee to receive feedback on their performance and adjust their actions immediately.

Literature debates (Ali et al., 2021; Zheng et al., 2022) that there is still little standardization in content, duration, or measuring of skills in the types of standard training research that enables the comparison with the alternative training. Also, alternative training types differ in the content, duration, skills, and tools used to measure skills (Ali et al., 2021), making comparison difficult. Furthermore, it is hard to find common ground in the techniques used in alternative training because the training forms are rapidly evolving and becoming less expensive, with an ever-growing amount of specific features, the so-called affordances. A promising alternative technique is VR, which will be discussed in the next section.

VR IN EDUCATION AND CPR

Over the past 28 years, literature has viewed the standard training as the 'golden standard' (Nas et al., 2019). However, driven by the need to reach more trainees to save more lives and due to the recent COVID-19 pandemic, VR is one of the alternative training options that has gained attention regarding CPR training (Hubail et al., 2022). Freina and Ott (2015) suggested that the main reason to use VR in education is that it can create situations that are otherwise inaccessible in time or space or dangerous or unethical. As such, VR seemed a practical solution to continue teaching when physical gatherings were not allowed (Radianti et al., 2020). Though VR has been used in education in different forms and levels for decades (Kavanagh et al., 2017), it is an emerging technique in CPR education. Mcgee and Jacka (2021) estimate that currently, 171 million people worldwide use VR, and they expect that the market in education will grow by 42% over the upcoming five years. By definition, VR is an interactive digital space in 3D representation (Howard et al., 2021) that often comes with a first-person experience rather than an external observation of such an environment.

Kuyt et al. (2021) emphasize the widespread use of VR in medical education and CPR because VR has shown to enhance performance and increase engagement. Some studies point out that VR enhances information retention and better application of what is learned. It is found (Krokos et al., 2019; Kuyt et al., 2021) that VR gives a spatial insight comparable to a classical method to aid the memory in remembering information, the so-called memory palaces; mnemonics to help remember information by spatially organizing it and associating it with salient features in that environment. Experiencing that virtual space becomes easier when an HMD is used.

However, the possibilities of VR as an effective tool for learning skills are not undisputed. For example, Ali et al. (2021) see a prominent role in utilizing technologies but identify shortcomings of technology-only solutions; they recommend not choosing the application of the technical tool as a starting point but basing the training format on the learning content. To help decide on the most effective way of providing training, Martin et al. (2014) have developed an overview; it is elaborated on in the section 'choosing between the different types of CPR training'.

Studies that date from 2021, following the latest trends in VR technology, indicate that VR can help acquire CPR skills in a more attractive and even non-inferior manner than standard training, though they advise that follow-up studies should corroborate these findings (Ali et al., 2021; Hubail et al., 2022; Kuyt et al., 2021). In addition, they suggest that studies with large sample sizes measuring more CPR-related skills could better compare VR and standard training types (Hubail et al., 2022) than until 2021. Although there is hardly any debate about whether VR is appropriate to be used, there is still a question of whether standard training and VR training for CPR can amplify one another (Issleib et al., 2021). Interestingly, until now, the question of whether the sequence in which standard training and VR are presented to the trainees matters regarding the effectiveness of learning to apply CPR skills has not been studied.

High hopes for VR in education are not new, even when VR raised a lot of enthusiasm, but its effectiveness for education could not be objectified (Jensen & Konradsen, 2018). The arrival of the first developer versions of the HMD by Oculus in 2013 changed this limitation, as this technology became widely accessible to a greater public, education, and research. Still, scientific research remains ambiguous about the added value of VR in combination with HMD, as Jensen and Konradsen (2018) indicate that a less immersive technology appears to lead to better learning outcomes for the acquisition of cognitive skills. Immersion is the degree to which the physical reality is excluded, the range of sensory modalities, the width of the surrounding environment, and the resolution and accuracy of the display (Slater, 2003). In a meta-analysis (Wu et al., 2020), it was found that VR using HMDs is slightly more effective than the less immersive Desktop VR and other learning tools, though findings among the studies stay contradictory. Jensen and Konradsen (2018) conducted a systematic review of VR use with HMDs in education, emphasizing their added value, especially zooming into cognitive, psychomotor, and affective skills.

Cognitive skills acquisition, like acquiring and remembering factual knowledge, showed better learning outcomes when taught in a classroom than by VR and HMDs. Jensen & Konradsen (2018) found that it is instead the correct type of simulation that evokes learning, being brought by an HMD, then the use of VR itself. The right type is that the simulation's immersion must not be too overwhelming and must leave room for cognitive skills acquisition. The trainee is helped in remembering and understanding visual and spatial aspects of a place, in combination with low interaction. However, the trainee should be familiar with the HMD and not suffer cybersickness (Jensen & Konradsen, 2018).

Psychomotor skills are often trained in a simulation in which the learner repeatedly goes through the actions being trained until a level of proficiency has been reached. HMD using hand tracking appears to have the highest level of simulation instead of using a joystick or pointing devices. Several studies find positive effects in learning outcomes with VR in combination with HMD. Examples are adhering to a safety technique after visually scanning an urban setting, assembly tasks, or juggling (Kahlert et al., 2015). A side note is that the effects of the VR training have only been tested within the simulation setting, not within the real world. Therefore it is not unequivocally established that trainees did not just get better at playing the simulation (Jensen & Konradsen, 2018). This transfer needs more research, but it was found that the successful transfer of psychomotor skills depends on the quality and realism of the peripheral haptic/tactile device independent of the HMD (Sportillo et al., 2015). Transfer can be heightened when simulation rules are applied in combination with improved peripheral technologies for including the user's body movements in the simulation. Notably, also regarding these skills, physical discomfort is mentioned by older and less experienced users.

Affective skills acquisition, such as interpersonal or communication skills combined with VR, is scarcely researched. In some studies, trainees were to interact with a virtual agent – but no difference in learning outcomes between standard training and VR was found (Jensen & Konradsen, 2018). Repetition, believability, and a highly interactive simulation are needed to train these skills effectively. When a simulation evokes an emotional response, for instance, in case of exposure to irrational anxiety or stress management, there is a learning effect (Anderson et al., 2013). Though this subject is understudied, the expectations are that there will be a growing number of affective skills that VR can train.

THE USE OF VR IN CPR TRAINING IN PARTICULAR

In the medical world, VR is considered feasible and effective, and it is highly valued, particularly in CPR training (Zheng et al., 2022). During CPR, the most complex skills that need to be mastered are psychomotor and cognitive skills. These skills can be trained using VR, but the cognitive skills are generally measured indirectly as they contribute to the application of psychomotor skills. When it comes to CPR training, VR can be used differently. Besides running on an HMD, VR has also been used in training on a computer screen, making it less immersive. This is still considered an effective form of training, combined with an interactive manikin, providing real-time feedback for the trainee while performing CPR (Zheng et al., 2022).

One form of VR training, the Lifesaver (Yeung et al., 2017), was developed and endorsed by the Resuscitation Council of the UK and is mentioned explicitly in current CPR guidelines (Wyckoff et al., 2021). In 2019, Nas et al. conducted a study with the Lifesaver app in cooperation with the UK council. After this, many studies followed that mostly found that CPR skills training, with or without professional manikins, is more accessible when VR is used. The Lifesaver VR is a

CPR training game with a first-person perspective, designed for use with a headset, enabling the user to experience the emergency of CPR while learning essential CPR skills.

Besides applications intended for training laypersons, recent studies have investigated the use of VR that is built into the measuring tools, namely the manikins. This way, trainees receive real-time feedback, enabling many repetitions until skills are mastered (Issleib et al., 2021; Semeraro et al., 2019; Zheng et al., 2022).

DIFFERENCE BETWEEN THE STANDARD TRAINING AND VR

In most VR training types, the number of skills that can be measured still falls short compared to the standard training. Often, the measurements are reduced to essential measurements that indicate survival chances: compression depth, compression rate, and Overall Achievement (Nas et al., 2019; Yeung et al., 2017). Partly due to Covid-19, it has also been a conscious choice to leave out the skills concerning 'breathing' because any physical proximity or contact increases the infection risk.

Although standard training is considered a complete 'golden standard' (Zheng et al., 2022), in the comparisons made in various studies, the technology of VR is becoming increasingly important and more widely embraced. Therefore, measuring all the skills trained with VR more broadly seems essential. Unfortunately, this is still under-researched, and the intention to do so is currently missing in the literature.

Although VR training is based on the training content of standard training, and this content is based on global guidelines, there is no standardization in the content of standard training. Ali et al. (2021) lay the foundation for this in their review of alternative training in general, which opens the way to better generalizing findings. Zheng et al. (2022) do that for VR training in the field of CPR.

POSSIBLE EFFECTS OF THE SEQUENCE OF THE TRAINING METHOD

Although almost all alternative training types (including VR training) have been compared to the standard training in scientific studies, little is said about the possible effect of the sequence in which the training methods are followed if participants are submitted to several training types. Therefore, it is not yet known if there is a preferred order in which the different types of training could be given. For example, one could question what sequence would be most effective, first VR and then standard training or first standard training and then VR. Although the literature does not dispute that VR is a good tool for CPR training, it is implicitly seen as a pivotal supplement. Participants are offered the standard training first to teach them the basics and then receive supplementary VR training. An exception is the work of Liu et al. (2021). They found that a pretraining intervention with VR significantly affected the level of CPR skills transfer and knowledge retention. However, this study was not included in the systematic review of Ali et al. (2021) because it was not determined whether the effect of the pretraining was compared to standard training. The tenor in research is that VR and standard training possibly interact, but further research will have to point this out.

CHOOSING BETWEEN THE DIFFERENT TYPES OF CPR TRAINING

In reviewing and analyzing different CPR training methods, Martin et al. (2014) have developed an overview that can help decide the most effective way of providing training for a given circumstance. They identified seven criteria: learning modality, learning environment, trainer presence, proximity, interaction level, cost considerations, and time demands. They are briefly explained below, and the best option is indicated for each criterion.

