Teach me CPR now!

Augmented Learning for One-Shot Teaching of Cardiopulmonary Resuscitation in Out-of-Hospital Cardiac Arrest

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Abstract

We propose a Virtual Reality (VR) solution for teaching Cardiopulmonary Resuscitation (CPR) in a dispatcher assisted scenario where the learner learns how to perform CPR in a single attempt. The goal of this research is to make it easier for a bystander to learn to perform CPR and to help improve the quality of CPR. The system that we created is called Augmented Reality CPR or ARC. Using immersive VR, the dispatcher is virtually present at the location where the victim and the bystander are. The bystander wears a Hololens that projects the dispatcher's representation over the real world. The dispatcher can use their hands and visual aids to help with giving instructions and feedback to the bystander. An experiment with 58 participants was conducted to compare ARC to the current way CPR is taught to bystanders, namely over the telephone. Participants of the experiment had to perform three different tasks; a chin lift, chest compressions and rescue breaths. The last two tasks were repeated eight times. Our findings support that ARC can make learning CPR easier for the bystander and we see an improvement in CPR quality when using ARC instead of a telephone. We found that ARC lowers the *Mental Demand* that the bystander perceives while learning CPR. We also found an increase in *Perceived message understanding* for the bystander. For the CPR quality aspect we looked at the chest compression task and found that ARC improves the compression depth and the hand position, while the compression rate is unchanged and the number of compression interruptions doesn't increase.

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Chapter 1

Introduction

You are walking down the street in a hurry because you're late. Someone is walking on the sidewalk before you and suddenly collapses. You look around in panic, but there is no-one around to help. You kneel down next to him and shake his shoulders, he is not responding. It looks like he is not breathing and you don't know what to do. You quickly call the emergency services using your smart glasses. A dispatcher answers the call and virtually appears before you. The dispatcher sees the victim and calms you down. The dispatcher shows you how to perform CPR using hands and helpful instruction videos. You feel you are not alone in facing this stressful situation and with the instructions and feedback from the dispatcher you perform high quality CPR until help arrives.

In the Netherlands, annually 7000-8000 cases of cardiac arrest occur outside of a hospital of which 77% cases don't survive (Bots, Buddeke, Dis, Vaartjes, & Visseren, 2017). Immediate action, eg. bystander CPR, can double or even quadruple the survival chances of cardiac arrest victims (Waalewijn, Tijssen, & Koster, 2001), (Valenzuela, Roe, Cretin, Spaite, & Larsen, 1997), (Holmberg, Holmberg, Herlitz, Gårdelöv, et al., 1998). Factors that are associated with successful bystander CPR are; the interval between the collapse and the start of bystander CPR, the quality of bystander CPR, whether or not the bystander is a layperson, the interval between collapse and the arrival of the ambulance, age and the place of arrest (Holmberg, Holmberg, & Herlitz for the Swedish Cardiac Arrest Registry, 2001). The first mentioned factor is the most important, therefore bystanders should always attempt to perform CPR even if they have no prior CPR training. Once the bystander has called the emergency services the only factors they can influence are the interval between the collapse and the start of bystander CPR and the quality of bystander CPR. The bystander must therefore start CPR immediately after calling the emergency services. If they do not know how, they are taught to do so as quickly as possible by the dispatcher, so called one-shot dispatcher assisted CPR or telephone-CPR. Dispatchers can help the bystander by verbally explaining how to perform CPR and talk them through the various steps. If the bystander already knows how to perform CPR, the dispatcher can help to maintain the correct tempo and the right amount of compressions and breaths. The quality of CPR outside

of hospitals is also not as good as it can be (Wik et al., 2005). Good quality CPR is important as it directly relates to higher survival rates (Abella et al., 2005), (Stiell et al., 2012). Dispatchers can help with reaching good quality CPR, but are limited in their ability to do so because they can only use verbal communication. This limits the dispatcher in two ways: 1) The only way to gather information about the state of the victim is to ask the bystander. 2) The dispatcher must give instructions and feedback verbally, which limits how well information can be conveyed. Solving these problems might decrease the time spent to teach the bystander CPR and improve the quality of CPR.

1.1 Research questions and goal of the thesis

We propose and test a VR solution, called Augmented Reality CPR (ARC), that allows a dispatcher to be virtually present on site where a bystander needs to reanimate a cardiac arrest victim. With the proposed solution communication is not limited to verbal communication only; the dispatcher has eyes on both the bystander and victim. Furthermore, the bystander can see a virtual representation of the dispatcher.
We used the following research questions to structure our investigation about how to create a VR solution for one-shot teaching dispatcher assisted CPR and compare it to the current solution used in practice:

RQ1 *How to create a VR application for one-shot teaching dispatcher assisted CPR?*

To answer the first main research question, a number of sub questions are constructed to to determine the context and give background information about CPR:

- **RQ1.1** What is CPR?
- **RQ1.2** What are existing VR systems for teaching CPR?

The first subquestion is answered by a literature study, talking to CPR instructors and observing CPR courses. Section 2.1 gives a detailed description of CPR, what determines the quality of CPR and how a regular CPR course is built up. Using VR for training CPR has the potential to open up new ways of learning (Zajtchuk & Satava, 1997), therefore we take a look at existing VR applications that focus on teaching CPR. This answers the second sub research question in section 2.2.
The third subquestion determines the purpose of the proposed VR solution:

- **RQ1.3** What is the best scenario for teaching CPR with a VR telepresence system?

The third subquestion is answered by a literature study. Chapter 3 describes a theory that can be used to enhance teaching CPR. The theory is used in section 4.2 to find a CPR learning scenario that can benefit the most from the principles of this theory. The choice for a CPR scenario also takes into account the immersive virtual reality system called "OpenIMPRESS" upon which ARC is built; this system is described in section 4.1.2. The chosen scenario is the basis for designing a CPR application with the goal to enhance learning CPR.
The next subquestions are about system design and implementation:

- **RQ1.4** What are the requirements for a VR application used to enhance one-shot teaching of dispatcher assisted CPR?
- **RQ1.5** What technology can be used for implementation?
- **RQ1.6** How to design an interface for the CPR instructor?

An overview of system requirements is given in section 4.4. To meet these requirements the proposed VR solution depends on a number of technologies, which are described in section 4.1. How these technologies are used to design the VR solution is described in chapter 5.
The second main research question aims to evaluate the VR solution:

RQ2 *How does ARC compare to telephone-CPR?*

- **RQ2.1** What kind of instructions and feedback can the dispatcher give using ARC?
- **RQ2.2** How does ARC influence the perceived task load when learning CPR in a dispatcher assisted scenario?
- **RQ2.3** How does ARC influence the social presence of the dispatcher for the bystander when learning CPR in a dispatcher assisted scenario?
- **RQ2.4** How does ARC influence the CPR quality performed by the bystander when learning CPR in a dispatcher assisted scenario?

The second main research question and its subquestions are answered with a quantitative user study in chapter 6. An experiment is done to find out how ARC compares to current telephone-CPR, regarding perceived task load, social presence and CPR quality.
The goal of this research is to design a system that could improve the learning of one-shot dispatcher CPR and investigate if the bystander can actually learn CPR easier with higher quality CPR compared to dispatcher assisted telephone-CPR. We try to improve learning by replacing the telephone with the ARC system. Improved learning means that the quality of CPR increases faster and/or more compared to dispatcher assisted telephone-CPR. Also the quality of CPR should be better maintained over time. Expected is that ARC creates new possibilities for giving instructions and feedback in dispatcher assisted CPR and that it improves the learning of the bystander.

Chapter 2

Background

To understand how VR can be used to improve teaching CPR, it is necessary to first understand what CPR is and how CPR is taught. Also examples of current VR solutions about to teaching CPR are given to get a better understanding of what the benefits of VR are for teaching CPR and how these are already used.

2.1 Cardiopulmonary Resuscitation

This section gives a detailed description of CPR, the determining factors for the quality of CPR and how CPR is taught.
Cardiopulmonary Resuscitation or CPR for short, means taking over the functions of the heart and lungs of a person. CPR is usually applied to a person who is in cardiac arrest, which is the loss of blood flow due to ineffective pumping of the heart, but it is recommended to apply it to any person who is unconscious and not breathing or breathing abnormally (Atkins et al., 2015) and (Perkins et al., 2015). CPR consists of chest compressions optionally combined with rescue breaths. The chest compressions take over the function of the heart, supplying a small but critical blood flow to vital organs such as the heart and brain. Rescue breaths can re-enrich the blood with oxygen prolonging the effective CPR time. The goal of CPR is not to restart the heart, but to keep the vital organs alive while appropriate action is taken to reestablish an effective heart rhythm. The heart rarely restores after just CPR, usually a shock from a device like an Automated External Defibrillator (AED) is needed to stop the heart from fibrillating and giving it a chance to reestablish an effective rhythm.
The European Resuscitation Council (ERC) gives action guidelines for what to do when a person in unconscious and not breathing normally. These are the steps that are also being thought at CPR courses and can be observed in Figure 2.1. It is important to always call the emergency services first, so help can be dispatched immediately. A trained person can start CPR and a lay person can be talked through giving chest compressions, usually without giving rescue breaths in between. When rescue breaths are given it is at a ratio of two breaths after every 30 chest compressions, so called 30:2 CPR. When an AED arrives it should be switched on immediately while CPR contin-

ues. CPR should only be interrupted by the AED when performing heart analysis or giving a shock. CPR should continue until the victim regains consciousness or is declared dead. A bystander almost always needs to continue until help arrives and can take over.

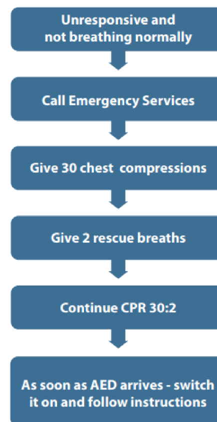


Figure 2.1: Flow of actions for Basic Life Support. Taken from (Perkins et al., 2015).

2.1.1 Quality of CPR

This section gives an overview of the factors that determine the quality of CPR. The quality of 30:2 CPR without AED can be divided into two parts, first the quality of chest compressions and secondly the quality of breaths. Combined they determine the overall quality which directly relates to survival chance (Abella et al., 2005). The determining factors are taken from the ERC based on their latest guidelines from 2015 (Perkins et al., 2015).
The quality of chest compressions depends on eight main factors:

- Compression rate (100-120 min^{-1})
- Depth (5-6 cm)
- Recoil of chest (full recoil)
- Interruptions (minimal hands-off time)
- Position of the hands (centre of the chest, between the breasts)
- Duty cycle (50%)
- Surface (firm)
- Technique (stretched hands and arms, shoulders above hands)

Compression rate The rate at which the chest is compressed at any one time, this is not calculated over a period of time. Based on two studies a compression rate of 100-120 min^{-1} gives higher survival rates compared to >140, 120,139, <80 and 80-99 min^{-1} (A. H. Idris et al., 2015) and (A. Idris et al., n.d.).

Depth A compression depth of 40-55mm results in the highest survival rate (Stiell et al., 2014). Compressions that are too shallow or deep result in an increased rate of injury, with compressions that are too shallow being considered more harmful (Hellevuo et al., 2013). Therefore the ERC has determined the ideal depth at 50-60mm.

Recoil of chest A full recoil of the chest results into higher blood return to the chest from the veins, which may improve the effectiveness of CPR (Niles et al., 2011).

Interruptions Interruptions in delivering chest compressions should be minimised. Pauses needed for rescue breaths, and other actions when using an AED, should be less than 10s (Beesems, Wijmans, Tijssen, & Koster, 2013).

Position of the hands The hand should be placed in the centre of the chest with the other hand on top. The exact location that results in the best blood flow is with the hand on the lower half of the sternum (Cha et al., 2013).

Duty cycle The ratio of the time the chest is compressed compared to the total time till the next compression. The recommended ratio is 50%, meaning the chest should be compressed half of the time during chest compressions. The duty cycle is difficult to change, as it is largely influenced by other factors such as compression rate and depth (Johnson et al., 2015).

Surface CPR is best performed on a firm flat surface. If a person in lying in bed, it is best to move the person to the floor.

Technique Good technique results in easier delivery of chest compressions, requiring less effort to reach the correct compression depth and rate. The heel of one hand is placed in the centre of the victim's chest with the heel of the other hand on top, while interlacing the fingers. Arms are kept straight with the shoulders above the hands.

The second part that contributes to the quality of CPR are the rescue breaths. These are given two times after every thirty chest compressions. Usually rescue breaths are only given by trained people, as they are more difficult to perform and are less important in the early stages (Weisfeldt & Becker, 2002). Rescue breaths are more important after a few minutes, when oxygen has depleted from the blood. It is recommended to not interrupt the chest compressions for more than 10s when performing rescue breaths. No more than two rescue breaths should be attempted every cycle, even if one was unsuccessful (Beesems et al., 2013).
The quality of rescue breaths depends on three main factors:

- Volume of breath (500-600 mL)
- Inflation duration (1s)
- Technique (chin lift, mouth seal, pinched nose)

Volume of breath Enough air to visibly rise the chest should be given to the victim each breath, this is about 500mL of air. A higher amount of air like 1L has shown to increase the airflow to the stomach, which should be avoided (Wenzel, Idris, Banner, Kubilis, & Williams, 1998).

Inflation duration Rescue breaths should not be given too quickly as this causes excessive airflow to the stomach (von Goedecke et al., 2004). Inflating the stomach can cause the victim to vomit during CPR. Too slow wastes time, therefore a single breath should take 1s.

Technique A good technique ensures that the air can easily flow to the lungs. First the airway should be cleared by performing a chin lift. With the other hand the nose is pinched closed. Lastly the mouth of the victim should be completely surrounded and sealed with the mouth.

2.1.2 Regular CPR course

Currently the conventional way to learn CPR is by following a basic CPR course that is given by one or two instructors. A CPR course can be part of a larger training such as an Emergency Response Officer training or a standalone course that takes about three to four hours total. Advanced courses are mostly directed towards medical personnel and focus on in-hospital cardiac arrest. The information in this section is based on three Dutch basic CPR courses that have been observed and interviews with two Dutch qualified CPR instructors. All courses covered the same material and contained very similar exercises. These courses follow the standard guidelines for teaching CPR set by the ERC (Greif et al., 2015) and cover the following core elements:

- Willingness to start CPR
- Recognition of unconscious abnormal breathing victims
- Good quality chest compressions and rescue breaths
- Feedback to improve skill acquisition and retention

Before learning how to perform CPR it is first discussed, in the courses, what it means to give CPR and when to give it. It is important that students understand potential (environmental) risks before they approach a victim. Next, the students learn the protocol that describes the flow of actions, as illustrated earlier in Figure 2.1. This part can be accompanied by instruction videos that are shown to the students. The first exercise practices the first set of actions, from checking for danger to checking the breathing. These actions are discussed beforehand and a chin lift is illustrated by the instructor. In this exercise the student must check for danger before approaching the victim, then try to get a response from the victim by talking and gently shaking the shoulders. If the victim doesn't respond, the student must call the emergency services and put the phone on speaker. Next the breathing is checked by performing a chin lift and listening above the mouth and nose while looking for movement in the chest. Each student has to individually perform all these actions on a CPR doll. After all students have performed

the exercise any mistakes and questions are discussed, this is done after every exercise. Next are the chest compressions and rescue breaths. The instructor first illustrates how to perform these actions separately and then repeats the first exercise followed by two cycles of compressions and breaths. Again every student repeats the example of the instructor. The instructor walks around to give feedback where required and the exercise is discussed afterwards. The last exercise is about how to use an AED. First the instructor explains how an AED works and how to use it. The instructor shows the exercise with the help of a student or second instructor. The student or second instructor repeats the second exercise while the instructor gets an AED and starts applying it while the CPR is in progress. Once the AED is operational they follow the instructions of the AED and keep performing CPR, until the AED is ready to give a shock. The exercise ends after the shock is given. All students perform the third exercise two times by switching roles. These three exercise combined with instructions, questions and discussion complete a full basic CPR course.
In the observed CPR courses three or four CPR dolls were used. Two courses used three dolls for 13 students with one instructor and the third course used four dolls for 28 students and two instructors. The dolls in the first two courses are equipped with a few basic indicators, that are used to give feedback to the instructor and surrounding students. The indicators on the CPR dolls present in the courses can be seen in Figure 2.2.

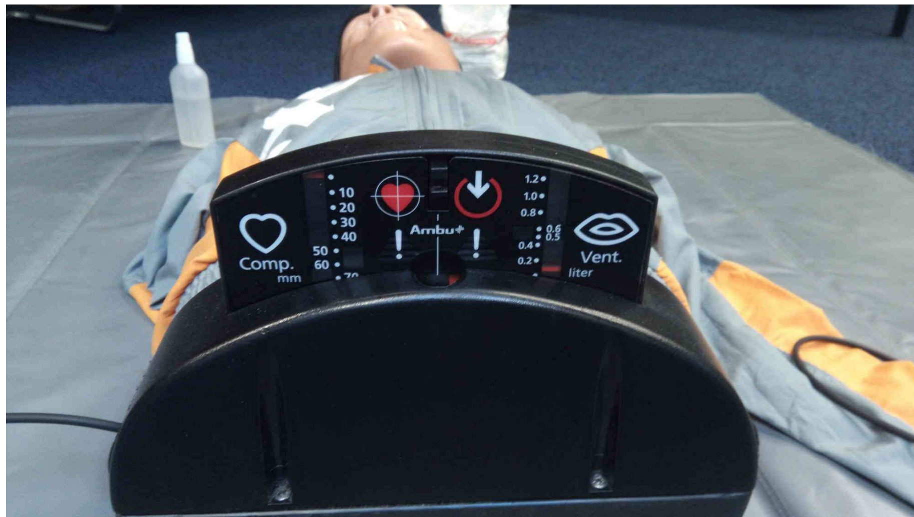


Figure 2.2: CPR doll used at a course, gives basic feedback to surrounding students about compression depth (left), hand position (middle) and volume of breath (right).