Learning modality is the most distinctive method of communication by which training content is brought to the learners. This is either by doing, seeing and, or hearing. The best modality is the one that suits the trainees. Training environment indicates whether the training is carried out in a natural environment or a real work environment, a simulated environment that is contrived as close as possible to the work environment, or a contrived or specially created environment without similarities to the work environment. This is also the order of most to least desirable environments for training. Trainer presence tells if a trainer is needed to convey the content, it is either yes or no. The presence of a trainer can provide monitoring and adjusting of the learning progress, and it can impact the learners' motivation. Proximity means if the training is done face to face or at a distance. Distance learning can enable reaching more extensive groups of trainees. Interaction level is divided into interactive, somewhat interactive, and not interactive, or variable: the more frequent the interaction, the more gainful. Cost considerations can be classified as low (only the costs of the trainer), moderate (costs for the trainer and the training space), or high (costs for the trainer, space, and equipment). Costs can also be classified as initial or ongoing. The lower the costs, the better. Time demands, lastly, can also be low, moderate, or high. Low time demand means that the training is given at a fixed time and exists as a singular event. Moderate time demand means that the training time is fixed, ongoing, or unspecified, and singular and high time demand means that the training time needed is unspecified and ongoing. The lower the time demands, the better (Martin et al., 2014).

Other considerations are that a combination of different methods is a suitable choice when the information and skills taught during the training are somewhat complex but tedious when the skills need to be kept up to be appropriately applied. In Table 1, the criteria are indicated per training type. Also, the best option for any organization, per criterion, recommended by Martin et al. (2014), is added to the table. When choosing between VR training with HMD or standard training, the choices that are not already recommended are trainer presence and proximity. But, as Martin et al. (2014) already mentioned, considering the number of skills that need to be trained during a CPR training, maybe no choice needs to be made, and the option to use a combination of both training types could be the most effective.

Table 1: *Criteria per training type*

criteria	**training in VR with HMD**	**Standard training**	**best option**
Learning modality	Doing	Doing	Doing
training environment	Natural and simulated	simulated and contrived	Natural
trainer presence	No	Yes	Depends
proximity	Distance	Face to Face	Depends
interaction level	Interactive	Interactive	Interactive
cost considerations	initially high, then low	High	Low
time demands	moderate	moderate	Low to moderate

To conclude this theoretical framework, it can be said that most research on CPR training types is limited to measuring compression rate and compression depth (Nas et al., 2019). The question about the most effective sequence in which standard training and VR are followed is lacking in the debate. If the stimulation in VR is not too overwhelming, it can leave room for cognitive skills acquisition. Likewise, the trainee can repeatedly carry out psychomotor skills, thus building on the desired level of proficiency (Jensen & Konradsen, 2018). This is especially the case when an HMD is combined with hand tracking. As a result, CPR skills training in VR can be effective (Nas et al., 2019).

RESEARCH QUESTIONS

The main research question of this exploratory study is: What is the effectiveness of learning to apply seven different CPR skills and overall CPR achievement by training in VR with HMD compared to the standard training? To answer this question, two sub-questions are interesting, namely:

- What is the effectiveness of VR training compared to the standard training concerning the different CPR skills that need to be mastered and the overall CPR achievement?
- What is the influence of the sequence in which both training types are followed on mastering different CPR skills and the overall CPR achievement?

METHOD

RESEARCH DESIGN

In this quantitative study, an experimental design was used, in which the participants were submitted to both a standard CPR training and a VR CPR training. Their CPR skills were determined before and after each training (Table 2). Table x also shows that participants were randomized into two groups, determining in which order the training types were attended.

Table 2

Research design.

group 1	**Test 0: pre-test**	4 duos train in **VR**, each individual of duo trains 1/2h	**Test 1**	8 participants train **standard training** during 1h	**Test 2**
group 2	**Test 0: pre-test**	8 participants train **standard training** during 1h	**Test 1**	4 duos train in **VR**, each individual of duo trains 1/2h	**Test 2**

PARTICIPANTS

Police employees were invited to participate in the study through posters put on the walls of the building, were sent through general mail, and team mailing. Registration was voluntary, and candidates were allowed by their team manager to reserve a free day on their agenda on the training day itself. The invitation stated that a certificate for resuscitation could be received if sufficient competency in CPR skills was obtained. It was decided not to set any in- or exclusion criteria for participation, such as education level, age, sex, previous participation in CPR training, or position. This could reduce the chance of having enough participants within the allotted recruiting time, as the study took place during a COVID-19 lockdown, and a homeworking policy was enforced. The participants all worked at the PDC. To enhance the reliability of the study, participants were randomized into two groups, and a pre-test to determine baseline CPR skills was conducted. An a priori power analysis was performed, which indicated that, expecting a medium effect size of $f = .25$, with an $\alpha = .05$ and a power of $1 - \beta = 0.95$, a sample size of at least 44 participants was recommended.

For three days, approximately 100 people volunteered to participate in the study, 72 of whom were able to fit a whole working day's schedule into research and training. Unfortunately, of those 72 applicants, 22 needed to stay in quarantine as was required after a Covid-infection of themselves or someone in their proximity or did not dare to risk coming to the PDC. Eventually, there were 50 participants left. 28 participants were women (56%), 22 were men (44%), no respondents identified as being neither female nor male, the oldest was 65 years old, the youngest 25, and the mean age was *M*= 36.2, (*SD* = 4.4).

INTERVENTIONS

This study used two types of training: standard and VR training. Each participant was submitted to both forms of training, but they were randomized into two groups that determined in which sequence they attended the types of training. Within both training types, the learning objective was to acquire CPR skills to be able to save a life. The VR training was designed to be easy to carry out within the domestic context, so the threshold for following the training remains as low as possible. The content of both training types was kept the same as much as possible. The theory of both types of training was based on the guidelines of the Dutch Resuscitation Council, and the structure of the pieces of training was according to the Mastery Learning principle (Cheng et al., 2018): first theory, then apply theory in an example and then apply it yourself.

For the standard training, a trainer from the NRR adjusted their usual training format to a CPR training limited to one hour in which only the six actions of the Basic Life Support were covered. The standard training was carried out by an independent and experienced instructor of the Council. For every six trainees, there was one instructor. CPR skills were taught on the AMBU manikin, with a universal AED trainer, which was also used in the three tests conducted.

Also, for the VR training, the information regarding knowledge and skills originates from the NRR, and images from the NRR have been used. The theory of Mayer (2014) was used to optimize learning and instruction within the VR training. This theory focuses on multimedia instruction, opting for the best combination of illustrations and written text and matching the senses used to receive the information. As the skill compression depth was found inferior in previous studies after the VR training compared to the standard training, it was decided to integrate Mayer's signaling technique into the VR training. This technique was applied as a spoken instruction: 'note: apply compression deep enough; they must be 5 to 6 cm'.

The VR training was followed in duos. Both trainees received a five-minute instruction by the project leaders beforehand on how to use the Oculus Quest 2, to which none of the participants were accustomed. Then, one participant put on the HMD, and the other participant of the duo was nearby to create a sense of safety for the person wearing the HMD and prevent them from becoming disoriented. The VR training could take up to 30 minutes, but all participants were asked to use up the entire half hour and keep training the last part of applying the theory into practice in case they finished the program early. The VR training consisted of a 3-dimensional office space in which the trainee had an immersive first-person experience in three rounds. In the first round, the theory of CPR was presented to the trainees interactively. In the second round, the theory was brought to practice using examples. The trainee could practice CPR guided by a voice-over and a built-in PowerPoint presentation. In the last round, the trainee performed CPR themselves without guidance. The VR trainees only received implicit feedback through the app; if some skill was not performed well, they could not proceed to other skills within the training. In every part of the VR training, the trainees were reminded to 'be sure to push deep enough, five to six cm deep', as in the study of Nas et al. (2019), the compression depth skill had proven to be inferior in the VR training. The CPR skills were performed on 10 cm thick pillows, as can be found in every household, while at the same time, the trainee saw a man in need of CPR lying on the office floor. The breathing skills are performed virtually, combined with the head- and hand-tracking software of the Oculus Quest 2. The same type of universal AED was used, though, in the VR training, it was a virtualization of the one used in the tests.

INSTRUMENTS

To obtain reliable information about the current skills levels of the trainees, an AMBU manikin with build-in software was used to collect the relevant data. Following the training 'basic resuscitation' developed by the trainers of the NRR (see appendix x), several variables were set for measurement as indicated in the section on CPR training. The data were collected through the software and stored by an AMBU manikin, who measured the variables and gave a percentage of Overall Achievement on the different skills. The optimal range for each skill is described in the section 'how are CPR skills typically measured' and indicated in Table 3.

Two testers from the NRR carried out the tests during all three study/training days; one test taker was present every day and the second tester was a different professional every day. Before the tests phase, all testers were instructed by one NRR employee and a software specialist from AMBU. These instructors are examiners of the NRR who train CPR teachers and trainers.

PROCEDURE

The BMS Ethics Committee has approved the research under number 220002.

Employees of the PDC in Rotterdam are the specific target group. All 50 participants were registered by name, birthday, and e-mail address in an excel data file. Then they were randomly assigned to group 1, VR training first, or group 2, standard training first. The entire training phase of the study was planned to take part over three days, November 15th, 22nd, and 23rd of 2021, in which all data were gathered. A new set of participants was trained each day, and every day was set up in the same manner. First, a pre-test (t0) was performed to determine the baseline

CPR skills of the respondents. The respondents were not asked if they had had prior CPR training; this was measured in the pre-test. After the first training session, the skills levels were measured again (test 1). Then the trainees followed the second training, which ended with the last skills measurements (test 2). The training in VR was half an hour; two trainees could be trained within the hour. The standard training was an hour. After each type of training, a half an hour break was scheduled. The three tests gathered the same skill data and were therefore comparable. Because every respondent followed both types of training (but in one of two possible sequences), the effect of the sequence in which they were followed can also be determined.

The research days went according to plan, well supported by facility staff of the PDC, testers, and trainers from the NRR, for which half of the fifth floor was in use. The testers and trainees only saw each other during the tests, so the testers could not guess which participant came from which group. All tests were conducted in a shielded room.

DATA ANALYSIS

After the data were collected from the AMBU Manikin, it was imported into SPSS 27. The data were inspected for missing and invalid data points. If invalid data points were found, they were set to be missing. If a participant had a missing skill score, it means that that particular participant could not be included in data analyses that included that skill. To start with the data analyses, first descriptive statistics (means, standard deviations, minimum and maximum) were calculated. Then, a randomization check was performed using independent samples t-tests to determine whether the average skill scores of the pre-test were comparable between the two groups (VR first and standard training first). The main analyses consisted of eight two-way mixed ANCOVA's, in which the overall CPR achievement and the seven skill scores for both the VR training and the standard training were the dependent variables. Type of training (VR or ST) was the within-subject factor, and the sequence in which the pieces of training were followed was the between-subject factor. The pre-test skill score of the respective skill was added to the model as a covariate. Before interpreting the results of the two-way mixed ANCOVA's, the assumptions were checked; namely, the data have no extreme outliers and are approximately normally distributed. A scatter plot was made between the pre-test and the test 1, showing a linear relationship between the covariate and the dependent variables, there is homogeneity of variances, and there is homogeneity of covariances. Additional frequency analyses and Cochran's Q tests were carried out on two skills, where respondents scored above the optimal range. Finally, a Bonferroni test was carried out to correct for multiple testing.

For all analyses, a threshold for significance of $\alpha = .05$ is used (95% confidence interval).

RESULTS

In total, 50 police employees participated in the study, of which one participant did not partake in the pre-test, and another did not register data on test 2. Table 3 shows the descriptive statistics of the measurements that have taken place during the training sessions. For the separate measurements depending on the sequence, will be referred to the results of the tables of the results of the main analyses (tables 5-6 and 12-16).

Table 3:
Characteristics of the Core Variables

action		*N*	*M*	*SD*	Optimal (range)	*Min*	*Max*
	Overall Achievement pre-test	49	50.20	19.71	100	0.00	87.00
	VR Overall Achievement	50	61.76	16.42		28.00	85.00
	ST Overall Achievement	49	68.33	13.45		28.00	89.00
give 30 chest compres sions	ECC pre-test	49	49.45	41.95	100-120	0.00	135.90
	VR ECC	50	65.73	44.09		0.00	140.60
	ST ECC	49	76.68	35.84		0.00	130.50
	Compression Depth pre-test	49	52.29	16.72	50-60	0.00	74.60
	VR Compressiondepth	50	59.97	10.28		27.20	73.80
	ST Compressiondepth	49	59.55	9.31		34.00	74.80
	Handposition pre-test	49	0.61	0.89	2	0.00	2.00
	VR Handposition	50	0.74	0.80		0.00	2.00
	ST Handposition	49	0.86	0.87		0.00	2.00
	Leaning pre-test	49	1.33	0.77	2	0.00	2.00
	VRLleaning	50	1.54	0.68		0.00	2.00
	ST Leaning	49	1.27	0.76		0.00	2.00
continue CPR 30-2	Ratio pre-test	49	0.16	0.37	2	0.00	1.00
	VR_Ratio	50	0.56	0.58		0.00	2.00
	ST Ratio	49	0.59	0.61		0.00	2.00
give 2 rescue breaths	Breathingfrequency pre-test	49	0.59	0.89	3-6	0.00	3.20
	VR Breathingfrequency	50	0.67	0.58		0.00	2.40
	ST Breathingfrequency	49	0.84	0.54		0.00	2.20
	Breatingvolume pre-test	49	0.64	0.93	1.5-3.6	0.00	2.80
	VR Breathingvolume	50	0.85	0.81		0.00	2.60
	ST Breathingvolume	49	1.01	0.78		0.00	2.60

Notes. ST = standard training; VR = virtual reality training; Optimal (range) is the (range of) the skill score considered most effective for CPR.

A randomization check was carried out, in which the means of the skills during the pre-test of group 1 (VR first) were compared to the average pre-test skill scores van group 2 (standard training first). Table 4 shows no significant differences between the groups, which indicates that the randomization has led to comparable groups regarding the baseline measurements of the CPR skills.

Table 4:
Randomization check on pre-test results

	VR first (*n* = 25)		ST first (*n* = 24)				
Variable	*M*	*SD*	*M*	*SD*	*t*(47)	*p*	*d*
Overall Achievement	47.44	18.86	53.08	20.57	-1.00	.322	-.286
ECC	43.99	39.86	55.15	44.13	-0.93	.357	-.266
Compression Depth	52.14	18.68	52.45	14.81	-0.06	.950	-.018
Handposition	0.56	0.87	0.67	0.92	-0.42	.678	-.119
Leaning	1.24	0.78	1.42	0.78	-0.80	.430	-.227
Ratio Compressions Breathings	0.08	0.28	0.25	0.44	-1.61	.117	-.463
Breathing Frequency	0.60	0.94	0.58	0.86	0.11	.911	.032
Breathing Volume	0.61	0.95	0.67	0.94	-0.23	.817	-.067

EFFECTIVENESS OF THE VR TRAINING VERSUS THE STANDARD TRAINING

To determine whether the VR and standard training had a different effect on overall CPR achievement and the seven skills and whether the sequence in which the VR and standard training were given was relevant, eight two-way mixed ANCOVA's were carried out in which Training type was the within-subject factor and sequence of the pieces of training was the between-subject factor.

Table 5 shows the results of the mixed ANCOVA with Overall Achievement as a dependent variable. The main effect of training type (VR vs standard training) was not significant, $F(1,45) = 1.42$, $p = .240$, $\eta_p^2 = .031$, but there was a significant main effect of training sequence, $F(1,45) = 9.48$, $p = .004$, $\eta_p^2 = .174$. Also, a significant interaction effect between sequence and training type was found, $F(1,45) = 11.05$, $p = .002$, $\eta^2_p = .197$, which means that the difference between the VR and standard training depends on the sequence in which the training is given. The main effects require additional interpretation when there is a significant interaction effect. Therefore simple main effects were conducted. In the group with training sequence VR – standard training, the VR training resulted in a significantly lower level of Overall Achievement ($M = 53.58$, $SE = 2.60$) than the standard training ($M = 67.68$, $SE = 2.62$; $p < .001$), but in the group that was given the sequence standard training -VR no significant difference between standard training ($M = 68.94$, *SE* = 2.62) and VR (*M* = 70.21, *SE* = 2.60) was found (*p* = .737). This means that adding a standard training after a VR training leads to higher overall CPR achievement, but giving a VR training after a standard training is already given does not improve overall CPR achievement.

The covariate Overall Achievement in the pre-test was significant, $F(1,45) = 14.03$, $p < .001$, $\eta_p^2 = .238$, which means that the Overall Achievement after the training is also dependent on prior skills in the area of CPR. A comparable effect of the pre-test measurements on the main test results was found across the analyses with all skills. Thus from here on, it will no longer be mentioned.

Table 5:

Results of the two-way mixed ANCOVA with Overall CPR Achievement as dependent variable

	Overall Achievement			
	VR first		ST first	
training type	*M*	*SD*	*M*	*SD*
VR	52.71	17.14	71.08	9.22
standard training	66.88	14.61	69.75	12.64
Effecten	*df*	*F*	*p*	η^2_p
Training type	1,45	1.42	.240	.031
Sequence	1,45	9.48	.004	.174
Sequence*training type	1,45	11.05	.002	.197
Pretest*training type	1,45	0.03	.854	.001
Pretest	1,45	14.03	.001	.238

The results of the mixed ANCOVA are also shown in Figure 3. As can be seen, the group who started with VR showed, on average, a lower overall CPR achievement (*M* = 53.15, *SD* = 17.02) than the group who started with ST (*M* = 69.75, *SD* = 12.64) during the first test after the first training. This was a significant difference, $t(48) = -3.89$, $p < .001$. But after both trainings were followed there was no longer a significant difference between the group that started with VR (*M* = 66.96, *SD* = 14.31) and the group that started with ST (*M* = 71.08, *SD* = 9.23; $t(47) = -1.19$, p = .239).

Figure 3:

Comparison of overall CPR achievement between the two groups and the two types of training

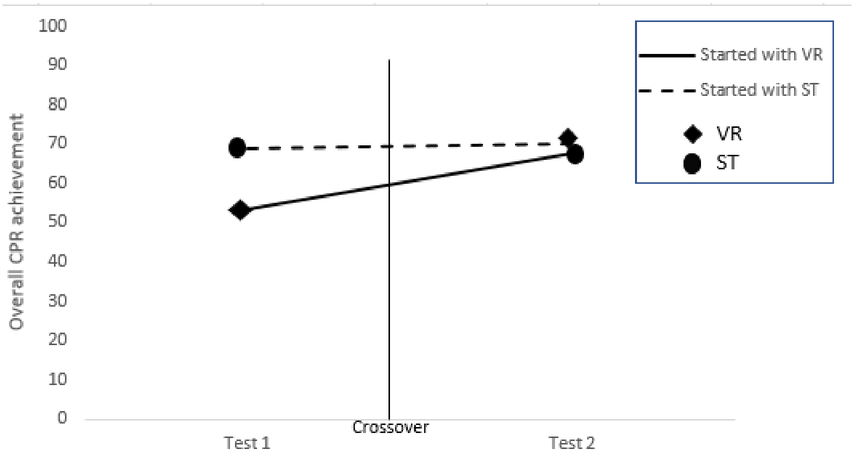


Table 6 shows the findings of the two-way mixed ANCOVA with **ECC** as a dependent variable. There was no significant main effect of training type, *F*(1,45) = 0.40, *p* = .532, $\eta_p{}^2$ = .009, meaning that on average the VR training and ST training did not significantly differ in compression rate. Also, there was no main effect of sequence, *F*(1,45) = 1.80, *p* = .186, $\eta_p{}^2$ = .038. Therefore the compression rate trainees showed during the tests was not significantly different between the two groups. Last, there was also significant interaction effect, *F*(1,45) = 0.87, *p* = 356, $\eta_p{}^2$ = .019.