The instructor and students can easily read from this indicator if the compressions and breaths are are good or need improvements. They can use the information from the indicator to give feedback to the student. The student performing the CPR cannot see the indicators as, according to CPR instructors, this distracts them from their tasks. Too much feedback can have a negative influence on learning of the student. Making big

mistakes is easier when focusing too hard on fixing minor mistakes. According to CPR instructors, feedback should be limited to the important factors and the focus of the student should always be on the task at hand. It is recommended to have one instructor for every six students. The reason for this recommendation is so every student can receive enough personal feedback, but according to the CPR instructors this ratio is financially not achievable. The learning in a CPR course relies on examples of actions given by the instructor and feedback from the instructor and peers. A student first sees someone else performing an action and has to replicate it later. During the act a student can receive verbal feedback or be interrupted by the instructor to give feedback using their hands, like correcting the hand position by moving the students hands.

2.2 Related Work

This section explores similar research that uses VR to improve teaching CPR, like VReanimate, Holo-BLSD and CPReality. There are also some other VR systems related to teaching and CPR like: the Immersive Virtual Reality based CPR training system (Pramanik & Mannivanan, 2015) and an application that allows a real time VR experience of a resuscitation event using an iPhone (Ohley & Delgado, 2017). These will not be discussed further however, as they are not as closely related to this research.

2.2.1 VReanimate

An example of a VR application with the goal to teach about CPR is VReanimate (Blome et al., 2017). The application uses a fully immersive VR setting to give non-verbal guidance in a virtual CPR course. A pictograph language is used to explain the different tasks and ask the learner questions. The goal of the application is to teach the learner about the procedures required for performing CPR and learn to make the right decisions in a stressful scenario. The learner learns by following visual instructions and performing actions, all without the need of a real instructor. The virtual environment can be manipulated to simulate a safe tutorial or exercise setting or a more real stressful environment with darker lighting and background sounds. During the tutorial, the learner follows visual clues that give instructions of what to do next. An example of such a visual clue can be seen in Figure 2.3. The application prompts the learner to check the pulse by showing an ghost image of the controller next to the neck of the doll. When the learner moves the controller to that position a visual indicator appears showing the pulse of the doll, which can be either regular, none or irregular.

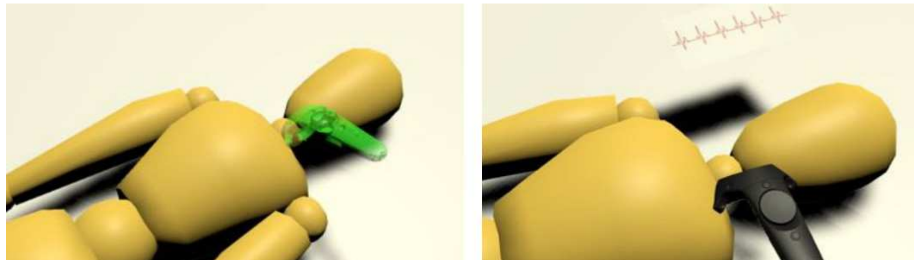


Figure 2.3: VReanimate; tutorial setting with visual instruction to check pulse. Green visual suggestion to check pulse (left), learner checking pulse with controller and receiving visual representation of a pulse (right). Taken from (Blome et al., 2017).

After the tutorial the learner can practice in the exercise setting or in a stressful scenario, see Figure 2.4. Here the doll is replaced with a more real model of a human body.
VReanimate removes the need for an instructor while teaching a learner about CPR procedures. The included stress scenario also prepares learners for the stress factors that come with a real CPR situation. This is a valuable addition to the training, as regular CPR training doesn't include practising under similar stress conditions.

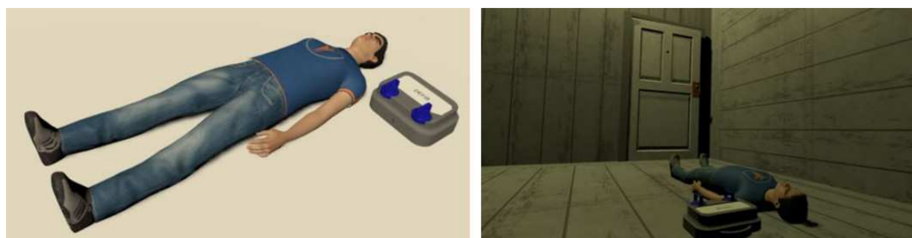


Figure 2.4: VReanimate; exercise setting (left) and stress scenario (right). Taken from (Blome et al., 2017).

However, there are also a number of limitations. Firstly, the goal is to learn about the procedures and not learn how to perform any actions by using your hands. Practising actual CPR is rather difficult in a fully immersive VR setting like in this application. The doll is virtual and can't be touched by using hands, instead controllers are used to perform the actions. This creates a difference between the learning scenario and real CPR that might make it more difficult to apply the acquired knowledge in the real world. Secondly, VReanimate suits best as a tool for learning CPR protocol and could serve as additional learning before a regular CPR course. Since there is no instructor to answer any questions, the training is limited to only the included material. The application is not a replacement for a CPR course or built to assist with a real cardiac arrest situation.

2.2.2 Holo-BLSD

Holo-BLSD is an AR solution for self-directed learning of Basic Life Support Defibrillation (BLSD) training (Bottino et al., 2018). Like VReanimate, this solution also reduces the need for an instructor by giving instructions. The main difference is that this solution is AR based and uses a physical CPR doll to provide the learner with haptic feedback. This allows the learner to perform any kind of action using their own hands. Users can learn how to perform CPR and practise on a CPR doll. If Holo-BLSD is equipped with elaborate instructions and feedback, it can replace a regular CPR course. The user can also see the effect of the chest compressions visualised by a heart and some veins, this gives feedback about the effectiveness of the chest compressions. The main difference from the system developed in this thesis is that Holo-BLSD is not suitable for dispatcher assisted CPR, as it doesn't allow for an instructor to be present from a remote location. Holo-BLSD also focuses on a CPR course scenario and not on one-shot teaching of CPR.

2.2.3 ImmERge Labs

ImmErge Labs has designed virtual and augmented reality applications with the goal to teach CPR, see Figure 2.6. One of these applications is CPReality, which has a similar approach to CPR training as Holo-BLSD, as it visualises the effectiveness of the chest compressions by projecting 3D models of the heart and veins inside the body.

Figure 2.5: Holo-BLSD; learner in front of doll wearing a Hololens (left) and doll with AR projections visible to the learner (right). Taken from (Bottino et al., 2018).

The system gives a score for the compression rate and depth and feedback on how to improve both factors. A second application is VR Sudden Cardiac Arrest (VR SCA) (Almodovar et al., 2017). This application uses fully immersive VR instead of AR. The advantage of this, is that cheap cardboard VR goggles can be used for a CPR course. The goal is to prepare CPR students better for a real-life emergency situation by making the CPR course more realistic. The victim is a virtual human that collapses on the ground, at the same location is a physical CPR doll where the student can perform CPR. Both applications are additions to regular CPR courses.

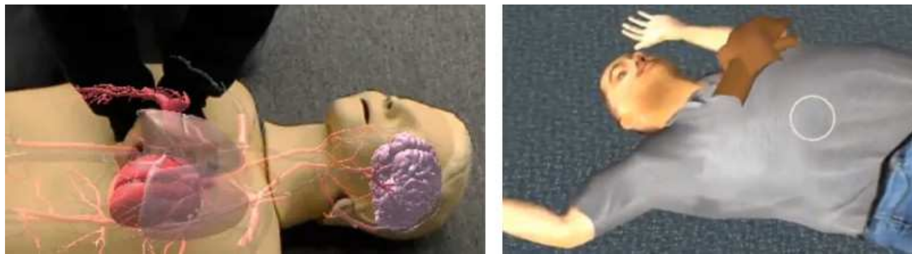


Figure 2.6: CPReality (left) and VR SCA (right); Taken from (Almodovar et al., 2017).

Chapter 3

Augmented Learning

Design choices of ARC are based on the multimedia theory described in this section. An unique quality of VR is that the technology allows to project things like objects or images anywhere in a virtual environment. Even in a real environment in case of AR. This means that information can be augmented close to the relevant object in real-time, which is called Spatial and Temporal Contiguity. Spatial and Temporal Contiguity are further explained in Section 3.1. VR learning applications can improve the learning by using these principles. In this thesis this is called Augmented Learning. How these principles can best be used for teaching CPR depends on the scenario. Therefore, first these principles will be further elaborated and then three CPR scenarios are discussed that can benefit from these principles, see section 4.2. This research focuses on a VR system that tries to enhance learning by applying the Spatial and Temporal Contiguity principles, because it explores the unique capabilities of VR and all VR learning applications can potentially benefit from this.

3.1 Spatial and Temporal Contiguity

Spatial Contiguity and Temporal Contiguity are two of the principles of Multimedia Design (R. Mayer, 2005). In this section these principles and their relation to learning are further explained.
According to the Principles of Multimedia Design, see Table 1, learners learn better when words are presented near the related image as well as at the same time (Mayer, 2001)(R. Mayer, 2005). According to Mayer, Multimedia is presenting both words and pictures (R. Mayer, 2002). Words can be both spoken and written, pictures are illustrations, photos, animation and video. These definitions of words and pictures will also be assumed for this thesis. VR makes it possible to augment information such as images together with words and also place the images next to the related object. This could enhance the learning according to the Spatial Contiguity principle. Spatial and Temporal Contiguity are also known as the Split-Attention effect (Chandler & Sweller, 1991), but will be referred to as the former.
A dynamically linked representation is when the information in multiple representa-

Principle	Description
Multimedia	Learners learn better from words and pictures than from words alone.
Spatial Contiguity	Learners learn better when corresponding words and pictures are presented near rather than far from each other.
Temporal Contiguity	Learners learn better when words and pictures are presented simultaneously rather than sequentially.

Table 3.1: Principles of Multimedia design, based on (Mayer, 2001)

tions changes together when either is changed. For example a number field on the left and an egg basket on the right, when the number is changed the amount of eggs in the basket also changes. In a static non-linked representation the number off eggs is not influenced by the number. In a complex learning environment, learners find it easier to learn with dynamically linked representations compared to static non-linked representations (van der Meij & de Jong, 2006). Especially learners that are novices on the subject have more difficulty to split their attention between multiple representations. Physically integrating multiple representations, makes it easier for the learner to interpret the similarities and differences of corresponding features (Chandler & Sweller, 1991). Integrating multiple representations corresponds with the Spatial Contiguity principle (Mayer, 2001), (R. Mayer, 2002) and (R. Mayer, 2005). Dynamic linking is also a way to make the relations between representations more explicit to the learner (Ainsworth, 1999). With dynamically linked representations, actions performed on one representation are simultaneously shown in the other representations, following the Temporal Contiguity principle. These principles can be applied to all types of learning, but will be most useful for more complex learning tasks that are limited by the cognitive process and problem solving capabilities of the brain.

3.2 Cognitive theory of multimedia learning

To better understand how the principles of Multimedia can be used to improve learning with VR, a closer look will be taken at the cognitive theory model of multimedia learning (R. E. Mayer et al., 2001), (R. Mayer, 2002) and (R. Mayer, 2005). The model is based on three primary assumptions:

- Visual and auditory experience/information comes to recipients from two different ways. This information is processed through separate and distinct information processing "channels."
- Each information processing channel is limited in its ability to process experience/information.
- Processing experience/information in these channels is an active cognitive process designed to construct coherent mental representations.

The model works as follows; words enter through both the ears and eyes channel and are processed in the verbal working memory. Pictures enter through the eyes channel and are processed in the visual working memory. Words and pictures are then organised into a verbal and visual mental model respectively. Both mental models are then integrated and combined with prior knowledge from the long-term memory, to form a final mental representation of the presented information. This process is also illustrated in Figure 3.1.

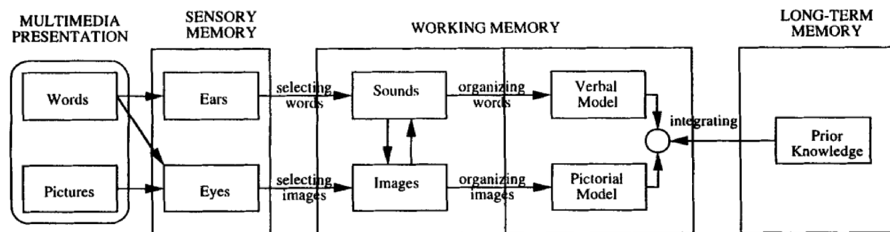


Figure 3.1: The cognitive theory of multimedia learning. Taken from (R. E. Mayer et al., 2001).

Mayer's principles of multimedia are based on this cognitive theory model. Comparing the Spatial and Temporal Contiguity principles to this model gives insight into how these principles can enhance learning. The second assumption of the model states that each information processing channel can only process a limited amount of information. Spreading out the information load over multiple channels could therefore increase the amount of information a learner can intake. This does however increase the load of the cognitive processes in the working memory (R. E. Mayer et al., 2001). Words and pictures need to be organised and integrated, if they are more relatable this will naturally be easier. Having words closer to pictures and presented at the same time, will make the words and pictures more relatable and therefore easier to process (R. E. Mayer et al., 2001), (R. Mayer, 2002) and (R. Mayer, 2005). In other words, the principles work by reducing the cognitive load on the learner, allowing the learner to learn more and easier.

3.3 Augmented Learning and CPR

The Spatial and Temporal Contiguity principles can be used to make it easier for a lay person to learn CPR. Especially in dispatcher assisted telephone-CPR, where information is given to the learner verbally. All information enters via the same channel and is therefore limited to how much information this single channel can handle. Enabling the use of pictures in dispatcher assisted CPR allows the information load to be spread out over multiple channels. AR also makes it easy to place pictures close to the related task, which reduces the cognitive load of combining information from multiple channels. AR can even go a step beyond what is possible with physical pictures, for example projecting hands exactly in the right position at the right time so the learner only needs to place their hands in the projection. This reduces the spatial and temporal

distance to an absolute minimum. Learning CPR requires multiple tasks performed by hand, which can really benefit from Augmented Learning. Especially telephone-CPR, as this currently makes no use of pictures. More people have realised the potential of AR for CPR, as is discussed in section 2.2 where other VR and AR CPR systems are described.

Chapter 4

System design

4.1 Technology

This section gives an overview of all the hardware (section 4.1.1) used in the ARC system and a description of the *OpenIMPRESS* (section 4.1.2) system that is used to achieve virtual presence of the dispatcher at the location of the bystander. In this scenario the dispatcher uses fully immersive VR and the bystander AR. A full overview of all the hardware is given in Figure 4.1.

Figure 4.1: Hardware used: 1. HTC Vive headset; 2. HTC Vive controller; 3. Leap Motion mounted on headset; 4. Kinect for Xbox One with a QR code to determine the position; 5. Hololens.

4.1.1 Software and hardware

Hololens [1] The *Hololens* is a head mounted device that can augment a virtual layer on top of the real world. Unlike fully immersive VR solutions, the *Hololens* doesn't block out the real world. This is useful if the user needs to interact with the physical world. *Hololens* is the first self-contained holographic computer and doesn't restrict the movement of the user. Depth cameras constantly map the world and combine it

[1]https://www.microsoft.com/hololens (accessed: 14-02-2018)

with data from sensors like a gyroscope and G-sensor to know its position in the world. This is so precise that augmentations stay in place, even if the user moves around. Augmentations are projected onto see-through holographic lenses with a resolution of 2.3M total light points. The user can interact with the *Hololens* using voice commands and gesture controls. Gestures are currently limited to only a bloom and tap gesture, for opening the menu and selecting respectively.

HTC Vive [2] At the date of writing the *HTC Vive* is the best room-scale commercially available immersive VR device. The headset has a 110°field of view and a combined screen of 2160 x 1200 pixels at 90Hz. Two wireless controllers with 6 degrees of freedom are also included. The headset and controllers are tracked using base stations and sensors inside, like a gyroscope and G-sensor. The base stations need to be placed in opposite sides of the room and track the devices using IR light pulses. Other well known immersive VR devices are the *Oculus Rift* and *Playstation VR*. But *Oculus Rift* lacks the same level room-scale tracking and *Playstation VR* is limited to the Playstation platform.

Unity 3D [3] The entire ARC application is created using *Unity 3D version 2017.1.1*. Unity can be used to develop VR applications with support for VR devices such as *HTC Vive* and *Hololens*. The *Steam VR plugin* [4] is needed to use the *HTC Vive* with *Unity*. For hand-tracking the *Leap Motion* is used, which requires the *Leap Motion SDK*[5] to work with *Unity*.

Kinect for Xbox One [6] *Kinect for Xbox One* is the successor of the original *Kinect*. *Kinect* is a motion sensing input device that uses depth cameras to create a coloured depth map. The most important changes to the *Kinect for Xbox One* are the improved depth camera with a 512 x 424 resolution and increased field of view of 70°horizontally and 60°vertically. The *Kinect* is used to get a coloured point cloud into the *Unity* scene, that allows the dispatcher to see detail live from the real world in a virtual 3D environment. There is a QR code on the *Kinect* that can be scanned by the *Hololens* to know its position relative to the *Hololens*. A computer vision *Unity* plugin called *Vuforia* [7] is used to for scanning the QR code. *Vuforia* can recognise images and determine the position in 3D space.

Leap Motion [8] *Leap Motion* is a small device that can easily fit on the *HTC headset*. The device is capable of smooth real-time skeleton tracking of hands. This information can be sent to *Unity* where a 3D hand model can replicate the detected motion of the hand. Hands can be detected anywhere in front of the device with a range further than arms length. In practice this means that the user must have their hands in front of their body, as the device is located a few centimetres in front of the head.