Table 6:

	ECC			
	VR first		ST first	
training type	*M*	*SD*	*M*	*SD*
VR	55.58	44.83	76.19	42.60
standard training	72.63	36.68	81.03	35.99
Effecten	*df*	*F*	*p*	η^2_p
Training type	1,45	0.40	.532	.009
Sequence	1,45	1.80	.186	.038
Sequence*training type	1,45	0.87	.356	.019
Pretest*training type	1,45	0.24	.626	.005
Pretest	1,45	3.40	.072	.070

Figure 4 shows the (nonsignificant) effects of group and training type. Although the main effect of sequence was not significant, independent samples t-tests showed that in test 1 the VR-first group had a significantly lower ECC (*M* = 56.07, *SD* = 44.02) than the ST-first group (*M* = 81.03, *SD* = 35.99; t(48) = -2.18, p = .034). During test 2 however, there was no longer a significant difference between the VR-first and the ST-first groups (respectively *M* = 72.51, *SD* = 35.92 and *M* = 76.19, *SD* = 42.60; *t*(47) = -0.33, *p* = .745) .

Figure 4:

Comparison of ECC between VR and ST and between the two groups

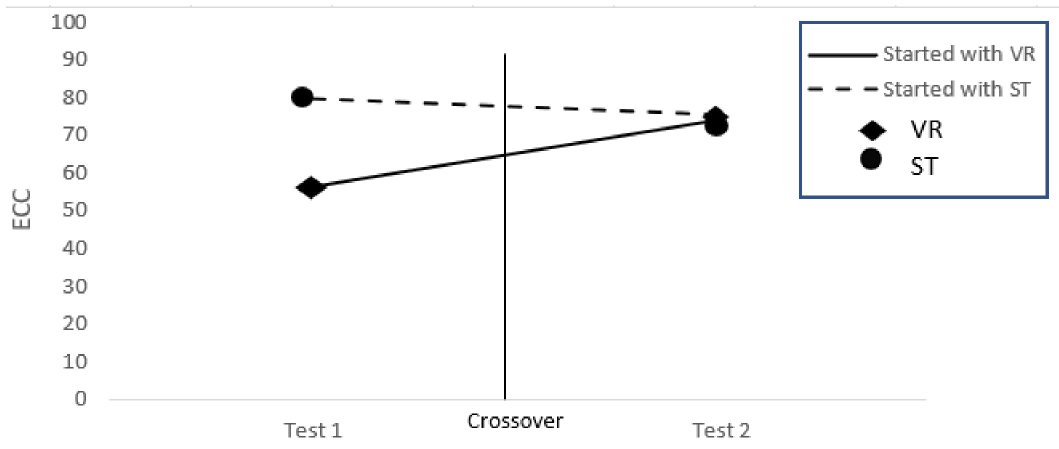


Table 7 shows the findings on **compression depth**.

There is no significant difference in the effect of the VR training compared to the standard training, F(1,45)= 1.891, p= .176, *η2p* = .040. The difference in effectiveness between VR and standard training does not significantly depend on the sequence in which the types of training are followed, F(1,45)= .483, p= .490, *η2p* = .011. The effectiveness of VR training is not significantly higher after sequence standard training-VR than after the sequence VR-standard training, F(1,45)= 1.205, p= .270, *η2p* = .027. The difference between VR and standard training in independent of the pre-test, F(1,45)= 2.663, p= .110, *η2p* = .056.

Table 7:

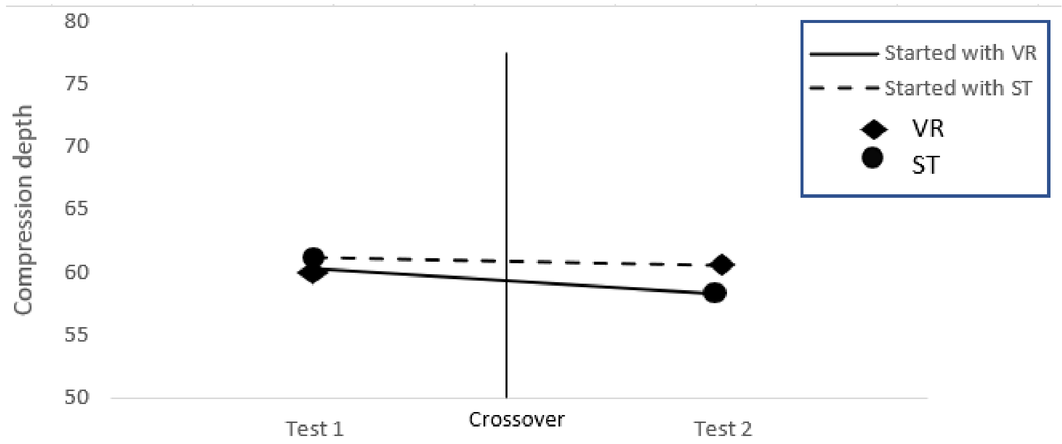
Results of the two-way mixed ANCOVA on compression depth.

	Compression depth			
	VR first		ST first	
training type	*M*	*SD*	*M*	*SD*
VR	60.24	11.78	60.56	8.34
standard training	58.15	11.24	61.20	6.93
Effecten	*df*	*F*	*p*	η^2_p
Training type	1,45	1.89	.176	.040
Sequence	1,45	0.48	.490	.011
Sequence*training type	1,45	1.21	.270	.027
Pretest*training type	1,45	2.66	.110	.056
Pretest	1,45	13.52	.001	.231

Figure 5 confirms that the compression depth did not differ between VR and ST and that the results of the compression depth did not depend on the sequence in which the pieces of training were given.

Figure 5:

Changes in compression depth after the VR and ST training



The results of the ANCOVAs of ECC and compression depth require further elaboration. In the ANCOVAs, the premise is that a higher skill score means the participant is better at CPR. But in fact, there is an 'optimal' range between which the measured skills are most effective. Too low isn't good, but neither is too high. The optimal range of all skills that have been examined is shown in the results section (table x). Looking at the maximum score, it is noticeable that there have been persons who scored above the ideal range for the ECC and the compression depth variables, which means that the results of the ANCOVAs with these dependent variables may be biased. Therefore, in addition, a Cochran's Q test was used. For the other skills, no participant has 'scored' above the optimal range, so the principle 'the higher, the better' applies here, and the ANCOVAs, therefore, give a good picture. The Cochran's Q was based on assigning a 0 to respondents who were outside the range and a 1 to those who were in it. This choice was made because it is in line with the method used during the tests and the algorithms of AMBU, and it is in line with the work of Nas et al. (2019).

The following was found for ECC. According to the guidelines, the optimal number of ECC ranges between 100 and 120 per minute. Table 8 shows that, prior to the training, 8% (n = 4) of the participants performed the chest compressions within this range. After the VR training, this percentage increased to 20% (n = 10), and after the standard training 15 participants (30%) showed an adequate number of chest compressions per minute. Cochran's Q test was used to determine whether the percentage of participants performing correct chest compressions differed during the pre-test, after the VR training, and after the standard training. The percentage of individuals showing an adequate chest compression rate significantly differed between the measurement points, Q = 8.27, p = .016. Pairwise comparisons in table 9, with Bonferroni correction, revealed that after the standard training, significantly more participants performed the number of chest compressions according to the guidelines than after the pre-test (p = .012). However, no significant difference in the percentage of participants with the correct number of chest compressions was found between the pre-test and VR training (p = .575) or between the VR training and the ST training (p = .352).

Table 8:

Frequencies on ECC per range per training type

	ECC		
	Pre-test n (%)	VR training n (%)	ST training n (%)
Within range	4 (8%)	10 (20%)	34 (68%)
Not in range	46 (92%)	40 (80%)	15 (30%)

Table 8:

Pairwise Comparisons

Sample 1-Sample 2	$\chi 2$	*p*
ST_ECC-VR_ECC	.102	.192
ST_ECC-ECC_pre	.224	.004
VR_ECC-ECC_pre	.122	.117

For compression depth, the same tests are carried out. Table 10 shows that, compared to the pre-test, the proportion of participants who have resuscitated within the ideal range has hardly changed (32% in the pre-test, 28% after the VR training, and 34% after the standard training). Through Cochran's Q, we see in table 11 that no significant differences between the measurements were found in a proportion of people who met the ideal range, Q = 0.92, p = .630

Table 10:

Frequencies on compression depth per range per training type

	Compression Depth		
	Pre-test n (%)	VR training n (%)	ST training n (%)
Within range	16 (32%)	14 (28%)	17 (34%)
Not in range	34 (68%)	36 (72%)	32 (64%)

Table 11:

Pairwise Comparisons

Sample 1-Sample 2	$\chi 2$	*p*
ompressiondepth_VR-Compressiondepth_t0	.041	.631
Compressiondepth_VR-Compressiondepth_ST	-.082	.337
Compressiondepth_t0-Compressiondepth_ST	-.041	.631

Table 12 shows the findings on **Handposition**.

There is no significant difference in the effect of the VR training compared to the standard training, F(1,45)= 1.070, p= .307, $\eta 2p$ = .023. The difference in effectiveness between VR and standard training does not significantly depend on the sequence in which the types of training are followed, F(1,45)= 1.539, p= .221, $\eta 2p$ = .033. The effectiveness of VR training is not significantly higher after sequence standard training-VR than after the sequence VR-standard training, F(1,45)= .410, p= .525, $\eta 2p$ = .009

Table 12:

Results of the two-way mixed ANCOVA on Handposition

	Handposition			
	VR first		ST first	
training type	*M*	*SD*	*M*	*SD*
VR	0.54	0.66	0.87	0.8
standard training	0.79	0.93	0.92	0.88
Effecten	*Df*	*F*	*p*	η^2_p
Training type	1,45	1.07	.307	.023
Sequence	1,45	1.54	.221	.033
Sequence*training type	1,45	0.41	.525	.009
Pretest*training type	1,45	0.23	.635	.005
Pretest	1,45	0.23	.634	.005

Figure 6 shows the differences between the groups and the training types in both test 1 and test 2.