[2] https://www.vive.com (accessed: 14-02-2018)
[3] https://unity3d.com/ (accessed: 14-02-2018)
[4] https://assetstore.unity.com/packages/templates/systems/steamvr-plugin-32647 (accessed: 14-02-2018)
[5] https://developer.leapmotion.com/unity#116 (accessed: 14-02-2018)
[6] https://www.xbox.com/xbox-one/accessories/kinect (accessed: 14-02-2018)
[7] https://www.vuforia.com/ (accessed: 22-02-2018)
[8] https://developer.leapmotion.com/ (accessed: 14-02-2018)

4.1.2 OpenIMPRESS

All technologies described in the previous section are combined into one system that is developed by Harmsen (2018). OpenIMPRESS is a VR solution that allows a person to be virtually present with someone in a different location. The person on location is the On Site Operator (OSO) and can see a virtual representation of the person who is virtually present, also known as the Remote Operator (RO). The virtual environment of the RO is constructed from a 3D mesh map of a Hololens and point cloud data from Kinect cameras. The OSO wears a Hololens that creates the 3D mesh map of its surroundings. The locations of the Kinect cameras need to be determined in this map, this is done by scanning a QR code that is placed on top op the Kinect. The position of the Kincect needs to be re-scanned if a Kinect is moved. The point cloud data from the Kinects are combined with the mesh from to Hololens into a single virtual environment that has more detail in the places where the Kinects are. The RO uses the fully immersive HTC Vive to be present in this virtual environment. OpenIMPRESS has not implemented a full body representation of the RO, currently only the hands are virtually recreated and the position of the head is visualised. The RO has a HTC Vive head mounted display with a Leap motion camera placed in front that does skeleton tracking of hands. The hands are visible in real time, both in the virtual environment of the RO and augmented for the OSO as animated 3D models. The OSO can also see where the head of the RO is, because of a blue visor that is shown at the location of the head. The RO and OSO can also talk to each other using Voice over IP. The Hololens has a microphone and speakers built-in and the RO uses a headset for easy hands free communication. The RO can move around in the virtual environment by physically moving or using a controller to move in all directions. All data is sent over the internet via a matchmaking server, allowing the RO to be virtually present anywhere where the OSO is, given a good internet connection. OpenIMPRESS provides a core system that allows for all requirements to be met, the requirements are described in section 4.4. Though the system needs further development to be suitable for teaching CPR. Mainly tools need to be implemented that the RO can use to teach the various steps of CPR.

4.2 CPR scenarios that benefit from Augmented Learning

The idea of using Augmented Learning to improve learning CPR in the context of OpenIMPRESS is further explored in this section. Three scenarios are proposed and compared. The scenario that benefits most from Augmented Learning is picked and used for development of the CPR application.
The three different scenarios for applying Augmented Learning to CPR are:

- CPR course with live instructor
- Prerecorded CPR course
- Dispatcher assisted CPR

Unlike most related work ARC uses a physical CPR doll, this doll can be the same in all scenarios. The purpose of the doll is to have something physical, that is not a real person, to perform CPR on and collect data about the quality of the CPR. All scenarios can use audiovisual augmentations to provide direct feedback to the learner based on the data from the CPR doll. Direct feedback is considered any feedback that is given by the Hololens while performing a task. Feedback can also be given indirectly, the instructor and other learners can use feedback from the doll to give personal feedback to the learner. Any feedback that is provided when the task is finished, is also considered indirect feedback.

4.2.1 Scenario 1; CPR course with live instructor

This scenario is the most similar to a regular CPR course. There is one instructor and n learners. Each learner wears a Hololens. The instructor can be either physically present in the room also wearing a Hololens or virtually present as a Remote Operator using immersive VR. The key to this scenario is the way feedback is provided to the learners and instructor. Feedback to the learner can be either direct or indirect. Direct means that the feedback is directly augmented on the doll, indirect means that information about performance is visualised to instructor and other learners who in turn use this information to provide feedback to the learner. This gives four different variations of this scenario:

		Instructor presence	
		Virtual	Physical
Feedback	Direct	Variation 1	Variation 3
	Indirect	Variation 2	Variation 4

Table 4.1: Live instructor course variations

A **virtual instructor** (variation 1 & 2), is a real instructor who is virtually present using the OpenIMPRESS system. With a virtual instructor, all instructions and feedback must be given through OpenImpress. This requires a *high level of virtual presence*

and freedom to interact, otherwise the ability of the instructor to teach CPR will be limited by the system. The virtual instructor will *need ways to give instructions and feedback* provided by the system. Switching to a virtual instructor does open up many opportunities to create a *better overview* for the instructor, *more movement freedom* to quickly switch between learners and options to simultaneously provide the same *personal feedback* virtually to multiple learners. For example showing all learners at the same time where to place their hands and all learners see the virtual hands of the instructor in front of them on the CPR doll.
With a **physical instructor** (variations 3 & 4, see Table 4.1) there is less change for the instructor, as the instructor is physically present with the learners. This makes it *easier for an instructor to adapt* the course to use the technology and learn how to use the technology, because the instructor doesn't have to get used to being virtually present. The role of the technology is *solely to provide feedback* to the learners and instructor that can be used to further enhance the learning during the course.

4.2.2 Scenario 2; Prerecorded CPR course

An CPR instructor pre-records instructions for different CPR learning tasks. Instructions can be filmed using Kinect cameras, so they can be played back virtually on the Hololens. The learner first watches the recorded instructions and then performs the exercise, similar to the structure of a regular CPR course. Sensors on the CPR doll can be used to provide feedback in two different ways. The first one is direct feedback to the learner in the form of augmentations on the CPR doll, for example an audiovisual representation of the target tempo. And secondly the sensors can detect mistakes and trigger pre-recorded feedback from the instructor, for example when the hand position is incorrect the hands of the instructor will appear and show the correct hand position. This scenario *doesn't require an instructor* after the course has been recorded. Students can do the course at *any time* when a doll and Hololens is available. Other benefits are that the learner receives the *full attention of the virtual instructor*, there is no real instructor that needs to split their attention over sometimes more than 10 learners. Full attention of the instructor means that all mistakes can be detected, so no opportunity for giving feedback is missed. However there are *no other learners* present that can give feedback or can be observed to learn. The course is also *limited to the recorded instructions and feedback*, so questions that are not in the system can't be answered and no accurate feedback can be given if a mistake is not detected.

4.2.3 Scenario 3; Dispatcher assisted CPR

This scenario focuses on learning CPR while performing CPR only a single time without having the instructor physically present. This is similar to a bystander of a cardiac arrest calling the emergency services and being talked through performing CPR over the phone while never having done it before. The goal is to achieve the *highest quality CPR possible on the first try*, while no other person is physically present to assist. Time is an extra important factor for this scenario, because the system should not cost time to use and might even have to potential to save time due to overcoming communication problems.

Dispatcher assisted CPR works as follows; A person notices a cardiac arrest and calls the emergency services. At the point where someone gets the AED, they also take the Hololens from there (alternatively the AED with Hololens is delivered by drone, which can simultaneously give eyes on the situation). The person that will perform the CPR puts on the Hololens which switches the contact from the telephone to the dispatcher being virtually present. Now the dispatcher can still talk the person through CPR, but also has more tools and information available to help teach the person CPR.
Dispatcher assisted CPR can be used either to learn CPR very quickly during a course or during a real cardiac arrest situation. The main difference between these situations is that during a course a doll with sensors can be used to provide the learner and instructor with more feedback. *An extra sensor device is required* during a real cardiac arrest to provide the same detailed information. Also during a course there is still the option of having the instructor physically present, while during a real cardiac arrest *it is not physically possible to have an expert instantly show up on site*.
The feedback that dispatcher assisted CPR provides can be useful to any person performing CPR, as the quality of CPR outside a hospital is not as good as it should be (Wik et al., 2005). The instructor can monitor the quality of CPR and ensure that it is as high as possible.

Key differences scenarios			
Scenario	1 (live instructor)	2 (prerecorded)	3 (dispatcher assisted)
Human instructor	Yes	No	Yes
Instructor virtually present	Yes/No*	Yes	Yes
Multiple learners that benefit from personal feedback	Yes	Yes	No
Better insight into performance of multiple learners for the instructor	Yes	No	No
Sensor data available for feedback	Yes	Yes	Yes/No**

Table 4.2: Key differences scenarios; * Depends on having a virtual or physical instructor. ** Depends if it is training or real situation, a real situation requires an alternative to sensors in a doll

4.2.4 CPR scenarios summary

The key differences between the three scenarios are summarised in Table 4.2. A CPR course with a live instructor aims to improve learning by providing the learners with more insight into their performance and mistakes. The instructor gets a better overview of the performance of each individual learner and the ability to simultaneously provide

personal feedback and instructions to multiple learners. A prerecorded CPR course eliminates the need for an instructor after recording. Each student receives fully personal feedback and instructions from the system as if it is a one-on-one training course. Dispatcher assisted CPR aims to achieve the highest quality CPR possible on the first try, while no other person is physically present to assist. Someone that has never performed CPR before should be able to do it faster and better, while someone who has can be kept an eye on to ensure high quality CPR. This is a real cardiac arrest situation that requires a virtual expert on location to teach a physical task. As also has been discussed in section 3.3, dispatcher assisted CPR can really benefit from AR since telephone-CPR has some major limitations. Dispatcher assisted CPR can potentially benefit the most from AR technology and is therefore chosen as the learning scenario for improving teaching CPR.

4.3 Objective

The objective of the system is to facilitate a dispatcher who supports a bystander in performing CPR. On the one hand, we want to give the dispatcher a better **awareness** of the situation and the actions of the bystander. On the other hand we want to make it possible for the dispatcher to give specific and detailed **instructions and feedback** to the bystander. To achieve this objective for the CPR scenario, as described in section 4.2.3, a VR solution is needed that allows the dispatcher to be virtually present at the bystander and teach CPR. OpenIMPRESS is used for this, where the RO is the dispatcher and the OSO the bystander. Based on the objective a set of requirements for the system is created in section 4.4.

4.4 System requirements

Both the dispatcher and bystander have different goals in the scenario, the bystander must learn and the dispatcher must teach CPR. The dispatcher is a trained CPR instructor who works at an emergency services call centre. The goal of the dispatcher is to teach CPR to the bystander over distance. To do this, the dispatcher needs information about the bystander, victim and environment. Bystanders in the scenario are inexperienced in giving CPR. They have never followed a CPR course or haven't done so in the past two year, this is considered too long for retaining the ability to perform good quality CPR (Greif et al., 2015). The goal of the bystander is to quickly learn how to perform CPR without being able to practice first. The bystander does this by following instructions and feedback given by the dispatcher. Combined with the objective these goals result in two sets of requirements; requirements for awareness and presence of the dispatcher (section 4.4.1) and requirements for instructions and feedback (section 4.4.2.

4.4.1 Requirements for awareness and presence of the dispatcher

There are two requirements related to awareness:

Dispatcher: observe bystander, victim and surroundings Mistakes can be detected and adequate feedback given if the dispatcher can see the actions performed by the bystander. Asking questions about what the bystander sees also takes valuable time. The dispatcher must be able to see the bystander, victim and surroundings, so all this information becomes available without asking questions. Also, being present in the surroundings of the bystander allow the dispatcher to use the space for visual instructions and feedback.

Bystander: awareness of dispatcher's presence Since the dispatcher is not physically present, the system needs a way to show where the dispatcher is so the bystander can notice their presence. This is necessary so the bystander knows where the feedback and instructions are coming from and does not feel alone.

4.4.2 Requirements for instructions and feedback

The rest of the requirements are related to instructions and feedback:

Both: enable instructions and feedback The dispatcher must be able to give the instructions and feedback, while the bystander must be able to receive it. In current telephone-CPR instructions and feedback are given verbally. To enhance learning, ARC must also allow visual instructions and feedback. With both verbal and visual modalities, the system can make use of the Spatial and Temporal Contiguity principles as described in section 3.1. This leads to more requirements regarding visual instructions and feedback.

Both: visuals to support instructions To enhance learning there need to be visual instructions that can be combined with verbal instructions. These visuals must be placeable by the dispatcher and visual to both sides at the same location.

Both: visuals dynamically linked with instructions According to the theory of Multimedia learning, as discussed in section 3.1, learners find it easier to learn when information is dynamically linked. Information from the instructor and instruction visuals must be dynamically linked to benefit from this principle.

Dispatcher: use hands A natural way to give instructions and feedback in a regular CPR course is with the use of hands, as all CPR tasks require hands to perform. For this reason the dispatcher must be able to use their hands while in the virtual environment. A controller is also needed to move around and interact with the virtual environment, so at least one hand should be free to use.

Dispatcher: quick insight into CPR quality Quick insight into factors that determine the quality of CPR helps the dispatcher with giving feedback. Besides being able to see the actions of the bystander in real-time, a virtual display needs to give insight into the past performance of the bystander. This display needs to provide the dispatcher with information about the most important factors like compression rate and depth.

Bystander: being able to ask questions A bystander that doesn't understand the instructions must be able to make this clear to the dispatcher. If the bystander is able to ask questions, the dispatcher can quickly repeat and elaborate on that part of the

instructions. This is naturally already possible with just voice communication, but the system must not prevent or hinder asking questions.

Bystander: no distractions Finally, as discussed in section 2.1.2, someone learning CPR must not be distracted by too much feedback. There mustn't be anything unnecessary that distracts the bystander, which results in lower quality CPR. Feedback needs to be limited to mistakes that have a big impact on the quality of CPR, such as mistakes related to: compression rate, compression depth, hand position, chest recoil and interruptions.

Chapter 5

Implementation

The OpenIMPRESS system (section 4.1.2), CPR scenario (section 4.2.3) and objective (section 4.3) are all used to create a CPR application. The goal of this application is to improve the learning of the bystander in a one-shot bystander CPR situation, where the bystander is instructed by a dispatcher who is virtually present. The Remote Operator (RO) of the OpenIMPRESS system is the dispatcher and the On Site Operator (OSO) is the bystander. OpenIMPRESS allows the dispatcher to be virtually present at the bystander and use their hands to explain. A way to give visual instructions and feedback is implemented to help the dispatcher with teaching CPR. A CPR doll is equipped with sensors to give the dispatcher feedback about the performance of the bystander. In real one-shot CPR there will be no doll with sensors present. However, for this research we use the doll to collect data about the performance of the bystander. First a full description of the CPR application and all of its components is given.

5.1 System overview

There are two sides of the system: the dispatcher's side and the bystander's side. The end result showing the perspectives of both sides of the system can be seen in Figure 5.1. A schematic overview of the entire system can be seen in Figure 5.2. The dispatcher is fully immersed in a virtual environment that represents the environment of the bystander. In the virtual space the dispatcher has access to a menu using a controller, this menu can be used to place visual aids. The visual aids are *video animations* that show the different tasks required to perform CPR and a *visual metronome* that moves up and down and makes a sound at the correct compression rate. The dispatcher can also see a virtual display above the head of the bystander that shows real-time data from the CPR doll. The dispatcher can use this information to gain quick insight into the performance of the bystander and determine suitable feedback. The bystander's side is kept simple to prevent distractions from performing CPR. The bystander wears a Hololens and can see the hands of the dispatcher and the location of the head. Any visual aids that the dispatcher places are also visible at the corresponding position in the real world. The dispatcher wears a wireless headset to hear and talk to the bystander.

The bystander can hear and talk to the dispatcher via the built-in speakers and microphone of the Hololens. A complete description of all the elements in the dispatcher system is given in section 5.2 and for the bystander system in section 5.3.

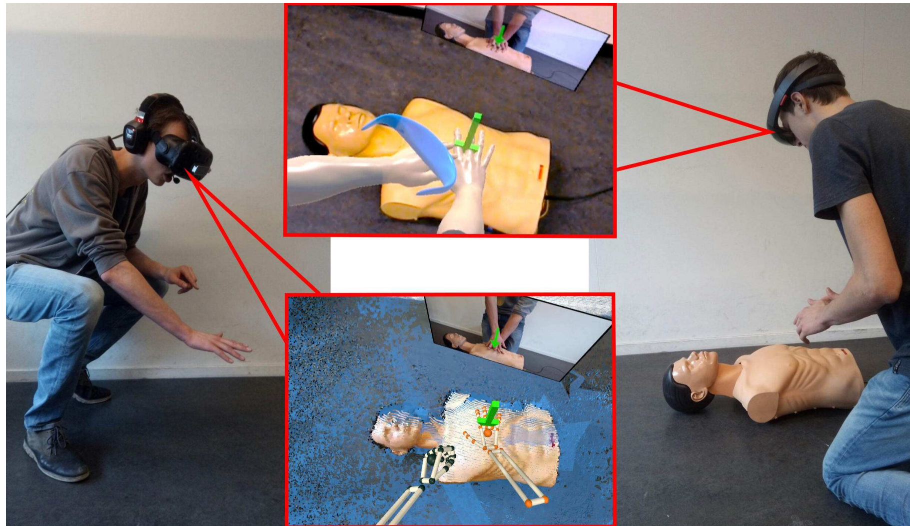


Figure 5.1: CPR application as experienced by the dispatcher (left) and bystander (right).

5.2 Dispatcher system

First we take a look at the dispatcher's side of the application. The dispatcher system can be split up into four main parts: 3D virtual environment, CPR tools, menu and controls and the CPR display. As described in section 5.2.1 the 3D environment is all that the dispatcher can see when fully immersed in VR, this includes the victim, bystander and part of the surroundings. CPR tools are the different visual aids that the dispatcher can use to complement instructions and provide feedback to the bystander; these tools are further discussed in section 5.2.2. The menu and controls, see section 5.2.3, include all the ways the dispatcher can interact with the virtual environment and use the CPR tools. The dispatcher also receives feedback from the system about the quality of CPR performed by the bystander; this is discussed in section 5.2.4. The bystander performs CPR on a CPR doll that is equipped with force sensors; information from these sensors is processed and displayed in a display that floats above the head of the bystander in the VR environment.
The goal of the dispatcher is to teach the bystander CPR. The dispatcher can use their hands and visual tools from to menu to do this. The hands are tracked by the Leap Motion device mounted on the HTC Vive. The dispatcher's hands are virtually represented by a skeleton model, so the dispatcher can see the hands in the virtual space. The position and pose of the hands are also sent to the bystander, where the bystander can see

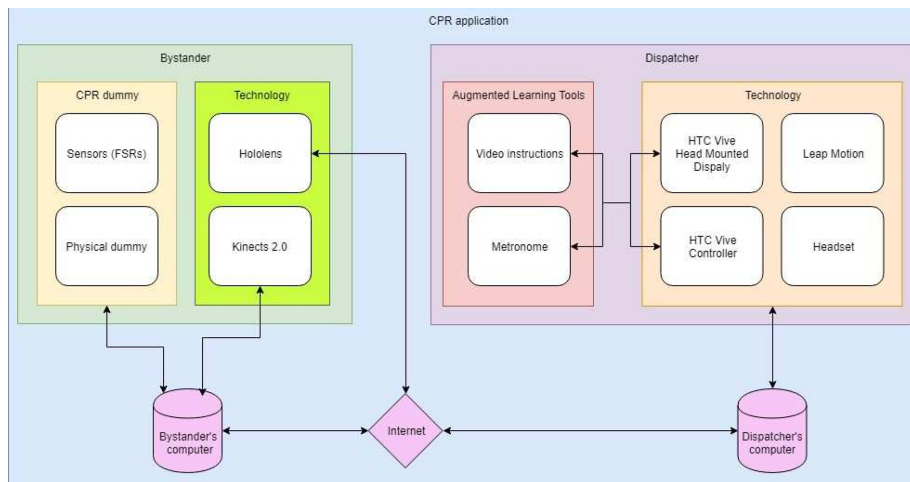


Figure 5.2: An overview of the CPR application, showing all the components and their interactions.

fully modelled hands and part of the arms. How the hands look to the dispatcher and bystander can be seen in Figure 5.3. The key here is that the hands accurately represent the real hands of the dispatcher, so the bystander understands a task if the dispatcher uses hands to explain the task.

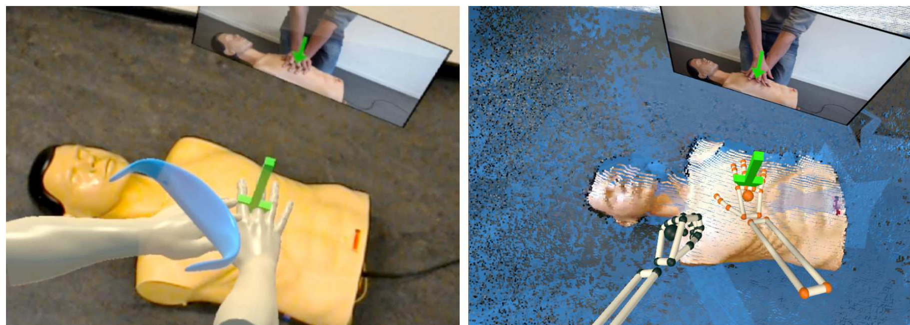


Figure 5.3: Left; 3D hand models augmented to the bystander, the blue visor represents the head of the dispatcher. Right; virtual skeleton hands visible to the dispatcher.

5.2.1 3D environment

The 3D virtual environment, as can be seen in Figure 5.4, is built up from two sources. The first source is the 3D map of the Hololens worn by the bystander. The Hololens uses depth cameras to create a low resolution map of its surroundings. This map is used by OpenIMPRESS to show a blue mesh in the virtual space. The mesh is useful

to see a rough shape of the environment, such as the ground and large obstacles, but the resolution and refresh rate are too low to see any actions of the bystander. More detail is needed to get a good view of the victim and bystander. OpenIMPRESS supports the use of multiple Kinect cameras that can stream a coloured point cloud, this gives a detailed real-time view of the areas where a Kinect is pointing. There is a QR code on the Kinect that is used to align the point cloud with the mesh of the Hololens. The Kinect with QR code can be seen in Figure 4.1. During setup the Hololens needs to scan the QR code to determine the position. The QR code has a fixed position on the Kinect, so the position of the Kinect can be calculated when the position of the QR code is known. The origin of the point cloud is placed relative to the mesh from the Hololens. Combined they provide a low resolution 3D environment with detail in the important places.

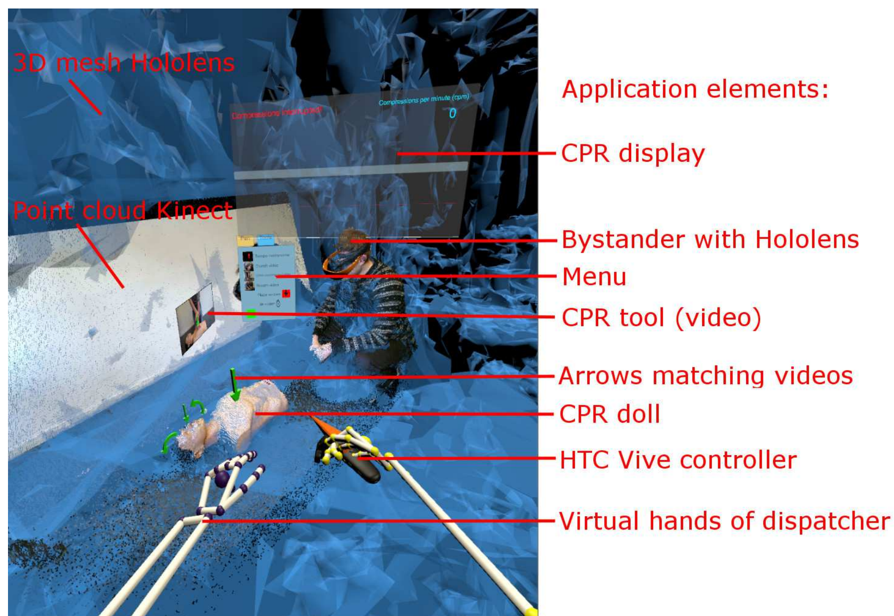


Figure 5.4: VR view of the dispatcher, consisting of the 3D virtual environment and application elements. The 3D map of the Hololens is visible as the low resolution blue mesh. The high resolution point cloud from the Kinect shows the bystander, CPR doll, floor and wall.

5.2.2 CPR tools

The CPR tools are visual aids designed to assist the dispatcher with giving instructions and feedback. The dispatcher can place them anywhere in the virtual space and they will be visible to the bystander. There are four different tools. The first three are instruction tools that visualise the instructions for a chin lift, chest compressions and rescue breaths. How these tools look to the bystander can be seen in Figure 5.5 and

how they look in the virtual environment of the dispatcher can be seen in Figure 5.6. The instruction tools are short videos that show a person performing the task on the same CPR doll. The videos loop every few seconds, so the bystander can easily pick up and mirror the task. The videos also contain arrows that are also augmented on the victim; these arrows indicate where the bystander needs to use their hands. The fourth tool is a feedback tool, which is a visual metronome that can be used to give the bystander feedback about the compression rate, see Figure 5.7.
The CPR tools make use of the Spatial and Temporal Contiguity principles, as are described in section 3.1. They can be placed right next to and at the same time of the actions of the bystander. To see how these principles are used by the tools we will compare it to an example from a regular CPR course. In a CPR course the instructor first shows a video of a person performing CPR and then gives an example on a CPR doll. After these instructions the student tries to repeat the actions. Both the video and example are given prior to the student performing the actions, which creates a temporal difference. The instruction tools in the CPR application show the actions while the bystander needs to perform them, completely removing the temporal difference. The video shown in the course also has a spatial distance to the learning task. The doll in the video is not the same as the doll the student practices on and the screen is also not in the same place as the practice doll. This distance makes is more difficult for the student to translate the instructions into actions on the practice doll. It can also be the case that the instructor gives the example on one of the other CPR dolls, which also creates a spatial distance. The instruction tools in the CPR application are placed right next to the victim and contain green arrows indicating where the hands need to touch the victim. These arrows are also augmented on the victim itself. The arrows on the victim are dynamically linked with the placed instruction tools, appearing and disappearing together. The purpose of the arrows is to further reduce the spatial distance between the tools and actions of the bystander.

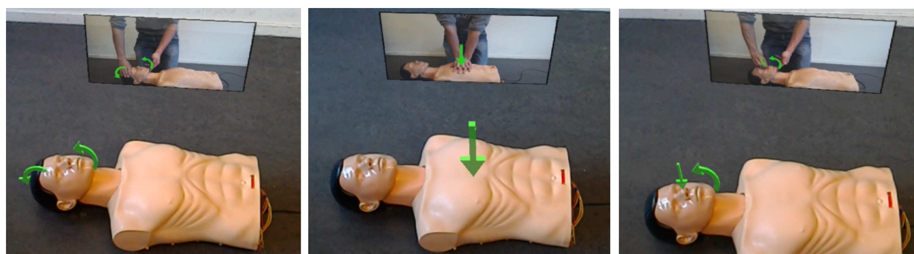


Figure 5.5: Augmented instruction videos with arrows: left; chin lift, middle; chest compressions and right; rescue breaths. As visible to the bystander using a Hololens.

The last CPR tool is the metronome, see Figure 5.7. In telephone-CPR a metronome can also be used to help maintain a compression rate of 100 min^{-1}, this metronome is audio only. The dispatcher can use this metronome to count together with the bystander at the right rate. In the CPR application the metronome is also visual. As can be seen in Figure 5.7, the metronome is a cylinder that changes height over time. In a single cycle it becomes shorter, flashes red and regains it original height. When it flashed

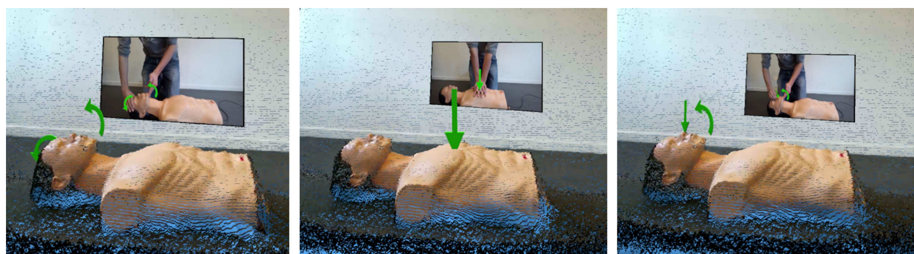


Figure 5.6: Virtual instruction videos with arrows: left; chin lift, middle; chest compressions and right; rescue breaths. As visible to the dispatcher using a HTC Vive.

red it also plays a ticking sound. The metronome has the same rate as the metronome used in telephone-CPR. The advantage of making the metronome visual, is that the bystander can move together with the cylinder up and down. It is also still possible for the bystander to just listen to the tick.

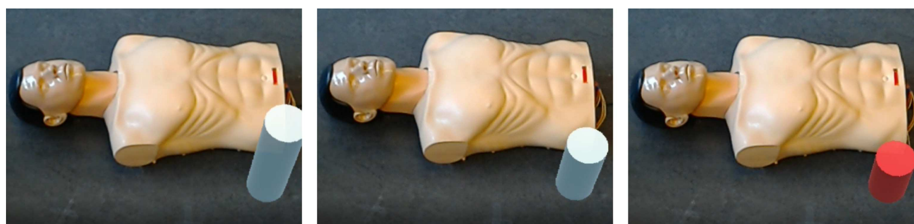


Figure 5.7: Augmented metronome next to CPR doll, with different snapshots over time from left to right.

5.2.3 Menu and controls

The dispatcher has access to a virtual menu that is used to select the four CPR tools. The menu can be seen in Figure 5.8. The buttons on the menu that correspond to the CPR tools act as toggles. When enabled, the dispatcher can place the tool and when disabled the tool will disappear. There are also three buttons on the menu that add some functionality required for the experiment, the experiment is described in section 6.3. The experiment tools are used to ensure consistency. There is a button to place the green arrows; this is used to determine the position of the victim. The dispatcher can ensure that the arrows always are in the same position by manually placing them on the doll and checking their positioning before the experiment. Secondly, there is a button to start the experiment. Pressing this button starts the data collection from the CPR doll and removes a red outline that is visible to the bystander before the experiment. The red outline is used to make sure the Hololens is on correctly so the bystander can see the full field of view from the Hololens. Lastly, there is a simple counter that increments by one every time it is pressed. This is to keep track of the compression and breath sets during the experiment.

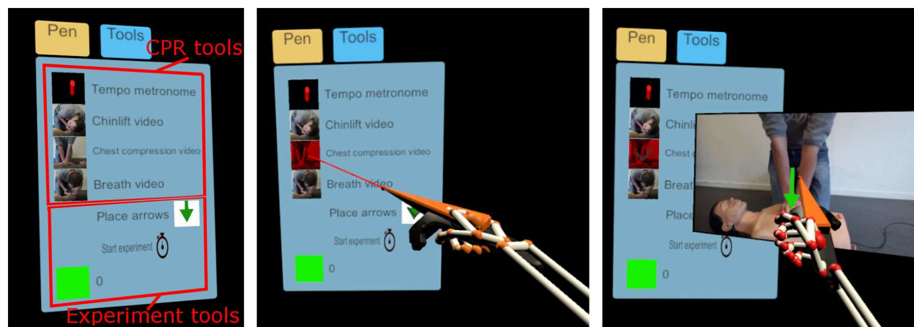


Figure 5.8: CPR menu. Left; difference between CPR tools and experiment tools, middle; selecting a tool, right; placing a tool by dragging.

The dispatcher uses a single HTC Vive controller to move around and use tools in the virtual space. The buttons used can be seen in Figure 5.9. In total there are four buttons, two for movement and two for interacting with the menu. The dispatcher has three ways to move around in the virtual environment. The first way is to simply walk inside the tracking area covered by the Vive base stations. The second way is to use the controller to drag towards a desired direction. Lastly the dispatcher can teleport to a fixed location using the controller. The grip button on the side can be used for dragging. It works like pulling yourself up on a rope. You press and hold the button while moving it towards your body, this way you move in the direction of the controller. The second button used for movement is the teleport button. When this button is pressed, the dispatcher teleports directly to a fixed location near the victim. This location is used during the experiment to have a constant location of the dispatcher over all experiments from where instructions are given. The location of the victim is manually determined by the dispatcher at the start. To do this, the dispatcher uses the menu and controller. First the menu is opened by pressing the trackpad on the controller. The menu stays at the position where it is opened; this way the dispatcher can easily place the menu and select tools using one hand. Pressing the button again closes the menu, so it can be opened somewhere else. The trigger button on the back of the controller is used to select and place tools from the menu. Once a tool is selected, the trigger button must be held to move it to the desired position. The tool is placed and shown to the bystander once the trigger is released. Tools are automatically rotated over the vertical axes so they are always facing the bystander. This way the bystander can always see the visual instructions, even when moving around.

5.2.4 CPR display

The CPR display shows real-time data from the CPR doll, see Figure 5.10. How the CPR doll collects data is explained in section 5.3.1. The display is always visible above the head of the bystander. Its location is fixed relative to the Hololens, so the dispatcher can always easily see the data from the CPR doll when looking at the bystander. The display consists of three main elements: a feedback message, the compression rate and

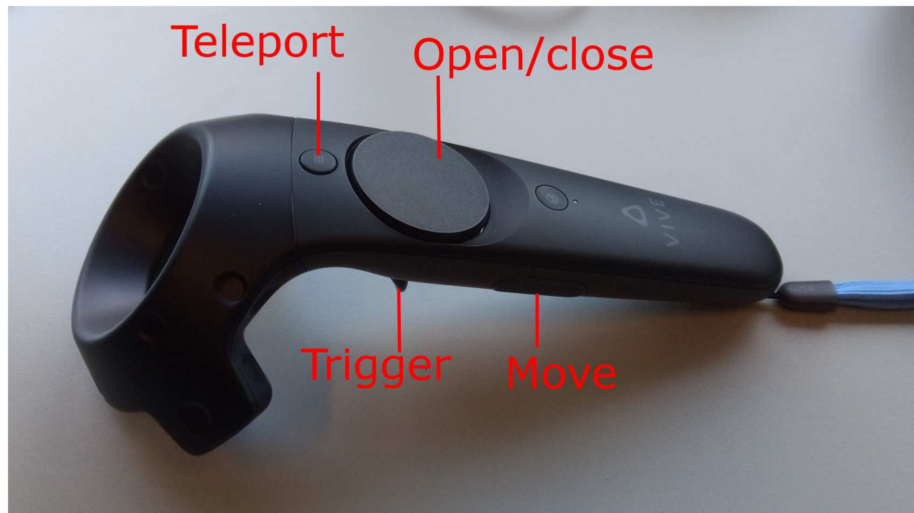


Figure 5.9: HTC Vive controller with the buttons mapped for different functions in the application. The button mapping is as follows: 'teleport' -> menu button, 'open/close' -> trackpad press, 'trigger' -> trigger and 'move' -> grip button.

a graph showing the pressure on the chest over time. The feedback message gives the dispatcher quick insight into the data. The message shows the most important deviation from optimal compressions, namely if the compressions are too fast, too slow, too deep, not deep enough or interrupted. There is no message displayed if compression rate and depth are within the optimal range. The function of the feedback message is to give the dispatcher easy to interpret feedback about the performance of the bystander and to suggest what feedback the dispatcher should give. The compression rate is also displayed in the top right; this quickly shows the dispatcher how far or close the compression rate is to the ideal range of 100-120 min^{-1}. Lastly there is the chest pressure graph. The graph plots the pressure on the chest over time and shows the ideal range where the peaks should be. This range is indicated by the light area in the centre of the display. The red line below indicates the pressure threshold that needs to be surpassed to count a peak as a compression. The graph only shows the past 10 seconds of data, so the dispatcher can quickly look at the current performance. The graph can give the dispatcher insight into the consistency of the bystander. The dispatcher can give the bystander feedback about the force used if the peaks are increasing or decreasing in height. The CPR display is only visible to the dispatcher, as it would be too much information distracting the bystander from the task at hand.