Figure 6:

Differences in handposition between the groups and the training types

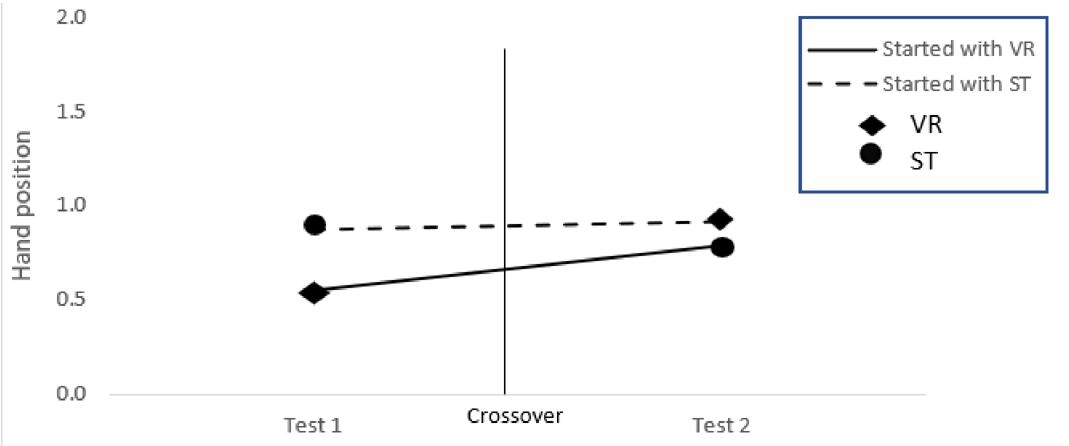


Table 13 shows the findings on **Leaning**.

There is no significant difference in the effect of the VR training compared to the standard training, F(1,45)= .250, p= .619, *η2p* = .006. The difference in effectiveness between VR and standard training does not significantly depend on the sequence in which the types of training are followed , F(1,45)= 1.903, p= .175, *η2p* = .041. The effectiveness of VR training is not significantly higher after sequence standard training-VR than after the sequence VR-standard training, F(1,45)= .475, p= .494, *η2p* = .010. The difference between VR and standard training in independent of the pre-test, F(1,45)= 1.104, p= .299, *η2p* = .024

Table 13:

Results of the two-way ANCOVA with leaning as dependent variable

	Leaning			
	VR first		ST first	
training type	*M*	*SD*	*M*	*SD*
VR	1.58	0.58	1.54	0.72
standard training	1.38	0.65	1.17	0.87
Effecten	*Df*	*F*	*p*	η^2_p
Training type	1,45	0.25	.619	.006
Sequence	1,45	1.90	.175	.041
Sequence*training type	1,45	0.48	.494	.010

Pretest*training type	1,45	1.10	.299	.024
Pretest	1,45	23.77	.000	.346

Figure 7 shows the average leaning levels after the tests for each training type and group. Although the average leanings scores were higher after the VR training (*M* = 1.54, *SD* = 0.65) than during the ST training (*M* = 1.17, *SD* = 0.87) during the first test, this was no significant difference, t(42.38) = 1.71, p = .095. Also, no significant difference between the VR and ST was found during the second test (*M* = .36, *SD* = 0.64 and *M* = 1.54, *SD* = 0.72; *t*(47) = -0.94, *p* = .354).

Figure 7:

The difference in Leaning between the groups and the training types

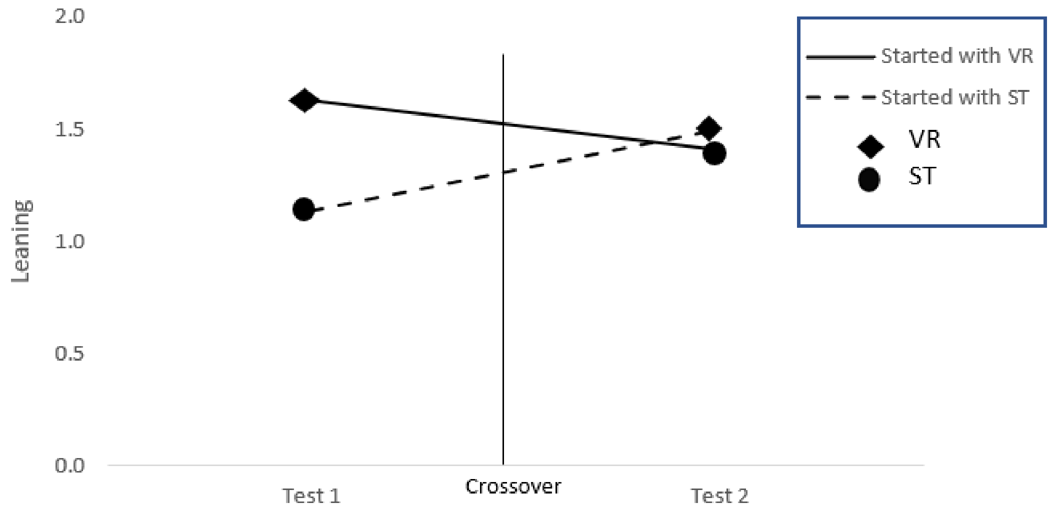


Table 14 shows the findings on **Ratio compressions breathings**.

There is no significant difference in the effect of the VR training compared to the standard training, F(1,45)= .102, p= .751, *η2p* = .002. The difference in effectiveness between VR and standard training does not significantly depend on the sequence in which the types of training are followed, F(1,45)= .18, p= .670, *η2p* = .004. The effectiveness of VR training is not significantly higher after sequence standard training-VR than after the sequence VR-standard training, F(1,45)= 1.777, p= .189, *η2p* = .038. The difference between VR and standard training in independent of the pre-test, F(1,45)= .048, p= .828, *η2p* = .001.

Table 14:

Results of the two-way mixed ANCOVA on Ratio compressions breathings

	Ratio compressions breathings

	VR first		ST first	
training type	*M*	*SD*	*M*	*SD*
VR	0.46	0.59	0.67	0.56
standard training	0.63	0.58	0.58	0.65
Effecten	*df*	*F*	*p*	η^2_p
Training type	1,45	0.10	.751	.002
Sequence	1,45	0.18	.670	.004
Sequence*training type[1]	1,45	1.78	.189	.038
Pretest*training type	1,45	0.05	.828	.001
Pretest	1,45	12.51	.001	.281

Figure 8:

Visualization of the mean differences in Ratio compression breathings between VR and standard and between the groups

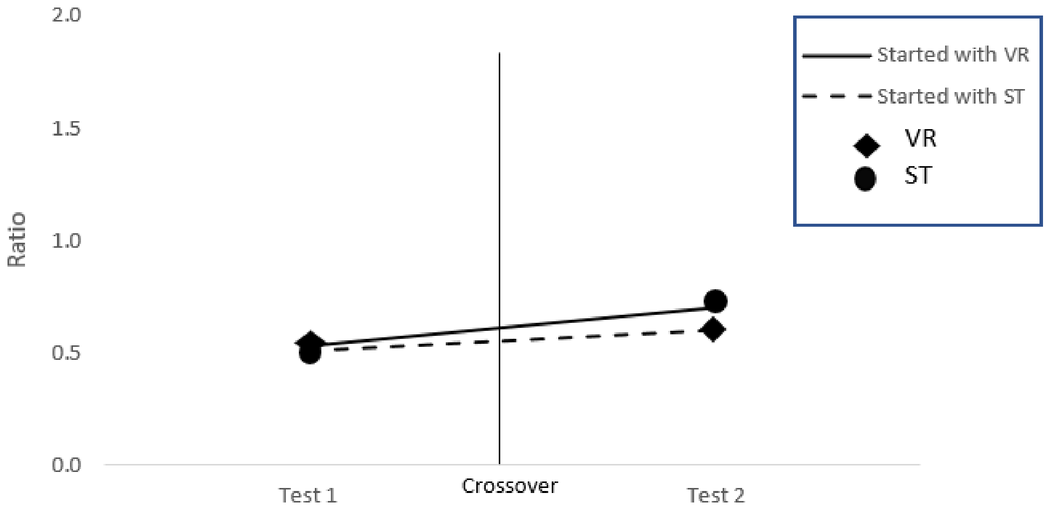


Table 15 shows the findings on **Breathing frequency**.

There is a significant difference in the effect of the VR training compared to the standard training, F(1,45)= 6.406, p= .015, *η2p* = .125 as it is estimated that during the VR training on average a lower breathing frequency of 0.67 (SE = 0.06) was measured, than during the standard training (M = 0.85; SE = 0.08) controlling for the pre-test measurements. The effectiveness of the training significantly depends on the sequence in which the types of training are followed, F(1,45)= .9.726, p= .003, *η2p* = .178. On average the first VR training showed a lower breathing frequency of 0.57 (SE = 0.09) then when the standard training first training was measured (M = 0.95, SE = 0.09). There is a significant interaction effect, F(1,45) = 18.65, p < .001, n^2_p = .293. Simple main effects indicate that the effectiveness of VR training is significantly higher after sequence standard training-VR (M = 1.00, SE = 0.09) than after the sequence VR-standard training (M = 0.33, SE = 0.09; p < .001). But no difference was found in the breathing frequencies after the standard training between the standard training first VR (M = 0.89, SE = 0.11) and the VR first groups VR M = 0.80, SE = 0.11; p = .563).

Table 15:

Results of the mixed ANCOVA with breathing frequency as a dependent variable

	Breathing frequency			
	VR first		ST first	
training type	*M*	*SD*	*M*	*SD*
VR	0.33	0.43	1.00	0.49
standard training	0.80	0.52	0.89	0.57
Effecten	*Df*	*F*	*p*	η^2_p
Training type	1,45	6.41	.015	.125
Sequence	1,45	9.73	.003	.178
Sequence*training type	1,45	18.65	<.001	.293
Pretest*training type	1,45	0.31	.578	.007
Pretest	1,45	5.57	.023	.110

As can be seen in Figure 9, the breathing frequency after the VR training in test 1 is lower (*M* = 0.37, *SD* = 0.49) than after the ST training (M = 0.89, SD = 0.57). This difference is significant, t(48) = -3.46, p = .001. In te second test, however there is no significant difference between the two training types, t(47) = -1.43, p = .160.

Figure 9:

Differences in breathing frequency between the groups and the training types.