5.3 Bystander system

The other side of the application is the bystander system. This side includes the CPR doll and the augmented layer received from the dispatcher. The CPR doll is equipped

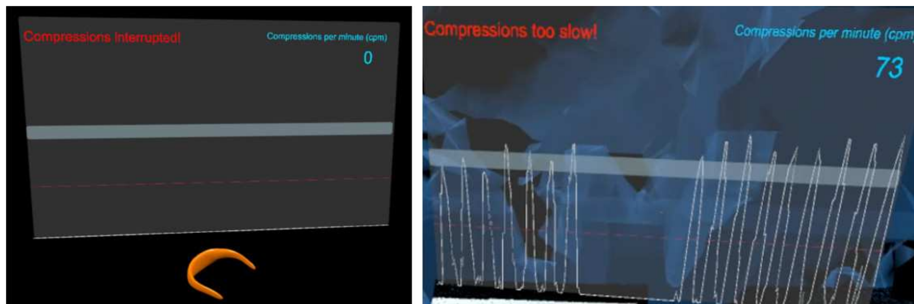


Figure 5.10: CPR display placed above the head of the bystander (left) and with real-time data (right). Display elements: top left; feedback message, top right; compression rate and bottom; chest pressure graph.

with sensors to give the dispatcher feedback about the performance of the bystander and to collect data during the experiment. The CPR doll is explained in detail in section 5.3.1. The augmented layer that the bystander can see through the Hololens consists of the hands and head of the dispatcher, see Figure 5.3, and the visual aids placed by the dispatcher, see Figure 5.5. The same models are used on both sides of the application, so everything visible to the bystander looks the same as for the dispatcher. The only exception are the hands, as the dispatcher sees a skeleton model of the hands instead of fully modelled hands. The menu, controller and CPR display that are used by the dispatcher are not visible to the bystander, as they could only distract.

5.3.1 CPR doll

A regular CPR doll, as used in CPR courses, is equipped with four force sensitive resistors (FSR) to collect data about the performance of the bystander, see Figure 5.11. By measuring the force on the chest of the doll, it is possible to determine the compression rate and estimate the compression depth. The compression rate is equal to the time in between peaks times 60, to get the compressions per minute. The compression depth is related to the height of the peak, with a higher peak meaning a deeper compression. The four FSRs are mounted on a wooden plate that fits the open shape on the bottom of the CPR doll. This way the FSRs can easily be attached to the CPR doll without damaging it and are securely fixed in place. The mounting points are spread out and are the only places where the CPR doll touches the ground, so all downward force gets picked up by the FSRs. The resistance of the FSRs is measured by an Arduino [1], which is a microcontroller with an open source computer platform. The Arduino turns the resistance into a value between 0 to 1024 for each FSR and sends the data to a computer when it receives a ping. This computer sends the data to the computer of the dispatcher. The values of the FSRs are averaged and shown in a graph of the CPR display. Also the compression rate and depth are calculated as described earlier.

[1] https://www.arduino.cc (accessed: 28-02-2018)

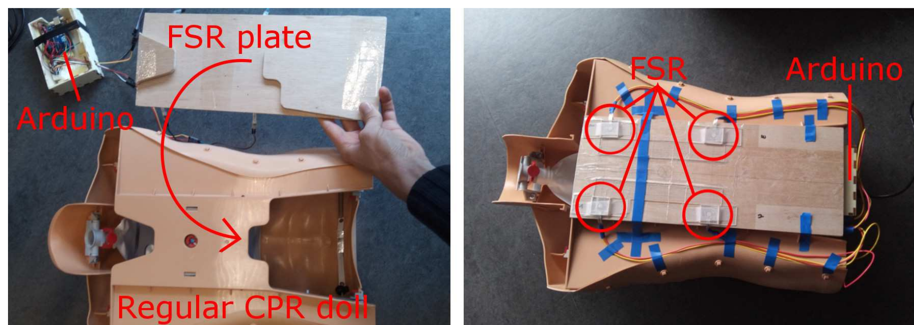


Figure 5.11: CPR doll equipped with four force sensitive resistors (FSR) and an Arduino.

5.4 System limitations

There are a number of technological limitations that constrain the possibilities of the application. First of all the **field of view of the Hololens** that is used for augmentation doesn't cover the full visual field of a person. Especially at close distances there is only a small area where the user can see the augmentations. Since CPR requires the person to be close to the victim, this limitation really becomes an obstacle. When Hololens users kneel before a victim, they can only see augmentations on the body of the victim when looking down or augmentations in front of them when looking up. AR glasses with a larger field of view can solve this problem in the future.
The tracking of the Hololens is also an issue. The **Hololens can lose tracking** if the sensors on the front of the device are covered, as these are used to determine the position of the device in an environment. If tracking is lost, the Hololens will remap its surroundings to find its position again. This temporarily pauses the running application, causing a short interruption of audio communication. Also, all the virtual objects placed in the virtual environment will be remapped to the new 3D map, this can cause all the virtual objects to move from their original position in the real world. The virtual environment doesn't match the real world if this happens. The QR codes on the Kinects need to be rescanned to solve this displacement. The best solution to prevent this problem is to make sure the sensors on the Hololens always have enough vision of the environment. Because of this, real rescue breaths are not possible with a Hololens on. If the bystander attempts to give a breath there is a chance the Hololens loses tracking, because its too close to the floor and can't see enough of the environment.
The Leap Motion does **skeleton tracking of the hands**. For accurate tracking, the device needs a clear line of sight to the hand. The device loses hand tracking if something obstructs the view. Placing one hand over the other while explaining chest compressions, results in a loss of tracking of the bottom hand. Therefore it is only possible to explain chest compressions with one hand using this system. There are alternatives for hand tracking that can solve this problem, namely special hand tracking gloves or room scale skeleton tracking.
The last limitation is regarding the **precision of the FSRs**. The FSRs used on the CPR

doll are not precise enough to determine an exact force applied to the chest. They work well for determining the compression rate and estimating the compression depth, but don't work well for determining the hand position on the chest and determining the exact compression depth. However, the precision is good enough for the purpose of this CPR application, as the purpose of the sensors on the CPR doll is mainly to give the dispatcher some insight into the performance of the bystander.

Chapter 6

Evaluation

The goal of this chapter is to answer the second main research question: **RQ2** *How does ARC compare to telephone-CPR?* To do this, we compare Hololens-CPR to telephone-CPR by answering the following subquestions:

- **RQ2.1** What kind of instructions and feedback can the dispatcher give using ARC?
- **RQ2.2** How does ARC influence the perceived task load when learning CPR in a dispatcher assisted scenario?
- **RQ2.3** How does ARC influence the social presence of the dispatcher for the bystander when learning CPR in a dispatcher assisted scenario?
- **RQ2.4** How does ARC influence the CPR quality performed by the bystander when learning CPR in a dispatcher assisted scenario?

RQ2.1 is answered in section 6.7.1. Here the system is compared to telephone CPR to see what new possibilities for giving instructions and feedback are created by the use of VR technology. The other research questions are answered in the rest of this chapter.

An experiment was done to answer these research questions. The goal of the experiment was to compare the effect of ARC on one-shot teaching CPR to telephone-CPR in a dispatcher assisted scenario. This experiment had two conditions; telephone-CPR (control condition) and Hololens-CPR (experimental condition). In the experiment a lay person took the role of bystander and was taught CPR either using ARC or over the phone. An experimenter took the role of dispatcher. This was someone who knows how to use ARC and can follow the procedure to teach CPR like used by dispatchers in the Netherlands. The task for the bystander was to perform CPR on a doll, this included sub tasks such as performing a chin lift, chest compressions and rescue breaths. The bystander was instructed by the dispatcher for every task. Instructions were given verbally and in the Hololens-CPR condition also with the aid of visual instructions and the use of hands, as can be seen in Figure 5.3. The experiment took place in a controlled environment, where the bystander and dispatcher were in separate rooms. The

methodology of the experiment is further explained in section 6.3 and the experiment setup is illustrated in section 6.4.

6.1 Measures and expectations

RQ2.2 Perceived task load. We use the Raw-TLX (Hart, 2006) to measure the perceived task load. Raw-TLX is a simplified version of the Nasa Task Load Index (NASA-TLX) (Hart, 1986). NASA-TLX is an assessment tool used to determine the perceived load for a given task. This is not the actual load related to a task, but how a person performing the task perceives it. Raw-TLX (Hart, 2006) removes a step where all six subscales are rated against each other to determine a weight for each subscale. This weight is used to determine how much each subscale contributes to the overall workload. Research suggests that Raw-TLX might increase experimental validity (Bustamante & Spain, 2008). Also, for this research the *Mental Demand* is considered the most important, so a weighted overall load is not necessary. Therefore the Raw-TLX is used. *Mental Demand* is one of the subscales used to determine the overall task load. In total, this overall task load is divided into six subscales:

- ***Mental Demand*** How much mental and perceptual activity was required.
- ***Physical Demand*** How much physical activity was required.
- ***Temporal Demand*** How much time pressure due to the rate or pace of the task.
- ***Performance*** How successful the goals of the task were accomplished.
- ***Effort*** How hard it was to accomplish the level of performance.
- ***Frustration*** How insecure, discouraged, irritated, stressed and annoyed the participant felt during the task.

ARC does not assist the bystander with performing the actual physical actions, but we expect that is does help with learning how to perform these actions. According to the Spatial and Temporal Contiguity principles, the addition of visual instructions and feedback should make the learning task less cognitively demanding. Therefore we expect that the *Mental Demand* is lower when using ARC. We expect that the *Physical Demand* and *Effort* are not affected. The physical task itself is not changed and will require the same effort, unless a person does not follow the exact instructions and uses a different technique. However, we don't expect that this plays a big enough role to make a significant difference. Any difference in *Performance* and *Frustration* is probably negligible. Better instructions might affect these subscales a little, but we expect that this effect will not be significant.

RQ2.3 Social presence. The *Networked Minds Measure of Social Presence* questionnaire is used to measure social presence (Harms & Biocca, 2004). The questionnaire is divided into six subscales:

- ***Co-presence*** Co-presence is the degree to which the observer believes he/she is not alone and secluded, their level of peripheral or focal awareness of the other, and their sense of the degree to which the other is peripherally or focally aware of them.
- ***Attentional allocation*** Attentional allocation addresses the amount of attention the user allocates to and receives from an interactant.
- ***Perceived message understanding*** Perceived message understanding is the ability of the user to understand the message being received from the interactant as well as their perception of the interactant's level of message understanding.
- ***Perceived affective understanding*** Perceived affective understanding is the user's ability to understand an interactant's emotional and attitudinal states as well as their perception of the interactant's ability to understand the user's emotional and attitudinal states.
- ***Perceived affective interdependence*** Perceived affective interdependence is the extent to which the user's emotional and attitudinal state affects and is affected by the emotional and attitudinal states of the interactant.
- ***Perceived behavioural interdependence*** Perceived behavioural interdependence is the extent to which a user's behaviour affects and is affected by the interactant's behaviour.

The evaluation of OpenIMPRESS also looked at social presence (Harmsen, 2018). Their findings suggest that the use of OpenIMPRESS to have the dispatcher virtually present will increase the *co-presence* and *perceived message understanding* for the bystander. We expect *co-presence* to increase, because the bystander can now see the dispatcher. Seeing someone really helps to be aware of this person. We also expect the *perceived message understanding* to increase, because the instructions and feedback given by the dispatcher are assisted by visuals. For example; if the bystander can see what the dispatcher means with an instruction, it will increase their understanding of this message.
We expect that the *attentional allocation* does not change, as the bystander will be mainly focused on the victim. However, potentially the additional aid from the dispatcher using ARC will be more compared to telephone-CPR, so this should increase the amount of attention the bystander allocates to the dispatcher. But the additional aid is carefully designed not to be distracting. Therefore we expect that the additional amount of attention required is insignificant.
We expect the *perceived affective understanding* and *perceived affective interdependence* don't change. ARC provides a new way to convey emotions, namely by using body language. But since there isn't a full body representation of the dispatcher, this will limit how well body language can convey emotions. So all emotions will mostly be conveyed verbally, like when using a phone. The experiment also takes place in a controlled environment with a CPR doll instead of a real victim. This takes away a lot of the emotional weight that comes with performing real CPR. Since emotions don't

play a big role in the experiment, we expect that there won't be a noticeable change to the social presence subscales related to affect.
Lastly, we expect that *perceived behavioural interdependence* does not change, because bystanders will be performing the exact same tasks with almost the same instructions. The behaviour of the dispatcher is very controlled in the experiment and is therefore not very different in both conditions. However, the bystander might feel watched, which could have an effect on their behaviour. Overall we expect that this will be insignificant.

RQ2.4 CPR quality. The CPR quality is determined by assessing the different factors that contribute to the overall CPR quality, described in section 2.1. For the chest compressions these factors are: compression rate, compression depth, position of the hands, technique and interruptions. These five factors are deemed the most important, as they contribute the most to the effectiveness of the CPR. The remaining factors are not used. These factors are: duty cycle and surface. The duty cycle is difficult to change, as it is largely influenced by other factors such as compression rate and depth. So a good duty cycle automatically results from a good compression depth and rate. The surface is fixed for the experiment, so this does not influence the CPR quality between conditions.
The average *compression rate* is expected to be the same when using ARC or telephone-CPR. Both telephone-CPR and Hololens-CPR allow the dispatcher to count with the bystander and use a metronome to maintain the correct rate. The addition of a visual metronome might make it easier for the bystander to pick up the rate and the average will be better if the correct rate is picked up sooner. So the compression rate of bystanders using ARC could approach the ideal compression rate faster, but ARC does not further improve the compression rate when the metronome is exactly followed, as in both conditions they indicate the same rate.
Compression depth is expected to improve when using ARC, as the dispatcher can see the bystander performing chest compressions. The system also shows the compression depth in a graph to the dispatcher. The dispatcher can use all of this information to give the bystander feedback about the compression depth. This kind of feedback is not possible with telephone-CPR.
Hand positioning is expected to improve when using ARC. The dispatcher can use their hands to show the correct position and use visual instructions that also show where and how the hands should be positioned. Combined with verbal instructions, this should make it easier for the bystander to place the hands in the correct position and use the best technique. If the bystander makes a mistake, the dispatcher is able to see this and give feedback. Giving visual instructions and observing the hand position is not possible with telephone-CPR.
The *number of interruptions* is expected to be the same or lower. Interruptions can occur when the bystander does not know what to do, does not understand the dispatcher or is distracted. On one side ARC can help make instructions clear to the bystander, so the bystander better understands what to do and what the dispatcher means. On the other side, the use of technology that the bystander is not very familiar with and the addition of visuals can be more distracting than telephone-CPR. Overall this effect is expected to be minor, as we designed the system to not be distracting. Therefore the number of interruptions should be the same if not lower.

6.2 Hypotheses

Based on the expectations a set of hypotheses are constructed for each subquestion. The hypotheses compare ARC to telephone-CPR and are listed below:

RQ2.2 How does ARC influence the perceived task load when learning CPR in a dispatcher assisted scenario?

- **H1** ARC decreases the mental demand for the bystander.
- **H2** ARC does not affect the overall perceived task load for the bystander.

We only expect the mental demand to be different. The other subscales of the Raw-TLX are not expected to change. Therefore we don't expect the overall perceived task load to change, since a change in mental demand is unlikely to make a big enough difference for the overall perceived task load.

RQ2.3 How does ARC influence the social presence of the dispatcher for the bystander when learning CPR in a dispatcher assisted scenario?

- **H3** ARC increases Co-presence.
- **H4** ARC increases Perceived message understanding.
- **H5** ARC does not affect overall Social presence.

We only expect the co-presence and perceived message understanding to increase. The other subscales of the social presence questionnaire are not expected to change. Therefore it is unlikely that the overall social presence is different.

RQ2.4 How does ARC influence the CPR quality performed by the bystander when learning CPR in a dispatcher assisted scenario?

- **H6** ARC does not change overall compression rate.
- **H7** ARC improves compressions depth.
- **H8** ARC improves hand position.
- **H9** ARC does not increase compression interruptions.

6.3 Methodology

The experiment had two conditions. The control condition was telephone-CPR, where a bystander learned one-shot CPR from a dispatcher over the phone. The experimental condition was Hololens-CPR, where a bystander learned one-shot CPR from a dispatcher while wearing a Hololens and using ARC. The dispatcher assisted scenario, described in section 4.2.3, was used for the experiment. This required bystanders who don't know how to perform CPR. Therefore, all participants were required to not have followed a CPR course in the past two years. Research suggest that two years is long

enough for someones CPR skill to deteriorate significantly so it is no longer at an effective level (Wilson, Brooks, & Tweed, 1983). Participants also needed to be above the age of 18 for ethical approval. The role of dispatcher was played by the experimenter. All participants took the role of bystander and had the same dispatcher to eliminate this variable. This does mean we had to take into account the learning curve of the dispatcher. Actions were taken to minimise the effect of the learning curve. First the conditions were alternated, starting with the telephone-CPR, so the learning effect was the same over both conditions. Also before the first experiment, the experimenter who takes the role of dispatcher discussed and practised how to be a dispatcher together with a CPR expert. Also a pilot was done to make sure ARC and the dispatcher were ready for the experiments. After the experiment, all participants were asked to fill in a questionnaire.

6.3.1 Participants

In total 58 participants participated as bystander. The telephone-CPR condition has 30 participants of which 17 are male and 13 female, the mean age is 24.5 (sd=8.6, max=56). The Hololens-CPR condition has 28 participants of which 15 are male and 13 are female, the mean age is 22.6 (sd=2.8, max=29). The Hololens-CPR condition originally had 30 participants, but two participants had to be discarded. One participant turned out to have followed a CPR course in the past 2 years, as became apparent from his answer in the questionnaire that asked about any previous experience with CPR courses. The experiment with the other participant is discarded because no data was recorded during the experiment due to a mistake by the experimenter.