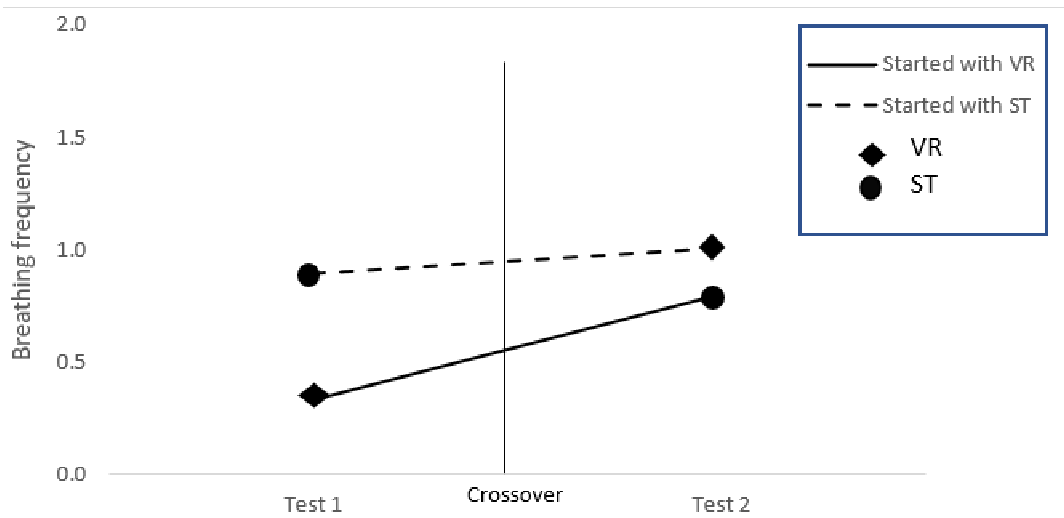


Table 16 shows the findings on **Breathing volume**.

There is no significant difference in the effect of the VR training compared to the standard training, F(1,45)= .632, p= .431, *η2p* = .014. There was significant main effect of sequence, F(1.45) = 11.71, p = .001, n^2_p= .207) meaning that on average the breathing volume was higher if the training first started with standard training (M = 1.21, SE = 0.11) then if the training started with VR (M = 0.66, SE = 0.11). There was a significant interaction effect, F(1,45)= .4.428, p= .041, *η2p* = .090. Simple main effects show that the effectiveness of VR training significantly higher after sequence standard training-VR (M = 1.25, SE = 0.14) than after the sequence VR-standard training (M = 0.45, SE = 0.14; p < .001), while there was no significant difference in standard training outcomes for breathing volume between the first VR (M = 0.88, SE = 0.15) and the first standard training-sequence (M = 1.17, SE = 0.15; p = .179).

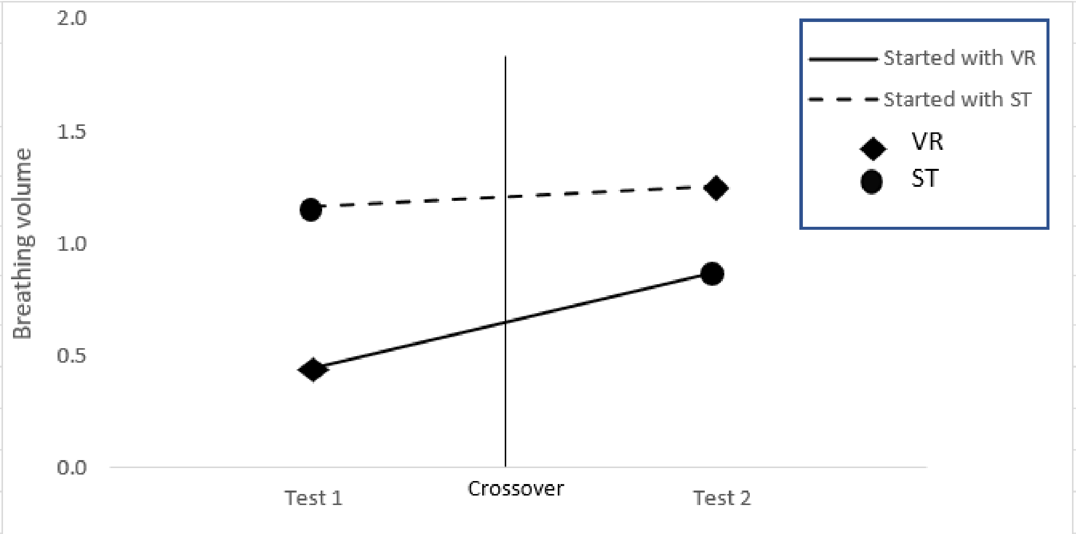
Table 16:

Results of the two-way mixed ANCOVA on Breathing volume

	Breathing volume			
	VR first		ST first	
training type	*M*	*SD*	*M*	*SD*
VR	0.44	0.63	1.26	0.76
standard training	0.88	0.71	1.18	0.84
Effecten	*df*	*F*	*p*	η^2_p
Training type	1,45	0.63	.431	.014
Sequence	1,45	11.71	.001	.207
Sequence*training type	1,45	4.43	.041	.090
Pretest*training type	1,45	0.41	.526	.009
Pretest	1,45	10.14	.003	.184

In Figure 10 the average breathing volume is shown per training type and per group. In test 1 the VR training resulted in a significantly lower breathing volume than the ST training (*M* = 0.48, *SD* = 0.68 vs *M* = 1.18, *SD* = 0.84; *t*(48) = -3.22, *p* = .002. Although the VR first group (*M* = 0.86, *SD* = 0.70) still showed lower breathing volume in test 2 than the ST first group (*M* = 1.26, *SD* = 0.76) the difference was no longer significant, *t*(47) = -1.93, *p* = .060.

Figure 10



To conclude this section, table 17 shows the answers for Overall Achievement and per skill on both sub-questions.

Table 17:

Answers to both sub-questions

	training most effective in learning to apply CPR skills	**which sequence of types of training is most effective?**
Overall Achievement	standard training more effective in the VR first group	no difference
ECC	no difference	no difference
Compression depth	no difference	no difference
Handposition	no difference	no difference
Leaning	no difference	no difference
Ratio compression/breathings	no difference	no difference
Breathing frequency	the standard training is more effective than the VR training in the VR first group	no difference
Breathing volume	the standard training is more effective than the VR training in the VR first group	First standard training sequence resulted in an overall higher breathing volume

DISCUSSION, CONCLUSIONS, LIMITATIONS

This study aimed to research the effectiveness of VR with HMD compared to the standard training when teaching Police personnel to apply seven different CPR skills and overall CPR achievement. Two sub-questions were posed to answer this question: What is the effectiveness of VR training compared to the standard training concerning the different CPR skills that need to be mastered and the overall CPR achievement? And what is the influence of the sequence in which both training types are followed on mastering different CPR skills and overall CPR achievement?

EFFECTIVENESS OF THE TRAINING

When it comes to the first research question, it is found that for overall CPR achievement and for the skills breathing frequency and breathing volume, the standard training is more effective than the VR training. This difference was especially found in the group who first received the VR training and then the standard training. If the standard training was given first, the VR training did not have much added value in terms of the Overall Achievement and skills scores. After both pieces of training were followed, the end result was in the form of Overall Achievement, and six of the seven skills were comparable between both sequences. Only for breathing volume, the sequence that started with standard training appeared more effective than the sequence in which the virtual reality training was followed first.

No differences in effectiveness in learning to apply the CPR skills were found when the training in VR and the standard training are compared regarding the skills ECC, Compression depth, Hand position, Leaning, and Ratio. Overall CPR achievement and the skills breathing frequency and breathing volume are learned most effectively after respondents followed the standard training. Based on the literature (Nas et al., 2019), it was expected that ECC and overall CPR achievement would show no difference between VR and standard training but that the skill compression depth would be less effective after training in VR. No comparable research has yet been conducted on the other skills. Explanations for the differences with the literature could be that the number of respondents was higher (N = 283) in the study by Nas et al. (2019) versus 50 in this study. And, because the study by Nas et al. (2019) showed an inferior score for compression depth, we decided to put more attention to the correct compression depth in our VR intervention; a message was integrated into the VR app of the current study that warned respondents to give the compressions deep enough, i.e., 5 to 6 cm. This particular type of clue, called the signaling technique (Mayer, 2014), was not included in an earlier study and may explain the difference in outcomes on compression depth between the findings of Nas et al.

(2019) and this study. Finally, the difference with the literature may be because the VR app in this study showed a more natural environment with a higher degree of simulation (Martin et al., 2014). The training in VR was a three-dimensional experience for the respondents that required more interaction than was the case with the lifesaver app used in previous studies (Yeung et al., 2017).

The desire is to ground theoretical implications in the literature, however, little has been standardized; Firstly, the currently included skills are new in research in the field of VR and CPR, but the motor skills of VR, in particular, are rare outside the field of CPR. As Radianti (2020) points out, most VR applications in education aim to teach procedural–practical knowledge, declarative knowledge and analytical and problem-solving skills, communication, collaboration, and soft skills. Secondly, in the studies that do exist, attention is paid to the medical aspects and compression rate and depth, but not to the underlying educational explanations. It is not that there is little to be found about this; it seems completely absent. Suppose you would rather leave the path of CPR and zoom in on VR in education. In that case, Radianti (2020) says: 'the literature which claims to create VR content or design VR applications for education surprisingly lacked reference to explicit learning theories.'

THE EFFECT OF SEQUENCE.

This study shows that the sequence of standard training first and training in VR afterward is most effective, but only for breathing volume. The attendees of the training sequence standard training – virtual reality training showed a higher level of breathing volume after the first training and maintained their advantage after the second training. Regarding overall CPR achievement, ECC and breathing frequency, there was a difference between the police employees who started with the standard training and those who started with the VR training, but after both pieces of training were followed, both sequences resulted in comparable skill levels. On the other five skills, no differences were found in effectiveness based on the order in which the training courses are followed. The question regarding the most effective sequence of types of training has not previously been examined in the literature to the author's best knowledge (Zheng et al., 2022).