6.4 Experiment setup

The experiment took place in a controlled environment. The position of the CPR doll and Kinects were kept the same in both conditions to ensure that the dispatcher has the same view in the Hololens condition. A floor plan of both experiment rooms can be seen in Figure 6.1. A picture of both rooms showing the experiment setup can be seen in Figure 6.2. In the bystander room, two Kinects were used to give the dispatcher a full detailed view of both the CPR doll and bystander. One Kinect was looking directly at the CPR doll and the other was looking over the CPR doll to where the bystander was located. A camera was placed in the centre of the room that has a full view of both the bystander and CPR doll. This camera was used to record the bystander during the experiment. The Kinects, camera and CPR doll were connected to the bystander PC. This PC sent all the data to the dispatcher PC. In the telephone-CPR condition the participant was given a telephone and in the Hololens condition a Hololens before entering the room. A blanket was placed in front of the CPR doll to make it more comfortable for the bystander to kneel during the experiment. The back of the room was covered up with a black sheet to hide some stuff that was present in the room and not part of the experiment.

The dispatcher room was located next to the bystander room. Since the rooms are separated by a wall it was not possible for the dispatcher and bystander to directly

communicate. Therefore all communication went through either ARC or a telephone. The dispatcher had a headset and complete HTC Vive VR setup connected to the dispatcher PC. This PC was also used after the experiment by the participant to fill in the questionnaire. For telephone-CPR, the dispatcher only used the headset and not the VR setup.

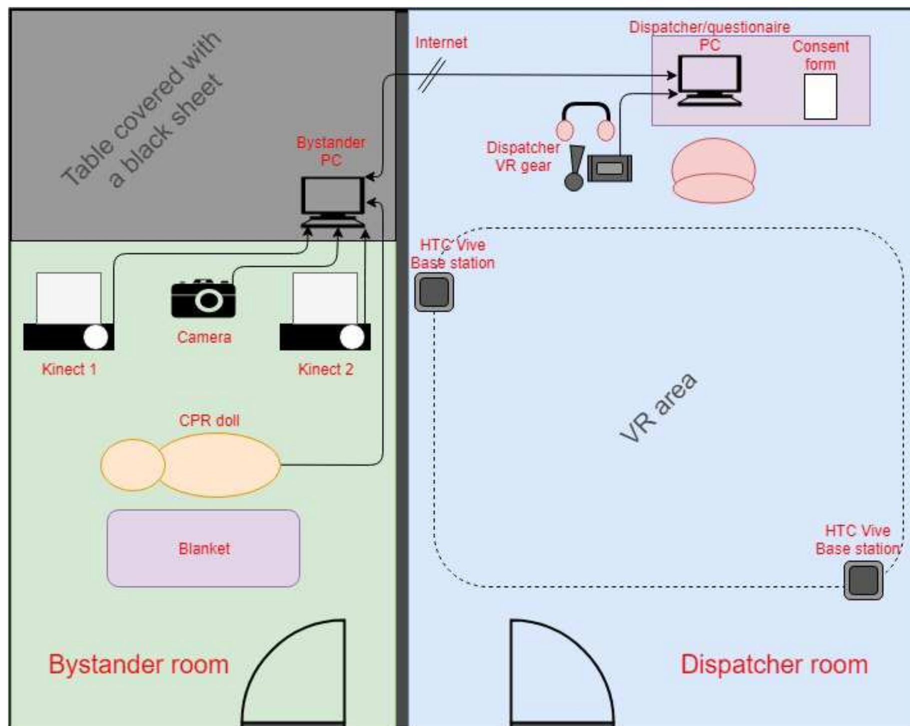


Figure 6.1: Floor plan of both rooms used for the experiment.

6.5 Experiment procedure

A strict protocol was followed by the dispatcher during the experiment. Before the experiment the participant was asked to sign a consent form, which can be found in Appendix A1. After the consent form was signed, the participant was guided to the bystander room with either a telephone or Hololens on and given instructions to wait. The dispatcher sets up in the dispatcher room and started communication with the bystander. The bystander was instructed that their would be guided through the process of performing CPR and that the doll in front of the participant is an unconscious person. The participant was also told that there would be a task where they needed to perform rescue breaths and that they should blow on the face of the doll instead of putting their mouth on the doll, this is to prevent tracking issues with the Hololens. These instructions were the same for both conditions. After the initial instructions the experiment

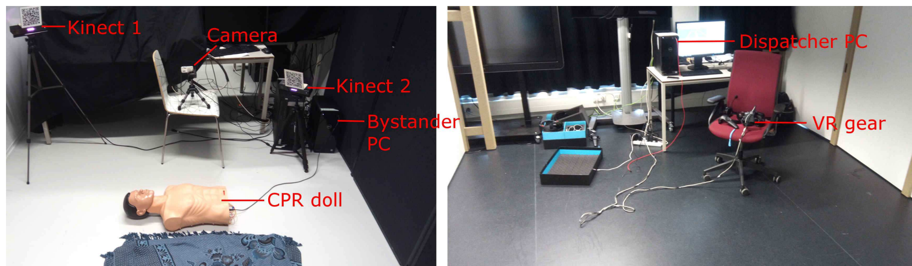


Figure 6.2: Experiment setup. Left; bystander room. Right; dispatcher room.

starts. The instructions used to teach the bystander CPR are copied from the dispatcher protocol used in Dutch emergency call centres. For Hololens-CPR these instructions are extended to include the placement of visual aids and the use of hands to guide the instructions. The full protocol for each condition that highlights the differences can be found in Appendix A2. The dispatcher teaches the bystander three different tasks; a chin lift, chest compressions and a rescue breath. First the chin lift is explained so the bystander can check if the victim is breathing. Second the chest compressions are explained followed by the rescue breath after 30 compressions. With Hololens-CPR the dispatcher places video instructions in front of the bystander before every task. For chest compressions and rescue breaths, the videos are only used during the first two sets. The arrows augmented on the CPR doll automatically appear when a video is active. The position of the videos is always at the same position to ensure consistency during the experiment. After the second set the video aids are no longer used to prevent distraction. After the second set the dispatcher can place the visual metronome if the bystander is not performing CPR at the correct compression rate. In both conditions the dispatcher can at any point count together with the bystander to help with the compression rate. After the participant has performed eight sets of CPR, the participants is asked to stop and come to the other experiment room to fill out the questionnaire.

6.6 Data Processing

We look at the difference between the scores of each condition. Scores that fall outside of 1.5 times the interquartile range above the upper quartile and below the lower quartile are considered outliers. Outliers are marked as dots in the box plots, as can be seen in Section 6.7, and are removed from the dataset for further analysis.

Task load. To test hypothesis H1 and H2, we use the *Raw-TLX* in the questionnaire. Participants rated each subscale on a scale of 0 to 20. The scores of all participants for Hololens-CPR are compared to the scores of the participants for telephone-CPR. First a Shapiro-Wilk test is performed to determine if the scores for each condition can't be rejected as a normally distributed sample. If we can't reject the sample as being normally distributed, we assume that the sample is normally distributed and perform a independent t-test to determine if there is a statistically significant difference between the scores of the subscales for both conditions. A one-tailed independent t-test is per-

formed to determine if the *Mental Demand* is lower compared to telephone-CPR. For the overall task load we add the scores of all subscales for each participant and compare the total scores. A two-tailed independent t-test is performed to determine if the *overall task load* is significantly different and if the remaining subscales are significantly the same between both conditions. If the Shapiro-Wilk test shows that the scores of the Hololens- or telephone-CPR are not normally distributed, we use a Mann–Whitney U test instead of a t-test.

Social presence. For hypothesis H3, H4 and H5 we use the same procedure. Participants filled in the *social presence* questionnaire which was embedded into the questionnaire after the experiment. All questions were on a five-level Likert scale from strongly disagree to strongly agree. We take the average scores of all questions for every subscale. (Harms & Biocca, 2004) only report positive factor loadings for each questions, so the scores of inverted questions are inverted before being added to the subscale average. An example of an inverted questions is: "The instructor did not receive my full attention.", instead of: "The instructor received my full attention." The numbers of the inverted questions are: 7, 8, 11, 12, 17, 18, 21 and 22. First a Shapiro-Wilk test is performed and then a independent t-test for the scores of each subscale that is assumed to be normally distributed. A one-tailed t-test is performed to determine if the *Co-presence* and *Perceived message understanding* is significantly higher. For the *social presence* we average the scores of all subscales for each participant and compare the total scores. A two-tailed independent t-test is performed to determine if the *social presence* is significantly different and if the remaining subscales are significantly the same between both conditions.

CPR quality. The data collected with the CPR doll is used to test hypothesis H6 and H7. A script was written that automatically classifies 8 sets of 30 chest compressions from the data of each participant. A set can be detected by looking for the first and last compression of a set. The last compression is classified by looking for the compression before there is a 3 second absence of compressions. The average compression rate (compressions per minute) and compression depth was recorded to a dataset, for the first half and second half of each set and for each full set. The compression rate is based on the time in between compressions and the compression depth is approximated from the force measured on the CPR doll. The force values for the 5 and 6 centimetre optimal range were calculated before the experiment. This was done by compressing the chest by either 5 or 6 centimetre and measuring the sensor values five different times and averaging the result. In practice a set does not always consist of exactly 30 compressions, so a tolerance of 10 compressions was allowed. From the 58 participants the script was able to successfully classify the data of 48 participants (23x telephone-CPR and 25x Hololens-CPR). Successful classification means that exactly 8 sets where found, all with around 30 compressions. Unsuccessful classifications are disregarded and not used for further analysis regarding CPR quality.
To test hypothesis H8 and H9 about improved hand position and interruptions, we annotated the video footage of 15 participants for each condition. The participants used were randomly selected and annotated in order of selection. We also alternated between both conditions, until the footage of all 30 participants was annotated. Since we used a single annotator, we created a strict set of rules to prevent any biases. The

hand position could either be labelled *correct* or *wrong*. All the footage where two hands are on the CPR doll must be labelled, this is always from the moment two hands touch the CPR doll till the end of a set when the hands no longer touch the CPR doll. The heel of the first hand needs to touch the centre of the chest. The other hand needs to be on top of the first hand. The fingers of both hands must point in the same direction. The last three rules are based on how the European Resuscitation Council dictates the hand technique (Perkins et al., 2015). If any of these rules are violated during any part of a set, that part is labelled as *wrong*, otherwise as *correct*. It should be noted that different techniques can also be effective, but our rules follow the official guidelines and the instructions given to the participant during the experiment are also according to these rules. This means that if the hand position is labelled wrong, the participant did not follow the instructions correctly. We also took special note of any participants where the heel of the hand wasn't on top of the centre of the chest, as this drastically affects the effectiveness of the chest compressions. The rules for annotating were easy to follow, with the only grey area being if the fingers of both hands were pointing in the same direction. If there was any doubt, the compressions were annotated as being *correct*. Figure 6.3 illustrates different hand positions and if they are *correct* or *wrong* according to the set of rules.
Interruptions were also annotated. We define an interruption as pause in chest compressions of at least two seconds in between the first and last compression of a set. For this research we only counted the interruptions during a set. These rules were easy to follow as their is a clear difference between the bystander performing compressions and the bystander pausing. Any delays or interruptions before the CPR starts or in between sets is out of the scope of this research.

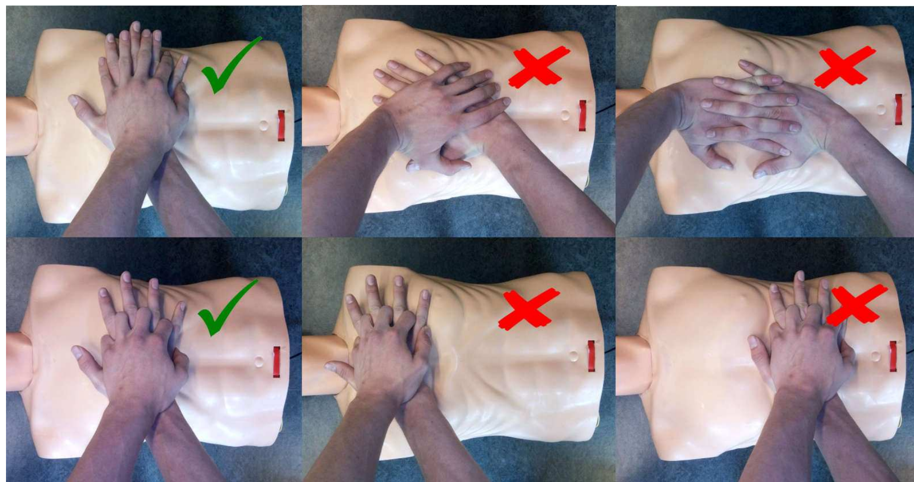


Figure 6.3: *Correct* and *wrong* hand positions according to the rules used. Top row illustrates direction of the fingers and the bottom row where the heel of the hand touches the chest.

6.7 Results

The results are split into four sections; first the observations of instructions and feedback given when using ARC, second the analysis of the Raw-TLX related to hypothesis H1 and H2, third the analysis of social presence related to H3, H4 and H5 and finally the analysis of CPR quality related to H6, H7 and H8. All score samples are first tested with a Shapiro-Wilk test. Only the results of this test that reject a sample as being normally distributed are given in this section. All other samples are assumed to be normally distributed.

6.7.1 New ways to give instructions and feedback

In this section we will answer the following research question:
RQ2.1 *What kind of instructions and feedback can the dispatcher give using ARC?*

We do this with the use of observations made during the experiment. There were three different tasks that the bystander had to perform during the experiment. For each task the instructor gave instructions and had the ability to give feedback. We'll look at by what type of communication the instructions and feedback were given and how. Table 6.1 shows a comprehensive list of observations made for the tasks of both the telephone-CPR and Hololens condition.
If we look at the similarities between conditions, we can see that Hololens-CPR has all of the different instructions and feedback possibilities that telephone-CPR has. In addition, Hololens-CPR in the experiment also shows new possibilities for giving instructions and feedback. On the instruction side the main difference is the addition of visual support when giving instructions. The dispatcher from Hololens-CPR used instructional videos, arrows pointing to where the hands need to be placed and the dispatcher's hands. On the feedback side we see new types of feedback that are not possible for telephone-CPR. These new types of feedback are possible in Hololens-CPR due to the dispatcher being able to see the bystander. With Hololens-CPR the dispatcher gives feedback about hand placement and technique of the bystander, also feedback about the compression depth is given.
In summary, due to the dispatcher being able to observe the bystander in Hololens-CPR, the dispatcher can give feedback about hand positioning, technique and compression depth of tasks performed by the bystander. Also the instructions and feedback can be both verbal and visual, compared to only verbal in telephone-CPR. The addition of visuals allows the dispatcher to direct attention by pointing using their hands or arrows and show examples of the tasks explained using their hands or videos.

Condition	Task	Type	Verbal	Visual	Observations (The dispatcher can...)
Telephone	Chin lift	Instruction	Yes	No	Describe hand position Describe movement of victim's chin
Hololens	Chin lift	Instruction	Yes	Yes	Describe and show hand position with use of hands, two arrows and video Describe and show hand movement with use of hands and video
Hololens	Chin lift	Feedback	Yes	Yes	Correct position of hand under the chin by pointing to the chin and referring to the example in the video Describe movement of victim's chin Give confirmation that the task is performed correctly
Telephone	Compression	Instruction	Yes	No	Describe hand, arm and shoulder position Describe movement and compression rate
Hololens	Compression	Instruction	Yes	Yes	Describe and show hand, arm and shoulder position with use of hands, one arrow and video Describe and show movement with use of video
Telephone	Compression	Feedback	Yes	No	Count out loud to indicate compression rate Tell to go faster/slower Use a metronome to help with compression rate
Hololens	Compression	Feedback	Yes	Yes	Count out loud to indicate compression rate Tell to go faster/slower Place a visual metronome to help with compression rate Tell to press harder/softer Correct wrong hand position by showing correct position with hands and referring to video Give confirmation that the task is performed correctly
Telephone	Rescue breath	Instruction	Yes	No	Describe hand positions Describe movement of victim's chin Describe how to pinch the victim's nose Describe Breath duration and volume
Hololens	Rescue breath	Instruction	Yes	Yes	Describe and show hand positions with use of hands, two arrows and video Describe and show movement of victim's chin with use of video Describe and show how to pinch the victim's nose with use of hands and video
Hololens	Rescue breath	Feedback	Yes	Yes	Correct position of hand under the chin by pointing to the chin and referring to the example in the video Correct if the nose is not pinched Tell to take a good breath in between rescue breaths

Table 6.1: Overview of all observations made about instructions and feedback given by the dispatcher during the experiment (only feedback related to a task is included).

6.7.2 Task load

In this section the results of the Raw-TLX are reported.

✓ **H1 ARC decreases the mental demand for the bystander.** A one-tailed independent t-test was performed to compare the perceived *Mental Demand* between Hololens- and telephone-CPR, see Figure 6.4a. There was a significant negative difference in the scores for Hololens-CPR (m=8.286, sd:4.487) and telephone-CPR (m=10.500, sd:4.703); t(56)=-1.835, p=0.036, mean of the differences = -2.214. The results show that ARC does decrease the *Mental Demand* for the bystander compared to telephone-CPR.