It is striking that little research has been done into the most effective way or the most effective sequence of CPR training, in which the standard CPR training is compared with training in VR. Furthermore, the research that has been done has only compared results of a small number of CPR skills. Both Ali et al. (2021) and Zheng et al. (2022) argued for greater standardization in conducting research. When the set-up of studies is more standardized concerning mapping the training types, the way the content is based on guidelines, and the

number of CPR-related skills researched, the comparison between studies becomes easier, and more concrete conclusions can be made. Looking at the contents of this study, it can be concluded that the standardization criteria of Ali et al. (2019) and Zheng et al. (2022) are met.

As the explanations for the findings on sequence can not be found in the literature, the best guess for the findings that show equal results for both VR and the standard training is that the VR training is well designed, closely following the guidelines.

CHOOSING THE TYPE OF CPR TRAINING

The results of this research concern the most effective way of training CPR skills and the best type of training to use for the police department in the Netherlands. The work of Martin et al. (2014) also takes this perspective in their research and highlights several other considerations to arrive at an optimal choice for a type of training. A comparison is shown in table 18 on the average VR and standard training on the seven criteria given by Martin et al. (2014), explaining why organizations would choose either one.

Table 18.

Criteria per training type regarding the policy of the Rotterdam Police

criteria	**training in VR with HMD**	**Standard training**	**best option**
Learning modality	Doing	Doing	VR
training environment	Natural and simulated	simulated and contrived	VR / standard
trainer presence	No	Yes	VR
proximity	Distance	Face to Face	VR
interaction level	Interactive	Interactive	VR / Standard
cost considerations	initially high, then low	High	VR
time demands	moderate	moderate	VR

Looking at the policy of the Rotterdam Police, this research, and the perspective of Martin et al. (2014), it can be concluded that also as a training type, VR training can be a good option to keep staff trained based on CPR skills: the training environment is as natural as possible which is an advantage compared to standard training, the initial costs have already been incurred, it now only requires further development; because no trainer presence and proximity are required, deploying the VR training makes training staff a lot more flexible. These arguments are in line with the policy of the police. However, it is found that some skills are less effectively trained in the VR training than in de standard training. This would suggest that it may not be justified to completely switch to VR training just yet but have employees take the standard training first and then the VR training to keep up the CPR skills.

Ali et al. (2021) suggested that future research into alternatives to standard training could improve compression depth and correct hand position. However, this study shows that VR training is as effective as the standard training regarding these skills. Additionally, scientific relevance is that compared to the Overall Achievement, not 'just' two but five additional skills have been objectively measured by the manikin software. In particular, the skills Breathing volume and Breathing frequency fit within an important part of the six actions of Basic Life Support. This opens the possibility of measuring more widely than has been done until now.

LIMITATIONS

The results of this study may be slightly biased in the three variables, hand position, leaning, and ratio. This is because they are ordinal variables which means they are not optimal for the used analyses (ANCOVA). They may have been better analyzed using a chi-square test (Field, 2013). However, as a mixed approach for ordinal data (comparable to the mixed ANCOVA) is more complex, it was decided it would be beyond the scope of this study to engage in those statistical analyses. Also, the results could be better compared using the same analysis method for all CPR skills. In addition, all these skills are part of calculating the overall CPR achievement score. Therefore, by calculating them in this way, they fit better in the entire analysis.

Furthermore, the training in VR was the first release of the VR program, while the standard training was already a highly developed training performed by experts from the Dutch Resuscitation Council. This makes it rather interesting that VR training is not inferior to the standard training on many skills and suggests that VR as a training method for CPR skills may have a promising future.

Finally, the number of respondents was smaller than intended due to the Covid-19 pandemic. Still, the results of the study overall agree with most other studies in terms of size. Only Nas et al. (2019) did a more extensive investigation, which is an exception in the field (Zheng et al., 2022).

RECOMMENDATIONS

In this section, the recommendations are made based on the results and conclusions for further research, the HR department of the PDC, and the VR training.

Regarding further research, it is recommended to repeat the study among a larger group of police employees when there are no Covid-19 restrictions to see the effects of the standard and virtual reality training compared to the current findings. As this study has many firsts, it makes sense to investigate it more broadly, especially when the VR training has been further developed. Furthermore, this study used several skills that the manikin of AMBU can objectively determine. These objectified skills could be added to the standardization that Zheng et al. (2022) have suggested, along with the maturation process in which the CPR training through VR evolves. This could complement or replace the 'secondary outcomes' described in their research proposal. Lastly, this study fits the design of Zheng et al. (2022), namely, randomized controlled cross-over trials, assessing the efficacy of VR techniques versus the standard training for adult participants accepting adult CPR training. Therefore, it will be interesting to compare the findings of this study with those of Zheng et al. (2022) expected this year. Additional research must be designed to fit these standards and examine multiple objectifiable skills. However, currently, there are studies developed in which VR is built into the measuring tools, namely the manikins. This way, trainees receive real-time feedback, which enables a lot of repetition until skills are mastered (Zheng et al., 2022) (Semeraro et al., 2019) (Issleib et al., 2021a). As mentioned earlier, this is beyond the scope of this study.

The question of HR of the PDC was how to organize time and cost-effective, place independent learning in frequently attended training types. The research has shown that the effectiveness of learning to apply CPR skills on five of seven skills, VR training does not differ from the standard training, and in two skills and overall CPR achievements, there are indications that the standard training is preferred if only one training can be followed. If both training types can be followed, the order in which the training sessions are taken falls in favor of the standard training first in Overall Achievement, breathing frequency, and breathing volume. The recommendation is to use the VR app after the standard training to keep the skills up to standard. For maintaining psychomotor skills based on cognitive skills, it is crucial that one can repeat the skill until it is fully trained. The availability of the VR training on the app makes more frequent training sessions to keep learned skills up to date possible (Radianti et al., 2020).

Regarding the VR training, this is already functioning reasonably well. However, it is still in its infancy because it was the first release. The recommendation is to develop the VR training further. It is important to do this together with the target group. Their learning styles and wishes are essential in facilitating their learning process, as Martin et al. (2014) reported. It seems essential to pay specific attention to the proper set-up of the breathing section during further development of the VR training.

This research has shown that this first release of the VR training is already a good option to learn to apply CPR skills.

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APPENDIX A: TABLE FROM ALI ET AL. (2022)

Table 3 Summarized findings of included CPR training methodology research articles

Year and Country	Intervention Tested	Study Design	Sample Size	Target Group	Prior Training	Outcome Measures	Key Findings
Standard versus Non-standard Face to Face CPR Training							
Singapore 2018 [19]	Simplified vs. standard CPR	Randomized Controlled Trial	85	Layperson	No	CPR quality	Simplified CPR group followed algorithm better ($p < 0.01$), had higher number and proportion of adequate compressions ($p < 0.01$), and had shorter hands-off time ($p < 0.001$).
Germany 2015 [20]	Peer-instructor vs. professional instructor	Randomized Controlled Trial	1087	School Children	No	CPR performance	Similar CPR performance between groups (40.3% vs. 41.0%).
Belgium 2016 [21]	Peer-based (jigsaw model) vs. expert instructor	Randomized Controlled Trial	137	School Children	No	CPR performance	All groups met European Resuscitation Council 2010 guideline. Chest compression depth different between ventilation vs. compression group ($p < 0.01$).
Austria 2013 [22]	Flowchart supported training	Randomized Controlled Trial	83	Layperson	No	CPR performance and quality	Flowchart group showed shorter hands-off time (147 s vs. 169 s, $p = 0.024$) and more confidence (7 vs. 5, $p = 0.0009$) but had longer time to chest compression (60s vs. 23 s, $p < 0.0001$).
UK 2001 [23]	Three-stage vs. conventional training	Randomized Controlled Trial	495	Layperson	No	CPR quality and knowledge	In first 8 min, using 50:5 ratio, 58% more compressions can be made. Staged group had better 'shout for help' after 2 months ($p = 0.02$ to $p < 0.01$) and adequate compressions after retraining ($p = 0.05$) and at 4 months ($p = 0.04$).
Korea 2015 [24]	Peer-assisted learning vs. professional instructor training	Prospective Case-Control Study	187	High-school Students	No	CPR performance and knowledge	No difference in willingness to perform CPR (64.7% vs. 55.2%, $p = 0.202$) and knowledge retention (61.76 ± 17.80 vs. 60.78 ± 39.77, $p = 0.848$) between peer-assisted and professional instructor groups.
Standard versus Hybrid CPR Training							
Japan 2017 [25]	Coventional vs. flipped learning	Interventional Study	108	Medical Students	No	CPR quality	No difference in time to first chest compression (33 s vs. 31 s, $p = 0.73$) or number of chest compressions (101.5 vs. 104, $p = 0.75$).
USA 2019 [26]	Traditional vs. video-only vs. video + hands-on session at a Kiosk	Randomized Controlled Trial	738	layperson	No	CPR performance and quality	After the initial education session, the video-only group had a lower total score (compressions correct on hand placement, rate, and depth) (−9.7; 95% confidence interval [CI] -16.5 to −3.0) than the classroom group. There were no significant differences on total score between classroom and kiosk participants.
USA 2006 [27]	Interactive-computer training and interactive-computer training plus instructor-led (hands-on) practice vs. traditional training	Cluster Controlled Trial	784	High School Students	No	CPR performance and knowledge	For all outcome measures mean scores were higher in the instructional groups than in the control group. Two days after training all instructional groups had mean CPR and AED knowledge scores above 75%, with use of the computer program scores were above 80%.
Standard versus Online CPR Training							
USA	Heartsaver CPR training	Prospective	89	Incoming	No	CPR	VSI trainees displayed superior

Table 3 Summarized findings of included CPR training methodology research articles *(Continued)*

Year and Country	Intervention Tested	Study Design	Sample Size	Target Group	Prior Training	Outcome Measures	Key Findings
1998 [28]	(traditional) vs. video self instruction	Randomized Controlled Trial		Freshmen Medical Graduates		performance	overall performance compared with traditional trainees. Twenty of 47 traditional trainees (43%) were judged not competent in their performance of CPR, compared with only 8 of 42 VSI trainees (19%; absolute difference, 24%; 95% confidence interval, 5 to 42%).
USA 2009 [29]	Traditional (group 1) vs. online (group 2 - computerized module with video) version	Randomized Controlled Trial	64	Undergrad Freshmen	No	CPR quality and knowledge	On the standardized knowledge examination and skill performance evaluation, Group 2 scored lower than Group 1; however, no statistically significant difference between the groups existed. MANOVA indicated there was a significant difference in the quality of CPR compressions (location, rate, depth, and release), ventilation rate and volume.
USA 2016 [30]	Brief video vs. traditional training	Cluster Randomized Trial	179	School Children	No	CPR quality	At post-intervention and 2 months, BV and CCO class students called 911 more frequently and sooner, started chest compressions earlier, and had improved chest compression rates and hands-off time compared to baseline.
USA 1999 [31]	Video self instruction vs. traditional CPR training	Randomized Controlled Trial	190	Layperson	No	CPR performance and knowledge	VSI trainees displayed a comparable level of performance to that achieved by traditional trainees. Observers scored 40% of VSI trainees competent or better in performing CPR, compared with only 16% of traditional trainees (absolute difference 24, 95% confidence interval 8 to 40%).
Korea 2011 [32]	Video based vs. traditional training	Single-Blind Case-Control Study	75	Students	No	CPR performance	Three months after initial training, the video-reminded group showed more accurate airway opening ($P < 0.001$), breathing check ($P < 0.001$), first rescue breathing ($P = 0.004$), and hand positioning ($P = 0.004$) than controls. They also showed significantly higher self-assessed CPR confidence scores and increased willingness to perform bystander CPR in cardiac arrest than the controls at 3 months ($P < 0.001$ and $P = 0.024$, respectively).
USA 2010 [33]	HeartCode™BLS with VAM vs. instructor-led training	Randomized Controlled Trial	604	Nursing Students	No	CPR quality	No difference in compression rate between groups. HeartCode™BLS with VAM group had more compressions with adequate depth and correct hand placement, and had more ventilations with adequate volume.
Spain 2013 [34]	Voice Advisory Mannequin vs. instructor training	Randomized Controlled Trial	43	Medical Students	No	CPR performance	VAM group performed more correct hand position (73% vs. 37%, $p = 0.014$) and had better compression rate (124/min vs. 135/min, $p = 0.089$). Women in VAM group showed improvement in compression depth (36 mm to 46 mm, $p = 0.018$) and percentage of insufficient compressions (56 to

Table 3 Summarized findings of included CPR training methodology research articles *(Continued)*

Year and Country	Intervention Tested	Study Design	Sample Size	Target Group	Prior Training	Outcome Measures	Key Findings
							15%, $p = 0.021$) after training.
India 2019 [35]	Video-based CPR training vs. instructor based CPR training	Randomized Controlled Trial	109	Undergrad University Students	No	CPR performance	Video-based group performed better scene safety (95.2% vs. 76.1%) and call for help (97.6% vs. 76.1%) than the instructor-based group ($p < 0.05$). Moreover, the video-based group had shorter response to compression time (35 ± 9 s vs. 54 ± 14 s) as compared to the instructor-based group ($p < 0.001$).
Denmark 2006 [36]	DVD-based self training vs. instructor training	Interventional Study	238	Layperson	No	CPR knowledge	After 3 months, no significant difference in total scores of CPR performance between groups. The instructor group had better score in assessment of breathing (91% vs. 72%) as compared to the DVD-based group ($p = 0.03$). However, DVD-based group had better average inflation volume (844 ml vs. 524 ml, $p = 0.006$) and chest compression depth (45 mm vs. 39 mm, $p = 0.005$).
Netherland 2020 [37]	Virtual reality CPR training vs. face-to-face CPR training	Randomized Controlled Trial	381	Layperson	No	CPR performance	The VR group was inferior to face-to-face training in chest compression depth (49 mm vs. 57 mm), chest compression fraction (61% vs. 67%, $p < 0.001$), proportion of participants fulfilling depth (51% vs. 75%, $p < 0.001$), and rate requirements (50% vs. 63%, $p = 0.01$), but superior in chest compression rate (114/min vs. 109/min) and compressions with full release (98% vs. 88%, $p = 0.002$). The VR group had lower overall scores (10 vs. 12, $p < 0.001$) as compared to the face-to-face group.
USA 2007 [38]	Video self-training vs. instructor training	Randomized Controlled Trial	285	Layperson	No	CPR performance and knowledge	Immediately post-training, video group had higher scores in overall performance (60% vs. 42%), assessing responsiveness (90% vs. 72%), ventilation volume (61% vs. 40%), and correct hand placement (80% vs. 68%) but lower scores in calling 911 (71% vs. 82%). At 2 months post-training, video group had higher scores in overall performance (44% vs. 30%), assessing responsiveness (77% vs. 60%), ventilation volume (41% vs. 36%), and correct hand placement (64% vs. 59%) but lower scores in calling 911 (53% vs. 74%).

APPENDIX B: AMBUMAN DEBRIEFING CALCULATION SPECIFICATION

AmbuMan Debriefing Calculation Specification

DEBRIEFING CALCULATIONS

A ventilation is detected when the ventilation sensor reaches a value equal or larger than 0.5 L and then moves down to 0.35 L or below.
If the stomach inflation sensor has been activated at any time between the top point and the bottom point, the ventilation is marked with stomach inflation.
Ventilation cycles are separated if the time between two ventilations are larger than 5 seconds.

A compression is detected when the compression sensor reaches a value of 10 mm or above and the moves down to 1/3 of the top point of the compression.
If the wrong hand position sensor has been activated at any time between the top point and the bottom point, the compression is marked with wrong hand position.
If the value at the end of the compression is larger than 5 mm, the compression is marked with leaning.
Compression cycles are separated if the time between two compressions are larger than 2 seconds.

Ventilation minute volume

Ventilation minute volume is only calculated if trainee has been in charge of doing ventilations during the session.

A: number of ventilations with volume within the boundaries of the selected algorithm and without stomach inflation sensor activated.
B: number of all ventilations without stomach inflation sensor activated. T: total time in minutes the trainee was in charge of doing ventilations.

$Ventilation\ minute\ volume =$

$$A + B$$

T

Cardiac output volume

Cardiac output volume is only calculated if trainee has been in charge of doing compressions during the session.

A: number of compressions with depth above the minimum boundary of the selected algorithm and without wrong hand position sensor activated.
B: number of all compressions without wrong hand position sensor activated. C: number of all compressions.
T: total time in minutes the trainee was in charge of compressions.

$$Cardiac\ output\ volume = \frac{0.03 \cdot A + 0.01 \cdot B + 0.001 \cdot C}{T}$$

Ventilation rate

Ventilation rate is only calculated if trainee has been in charge of doing ventilations during the session.

A: number of ventilations with volume within the boundaries of the selected algorithm and without stomach inflation sensor activated.
B: number of all ventilations without stomach inflation sensor activated. T: total time in minutes the trainee was in charge of doing ventilations.

$$Ventilation\ rate = \frac{A + 0.5 \cdot B}{T}$$

Ventilation volume

Ventilation volume is only calculated if trainee has been in charge of doing ventilations during the session.

A: sum of the value of all ventilations without stomach inflation sensor activated. B: sum of the value of all ventilations.

$$Ventilation\ volume = \frac{A}{B}$$

Stomach inflation

Stomach inflation is only calculated if trainee has been in charge of doing ventilations during the session.

A: number of ventilations with stomach inflation sensor activated.

$$Stomach\ inflation = A$$

ECC rate

ECC rate is only calculated if trainee has been in charge of doing compressions during the session.

A: number of compressions with depth within the boundaries of the selected algorithm and without wrong hand position sensor activated.
B: number of all compressions without wrong hand position sensor activated.
T: total time in minutes the trainee was doing compressions. The time between compression cycles are not included.

$$ECC\ rate = \frac{A + B}{T}$$

Compression depth

Compression depth is only calculated if trainee has been in charge of doing compressions during the session.

A: sum of the value of all compressions. B: number of all compressions.

$$Compression\ depth = \frac{A}{B}$$

Pause between compressions

Pause between compressions is only calculated if trainee has been in charge of doing compressions during the session.

A: sum of the time between all compression cycles. B: number of compression cycles.

$$Pause\ between\ compressions = \frac{A}{B}$$

Compression relax ratio

Compression relax ratio is only calculated if trainee has been in charge of doing compressions during the session.

A: sum of all compressions compressing time. B: sum of all compressions releasing time.
C: number of all compressions.

$$factor = \frac{100}{\frac{A}{C} + \frac{B}{C}}$$

$$Compression\ relax\ ratio = \left(\frac{A \cdot factor}{C}\right) / \left(\frac{B \cdot factor}{C}\right)$$

Wrong hand position

Wrong hand position is only calculated if trainee has been in charge of doing compressions during the session.

A: number of compressions with wrong hand position.

$$WWrong\ hand\ position = A$$

Leaning

Wrong hand position is only calculated if trainee has been in charge of doing compressions during the session.

A: number of compressions with leaning.

$$Leaning = A$$

Compression/ventilation ratio

A: number of all compressions where the trainee was in charge of either compressions or ventilations.
B: number of compression cycles where the trainee was in charge of either compressions or ventilations.
C: number of all ventilations where the trainee was in charge of either compressions or ventilations.
D: number of ventilation cycles where the trainee was in charge of either compressions or ventilations.

$$Compression\ ventilation\ ratio = \frac{A}{B} / \frac{C}{D}$$

Hand off time

A: total time no compressions are performed.

$$Hand\ off\ time = A$$

Time to defibrillation

A: sum of the time between all defibrillations and their previous compression. B: number of defibrillations.

$$Time\ to\ defibrillation = \frac{A}{B}$$

Total score

The total score is calculated as a total percentage from all enabled parameters in the configuration. Pseudo code is explaining the algorithm below.

```
total_score = 0
max_score = 0

loop through all parameter scores:
    if parameter is enabled in
        configuration: total_score +=
        parameter score max_score += 10

return total_score/max_score * 100
```

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