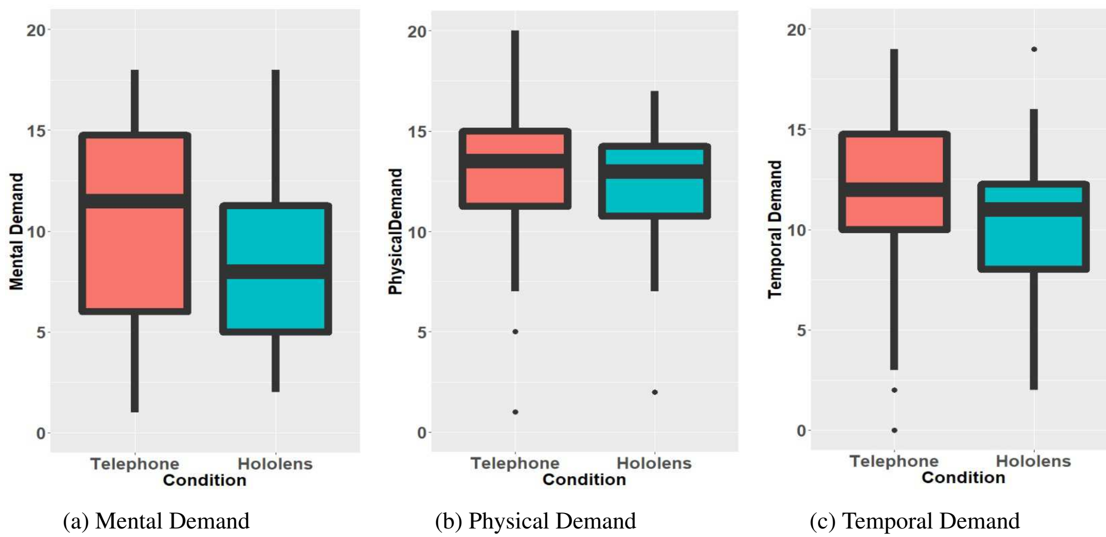
✗ **H2 ARC does not affect the overall perceived task load for the bystander.** A two-tailed independent t-test was performed to compare the overall *perceived task load* between Hololens- and telephone-CPR, see Figure 6.6. There was a significant negative difference in the scores for Hololens-CPR (m=61.370, sd:11.513) and telephone-CPR (m=70.267, sd:16.526); t(52)=-2.377, p=0.021, mean of the differences = -8.896. The results suggest that ARC does not have the same *overall task load* compared to telephone-CPR.

A Shapiro-Wilk test for the difference in *Frustration* resulted in a p-value of p=0.0376. This suggests that the distribution of the sample is not normally distributed and a t-test cannot be conducted. Instead we used a two-tailed Mann–Whitney U test to compare the perceived *Frustration* between Hololens- and telephone-CPR, see Figure 6.4a. There was not a significant difference in the scores for Hololens-CPR (m=6.500, sd:4.694) and telephone-CPR (m=8.500, sd:4.833); w=313.5, p=0.0979, mean of the differences = -2.000. The results suggest that ARC does not change the *Frustration* for the bystander compared to telephone-CPR.

A two-tailed independent t-test was performed for the remaining subscales of the Raw-TLX to determine if there is no significant difference between both conditions. These results are summarised in Table 6.2. The corresponding box plots for these subscales are shown in Figure 6.4 and Figure 6.5. These results show that the *Effort* is not significantly the same for Hololens-CPR compared to telephone-CPR, with p=0.049. This suggests that ARC has not the same perceived *Effort* compared to telephone-CPR. The results for the other subscales show that we can't reject the hypothesis that the scores are the same between conditions.

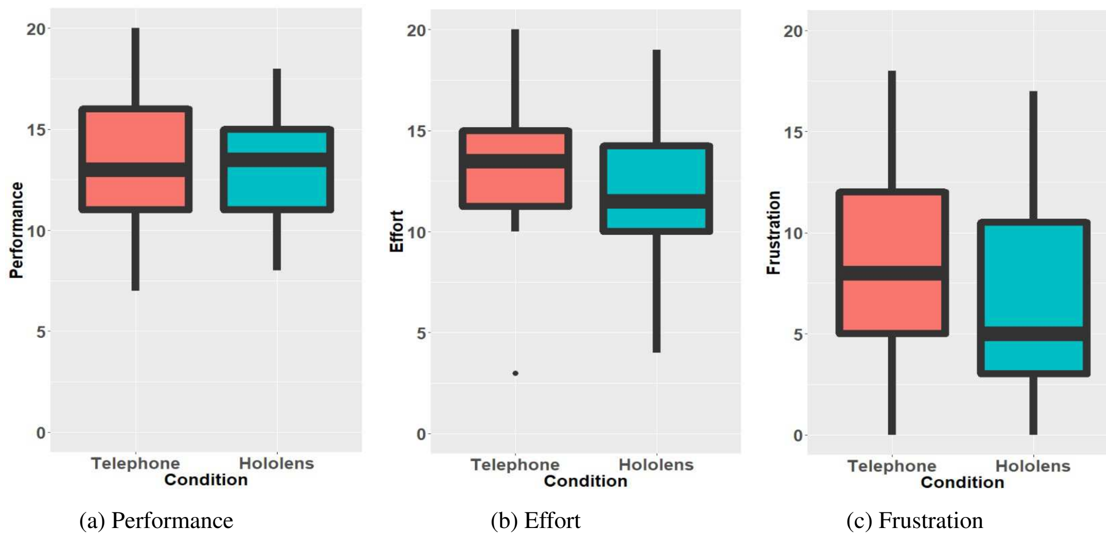
Subscale	Condition	mean	sd	df	t	p	diff. mean	w
Mental Demand								
	Hololens-CPR	8.286	4.487	56	-1.835	**0.036**	-2.214	
	telephone-CPR	10.500	4.703					
Physical Demand								
	Hololens-CPR	12.654	2.799	51	-1.414	0.163	-1.203	
	telephone-CPR	13.857	3.440					
Temporal Demand								
	Hololens-CPR	10.481	3.105	52	-2.001	0.051	-1.876	
	telephone-CPR	12.357	3.822					
Performance								
	Hololens-CPR	13.357	2.711	54	0.110	0.9125	0.090	
	telephone-CPR	13.267	3.503					
Effort								
	Hololens-CPR	11.929	3.600	49	-2.019	**0.049**	-1.692	
	telephone-CPR	13.621	2.638					
Frustration								
	Hololens-CPR	6.500	4.694			0.0979	-2.000	313.5
	telephone-CPR	8.500	4.833					

Table 6.2: Two-tailed independent t-test results of Raw-TLX subscale scores for Hololens-CPR versus telephone-CPR (a Mann-Whitney U test was used for the Frustration subscale scores).



(a) Mental Demand (b) Physical Demand (c) Temporal Demand

Figure 6.4: Raw-TLX scores of first three subscales.



(a) Performance (b) Effort (c) Frustration

Figure 6.5: Raw-TLX scores of last three subscales.

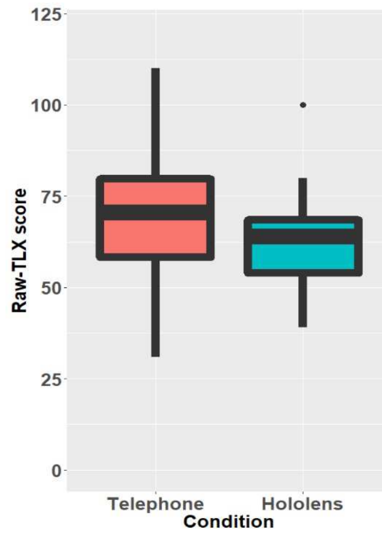


Figure 6.6: Overall Raw-TLX scores.

6.7.3 Social presence

In this section the results of the Social presence questionnaire are reported.

✗ **H3 ARC increases Co-presence.** A one-tailed independent t-test was performed to compare the *Co-presence* score between Hololens- and telephone-CPR, see Figure 6.7a. There was not a significant difference in the scores for Hololens-CPR (m=4.222, sd:0.599) and telephone-CPR (m=4.183, sd:0.392); t(44)=0.286, p=0.3879, mean of the differences = 0.038. The results show that ARC does not increase the *Co-presence* for the bystander compared to telephone-CPR.

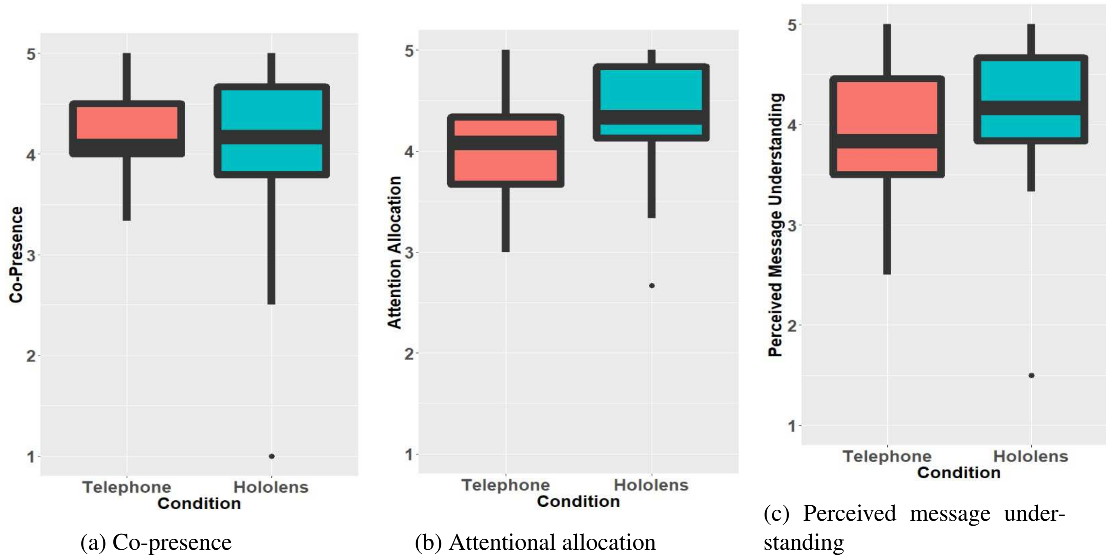
✓ **H4 ARC increases Perceived message understanding.** A one-tailed independent t-test was performed to compare the *Perceived message understanding* between Hololens- and telephone-CPR, see Figure 6.7c. There was a significant positive difference in the scores for Hololens-CPR (m=4.222, sd:0.460) and telephone-CPR (m=3.850, sd:0.716); t(50)=2.359, p=0.011, mean of the differences = 0.372. The results show that ARC does increase the *Perceived message understanding* for the bystander compared to telephone-CPR.

✗ **H5 ARC does not affect overall Social presence.** A two-tailed independent t-test was performed to compare the *Social presence* score between Hololens- and telephone-CPR, see Figure 6.9. There was a significant negative difference in the scores for Hololens-CPR (m=3.799, sd:0.293) and telephone-CPR (m=3.523, sd:0.356); t(54)=3.18, p=0.002, mean of the differences = 0.276. The results suggest that ARC does not have the same *Social presence* compared to telephone-CPR.

A two-tailed independent t-test was performed for the remaining subscales of the Social presence questionnaire to determine if there is no significant difference between both conditions. These results are summarised in Table 6.3. The corresponding box plots for these subscales are shown in Figure 6.7 and Figure 6.8. These results show that the *Attentional Allocation* is not significantly the same for Hololens-CPR compared to telephone-CPR, with p=0.001. Also the *Perceived Behavioural Interdependence* is not significantly the same for Hololens-CPR compared to telephone-CPR, with p=0.0268. The results for the other subscales can't reject the null hypothesis that the scores are different between conditions.

Subscale	Condition	mean	sd	df	t	p	diff. mean
Co-presence							
	Hololens-CPR	4.222	0.599	44	3.420	.3879	0.038
	telephone-CPR	4.183	0.392				
Attentional Allocation							
	Hololens-CPR	4.438	0.453	55	0.286	**0.001**	0.444
	telephone-CPR	3.994	0.526				
Perc. message understanding							
	Hololens-CPR	4.222	0.460	50	2.359	**0.011**	0.372
	telephone-CPR	3.850	0.716				
Perc. Affective Understanding							
	Hololens-CPR	3.018	0.750	47	0.870	0.388	0.149
	telephone-CPR	2.869	0.506				
Perc. Affective Interdependence							
	Hololens-CPR	2.790	0.586	53	1.465	0.149	0.268
	telephone-CPR	2.522	0.789				
Perc. Behavioural Interdependence							
	Hololens-CPR	4.080	0.385	53	2.279	**0.0268**	0.241
	telephone-CPR	3.839	0.399				

Table 6.3: Two-tailed independent t-test results of Social presence subscale scores for Hololens-CPR versus telephone-CPR.

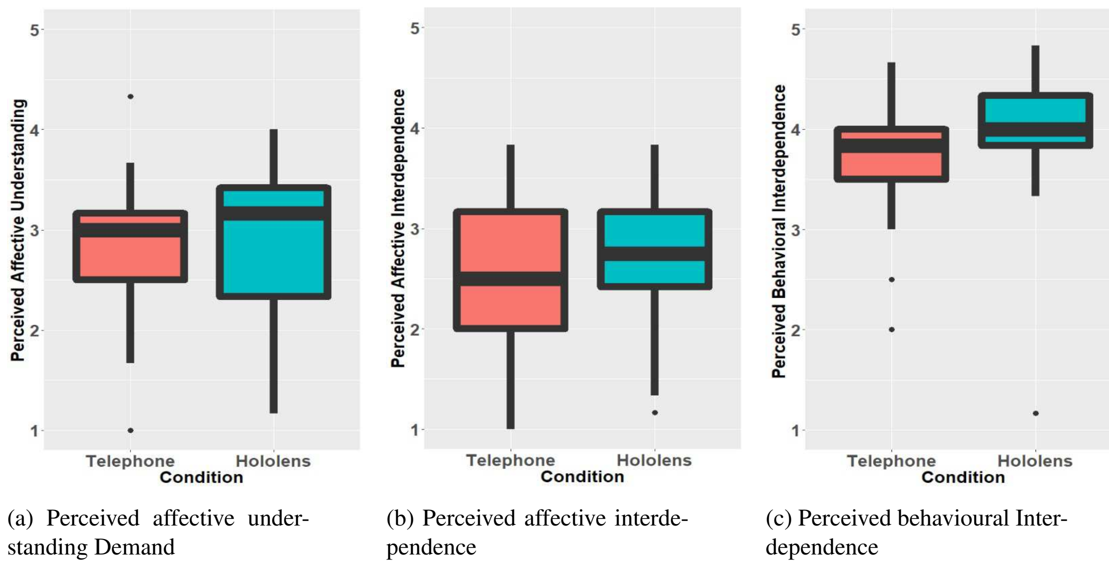


(a) Co-presence

(b) Attentional allocation

(c) Perceived message understanding

Figure 6.7: Social presence scores of first three subscales.



(a) Perceived affective understanding Demand

(b) Perceived affective interdependence

(c) Perceived behavioural Interdependence

Figure 6.8: Social presence scores of last three subscales.

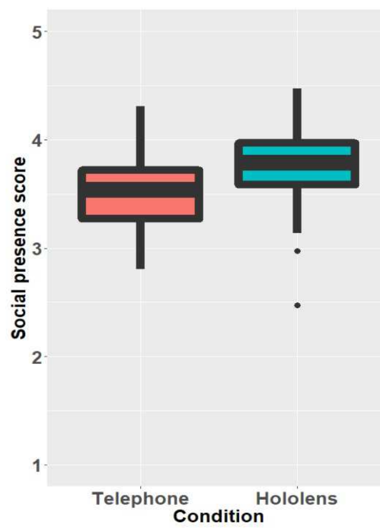


Figure 6.9: Overall Social presence scores.

6.7.4 CPR quality

In this section the results for the different CPR quality factors are reported.

✓ **H6** ARC does not change overall compression rate.
For the overall compression rate we first look at the average compression rate for each of the eight sets. Since there is a range of 100-120 cpm indicating the optimal compression rate, we take the distance from this range as score. A lower score means higher quality CPR as it represents a compression rate that is closer to the optimal range. We performed a repeated measures ANOVA with the set as the independent variable and average compression rate score for the set as dependant variable. The descriptive statistics are reported in Table 6.4. Figure 6.10 shows a box plot of the compression rate score and Figure 6.11 shows a box plot of the absolute compression rate score. The absolute compression rate score is regardless of whether the compression rate was above or below the ideal range. The absolute score is used for further analysis of the compression rate.
First we performed a Mauchly's Test of Sphericity to test the null hypothesis that the error covarience matrix of the dependent variables is proportional. The result is significant with p<0.001, Mauchly's W=0.008, Chi-Square=208.314 and df=27. This means that we can not assume sphericity and have to use a GreenHouse-Geisser test for our within-subjects effects, because this test corrects for the violation of sphericity. Also a type III sum of squares is used, since we do not assume equal variances. The results showed a significant difference in compression rate scores over the first (set 1) to the last set (set 8); F(2.677, 123.135)=28.716, p<0.001. Bonferonni post-hoc analysis showed that set 1 is significantly higher compared to all other sets (p<0.001) and set 2 is significantly higher than set 3 (p=0.23), 7 (p=0.03) and 8 (p=0.031). All other set pairs are not significantly different. Lower compression rate scores equal better quality CPR, since the compression rate is closer to the ideal range. Next we performed a test of between-subjects effects, to see if the condition has an effect on the increase of compression rate performance during the first sets. The result showed no significant difference in variation between Hololens-CPR and telephone-CPR; F(1)=2.083 and p=0.156.
We also compared the compression rate score average of all eight sets combined between Hololens-CPR and telephone-CPR, see Figure 6.12. A Shapiro-Wilk test resulted in a p-value of p<0.001. This suggests that the distribution of the sample is not normally distributed and a t-test cannot be conducted. Instead we used a two-tailed Mann-Whitney U test to test if the averages of both conditions are the same. There was not a significant difference in the scores for Hololens-CPR (m=3.799, sd:4.101) and telephone-CPR (m=6.266, sd: 8.194); w=15641, p=0.265, mean of the differences = -2.467. The results show that ARC does not influence the average compression rate score of all sets combined compared to telephone-CPR.
The repeated measures ANOVA shows that the average compression rate over a set gets closer to to the optimal range after set 1 and set 2 for both Hololens-CPR and telephone-CPR, but there is no significant difference in variation between both conditions. The Mann-Whitney U test showed that the average compression rate deviation from the optimal range over all sets is the same for both Hololens-CPR and telephone-CPR.

Set	Condition	mean	sd	participants
1				
	Hololens-CPR	11.68	8.943	25
	telephone-CPR	16.22	11.560	23
2				
	Hololens-CPR	5.96	6.605	25
	telephone-CPR	9.22	10.979	23
3				
	Hololens-CPR	4.96	4.783	25
	telephone-CPR	5.61	8.338	23
4				
	Hololens-CPR	4.32	3.739	25
	telephone-CPR	5.43	9.990	23
5				
	Hololens-CPR	3.56	3.525	25
	telephone-CPR	5.96	9.772	23
6				
	Hololens-CPR	3.00	2.944	25
	telephone-CPR	6.48	8.790	23
7				
	Hololens-CPR	2.36	3.604	25
	telephone-CPR	5.30	9.484	23
8				
	Hololens-CPR	2.40	3.594	25
	telephone-CPR	5.74	8.454	23

Table 6.4: Descriptive statistics of the average compression rate from optimal 100-120 cpm range for each set.

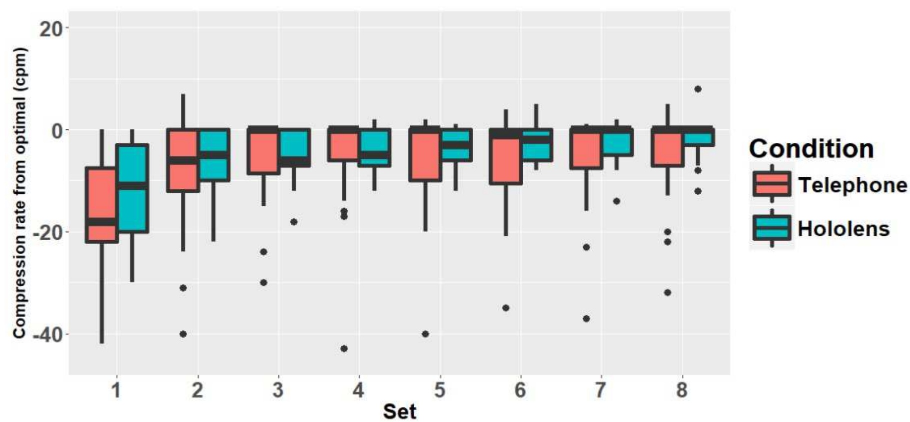


Figure 6.10: Compression rate deviation from optimal 100-120 cpm range for each set.

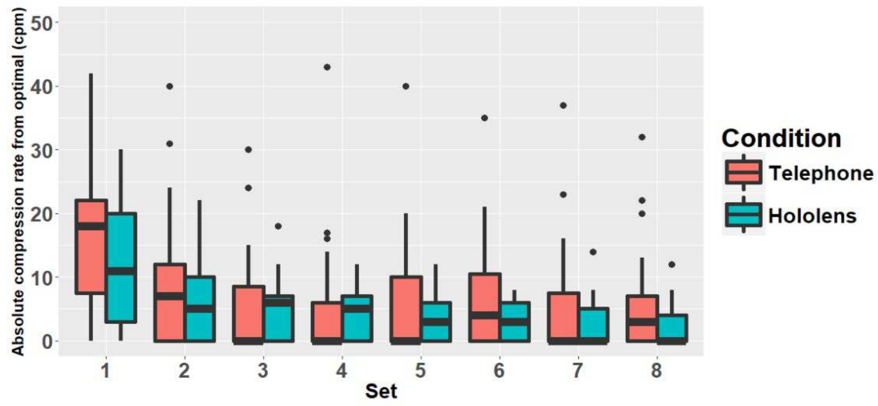


Figure 6.11: Absolute compression rate deviation from optimal 100-120 cpm range for each set.

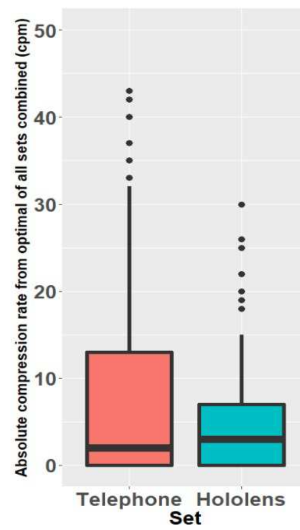


Figure 6.12: Average compression rate deviation from optimal 100-120 cpm range of all sets combined.

✓ **H7** ARC improves compressions depth.
For the compression depth we first look at the average compression depth for each of the eight sets. Since there is a range of 5-6cm indicating the optimal compression depth, we take the distance from this range as score. A lower score means higher quality CPR as it represents a compression depth that is closer to the optimal range. We performed a repeated measures ANOVA with the set as the independent variable and average compression depth score for the set as dependant variable. The descriptive statistics are reported in Table 6.5. Figure 6.13 shows a box plot of the compression depth score and Figure 6.14 shows a box plot of the absolute compression depth score. The absolute compression depth score is regardless of whether the compression depth was above or below the ideal range. The absolute score is used for further analysis of the compression depth.
First we performed a Mauchly's Test of Sphericity to test the null hypothesiss that the error covarience matrix of the dependent variables is proportional. The result is significant with p<0.001, Mauchly's W=0.120, Chi-Square=92.082 and df=27. This means that we can not assume sphericity and have to use a GreenHouse-Geisser test for our within-subjects effects, because this test corrects for the violation of sphericity. Also a type III sum of squares is used, since we do not assume equal variances. The results showed a significant difference in compression depth scores over the first (set 1) to the last set (set 8); F(3.926, 180.583)=4.057, p=0.004. Bonferonni post-hoc analysis showed that set 1 is significantly higher compared to set 2 (p=0.096), 3 (0.009), 4 (0.008) and 5 (0.012). All other set pairs are not significantly different. Lower compression depth scores equal better quality CPR, since the compression depth is closer to the ideal range. Next we performed a test of between-subjects effects, to see if the condition has an effect on the increase of compression depth performance during the first sets. The result showed no significant difference in variation between Hololens-CPR and telephone-CPR; F(1)=2.339 and p=0.133.
We also compared the compression depth score average of all eight sets combined between Hololens-CPR and telephone-CPR, see Figure 6.15. A Shapiro-Wilk test resulted in a p-value of p<0.001. This suggests that the distribution of the sample is not normally distributed and a t-test cannot be conducted. Instead we used a one-tailed Mann-Whitney U test to test if the average of Hololens-CPR is lower than for telephone-CPR. There was a significant difference in the scores for Hololens-CPR (m=0.294, sd:0.493) and telephone-CPR (m=0.500, sd: 0.734); w=16153, p=0.012, mean of the differences = -0.206. The results show that ARC lowers the average compression depth score of all sets combined and therefore improves the compression depth factor for CPR performed by the bystander compared to telephone-CPR.
The repeated measures ANOVA shows that the average compression depth over a set gets closer to to the optimal range after set 1, but deviates again for the last three sets. There is no significant difference in variation found between Hololens-CPR and telephone-CPR. The Mann-Whitney U test showed that the average compression depth deviation from the optimal range over all sets is lower for Hololens-CPR compared to telephone-CPR.

Set	Condition	mean	sd	participants
1				
	Hololens-CPR	0.669	0.656	25
	telephone-CPR	0.704	0.676	23
2				
	Hololens-CPR	0.296	0.642	25
	telephone-CPR	0.509	0.782	23
3				
	Hololens-CPR	0.322	0.535	25
	telephone-CPR	0.371	0.522	23
4				
	Hololens-CPR	0.218	0.303	25
	telephone-CPR	0.418	0.631	23
5				
	Hololens-CPR	0.216	0.376	25
	telephone-CPR	0.320	0.594	23
6				
	Hololens-CPR	0.202	0.321	25
	telephone-CPR	0.601	0.906	23
7				
	Hololens-CPR	0.215	0.415	25
	telephone-CPR	0.534	0.820	23
8				
	Hololens-CPR	0.214	0.445	25
	telephone-CPR	0.545	0.879	23

Table 6.5: Descriptive statistics of the average compression depth from 5-6 cm range for each set.

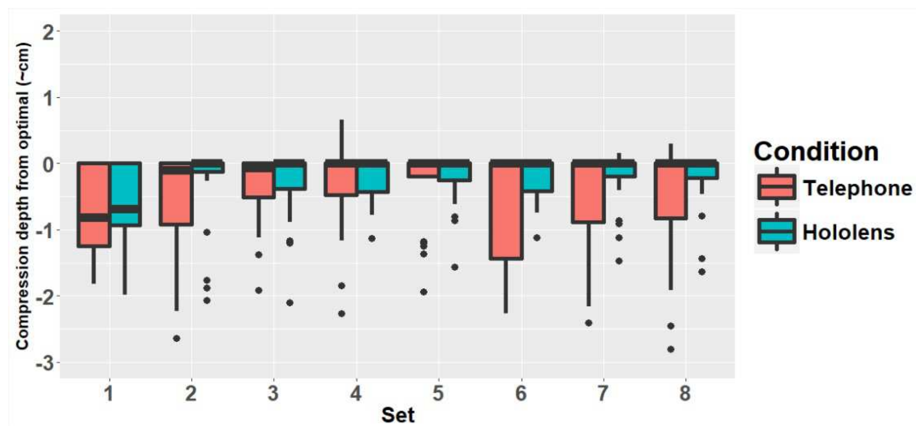


Figure 6.13: Compression depth deviation from from 5-6 cm range for each set.

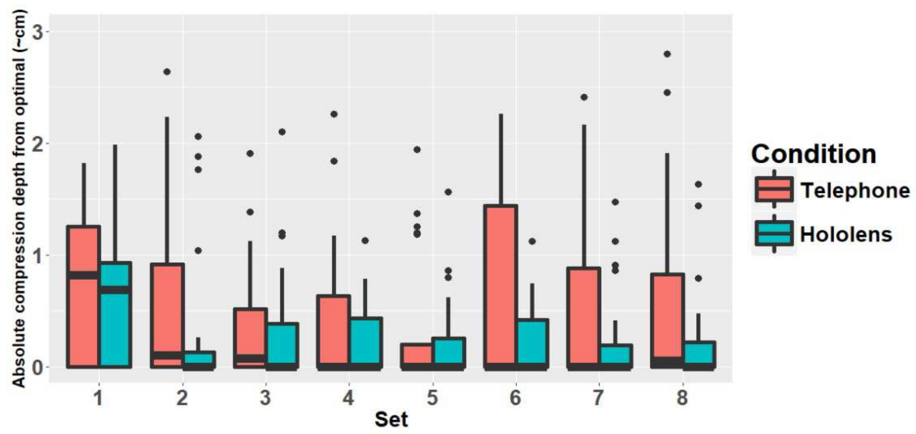


Figure 6.14: Absolute compression depth deviation from 5-6 cm range for each set.

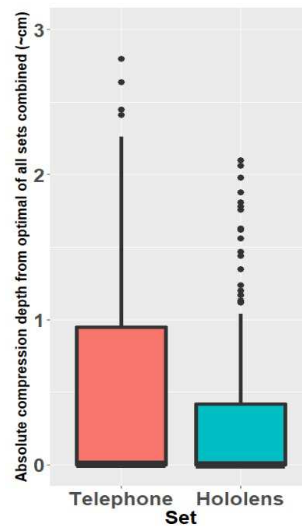


Figure 6.15: Average compression depth deviation from optimal 5-6 cm range of all sets combined.

✓ **H8** ARC improves hand position.
Correct and *wrong* hand positions are determined following the rules described in section 6.6. We look at the differences of hand position between Hololens-CPR and telephone-CPR by categorising the 15 participants who were annotated for each condition. The first category consists of participants who only had *correct* hand positions during all eight sets. The second category consists of participants who made one or more mistakes and have parts of a set labelled as *wrong*. All these mistakes were only during part of a single set, which means these participants improved their hand position during the set where the mistake took place. The last category consists of the remaining participants who only had *wrong* hand positions during all eight sets. The results are summarised in Table 6.6.

Condition	Category			Total participants
	Only *correct*	One or more *wrong* occurrences	Only *wrong*	
Hololens-CPR	9	6	0	15
telephone-CPR	4	4	7	15

Table 6.6: Number of participants that fall into the different categories of hand position.

The results show that only participants using telephone-CPR were labelled with *wrong* hand positions for all eight sets. These participants didn't use the technique that was instructed over the phone and retained this for the duration of the CPR. We also observed that out of these 7 participants, two participants didn't have the heel of their hand on top of the centre of the chest. One of these participants had the heel on the stomach of the CPR doll and the other participant on the upper part of the chest. These observations combined suggest that Hololens-CPR improves hand position compared to telephone-CPR.

✓ **H9** ARC does not increase compression interruptions.
Interruptions are determined following the rules described in section 6.6. The results are summarised in Table 6.7. There were only a few interruptions over all participants combined. The number of interruptions we observed for both conditions suggest that Hololens-CPR indeed does not increase compression interruptions compared to telephone-CPR.

Condition	Interruptions	Average interruption time (sec)	Total interruption time (sec)
Hololens-CPR	3	3.31	9.93
telephone-CPR	5	5.10	25.51

Table 6.7: Summary of chest compression interruptions.

6.8 Discussion

An experiment has been conducted to compare Hololens-CPR to telephone-CPR in a controlled one-shot dispatcher assisted CPR scenario. The only difference between the conditions is the use of the ARC system instead of a telephone. The ARC system allowed the dispatcher to be virtually present and see the bystander. ARC also allowed the dispatcher to make use of visual aids to support giving instructions and feedback. In this section we will look at how the use of ARC affected the perceived task load, perception of social presence and CPR quality of the bystander.

Task load. Having the dispatcher virtually present with access to visual tools, that can be used for giving feedback and instructions, results in a lower *Mental Demand* for the bystander when learning how to perform CPR. We think this decrease is caused by the addition of visuals that can be directly related to the learning tasks. Our finding matches with Mayer's principles of Multimedia. Compared to telephone-CPR, in Hololens-CPR information is provided to the bystander via an additional channel, namely the visual channel. According to Mayer the use of multiple channels can lower the *Mental Demand* and improve learning (R. Mayer, 2002). Our finding also agrees with Mayer's Spatial and Temporal Contiguity principles. The visual tools can be used at the same time when explaining the learning tasks, therefore there is no temporal distance. The visuals can also be placed very close to the bystander, even removing the spatial distance completely when the dispatcher places their hands at the exact position where the bystander needs to place their hands. We think that this low Spatial and Temporal distance also contributed to the lower *Mental Demand*.
The results also showed that the perceived *Physical Demand*, *Temporal Demand*, *Performance* and *Frustration* are the same for Hololens-CPR and telephone-CPR, as we expected. This shows that ARC has no significant impact on these task load subscales. We could not establish that the *overall Task load* and perceived *Effort* are the same for Hololens-CPR compared to telephone-CPR. Future research is required to further investigate the effect of ARC on these measures. It could be that *Effort* is more strongly related to *Mental Demand* than we initially thought, being that a task is perceived easier to accomplish if less mental activity is required. Future research could also show if Hololens-CPR can lower the *overall Task load*. It is possible that the lower *Mental Demand* had a bigger impact on *overall Task load* than we predicted and that is why we could not establish that the *overall Task load* is the same for Hololens-CPR compared to telephone-CPR.

Social presence. As expected, Hololens-CPR increases the *Perceived message understanding* for the bystander compared to telephone-CPR. We believe this effect is caused by the addition of visuals. Making use of multiple communication channels can lower the required cognitive load of the bystander (R. Mayer, 2002), making the processing of information easier and resulting in a better understanding of instructions and feedback.
The results also showed that the *Perceived affective understanding* and *Perceived affective interdependence* are the same for Hololens-CPR and telephone-CPR, as we expected. This shows that ARC has no significant impact on these *Social presence*

subscales. We think the reason for this finding is the lack of a full body representation of the dispatcher. ARC only shows the hands and head position of the dispatcher, this only adds a very limited way of using body languages to convey emotions. Also the experiment itself does not promote emotional interaction, as the focus lies on performing tasks and takes place in a controlled setting. We think that emotions play a larger roll if CPR is performed on a real person, it is possible that the *Social presence* subscales related to emotions will be affected differently if measured with bystanders who performed CPR on a real person.
We could not establish that the overall *Social presence*, *Attentional allocation* and *Perceived behavioural interdependence* are the same for Hololens-CPR and telephone-CPR. Future research is required to further investigate the effect of ARC on these measures. For constructing the hypothesis for *Attention allocation* we only took into account the amount of attention that the bystander allocates to the dispatcher, as we deemed this the most important. We did not take into account the attention that the bystander receives from the dispatcher. It could be that bystander perceives the *Attention allocation* differently, caused by the fact that the dispatcher can see the bystander.
We could also not prove that Hololens-CPR results in a lower *Co-presence*. We think that this has to do with the way that the dispatcher was present during the experiment. The dispatcher was standing on the right side of the bystander and was therefore mostly out of the peripheral view of the bystander. Only the hands were sometimes visible during instructions and feedback. *Co-presence* is the level of peripheral awareness of the other and the way the dispatcher was present does not promote peripheral awareness.

CPR quality. The first CPR quality factor that we measured is the compression rate. As expected, Hololens-CPR does not change compression rate compared to telephone-CPR. Both conditions show an improvement of compression rate during the first two sets. From the third set on wards there was no significant change between sets for both conditions. This suggest that most of the learning takes place in the first two sets, as can be expected when learning CPR. The overall compression rate average is also the same for both conditions. We expected to see this results, because in both conditions the dispatcher has access to information about the compression rate. The bystander is asked to always count out loud. This helps with doing 30 chest compressions in between rescue breaths and also gives the dispatcher insight into the compression rate. If necessary, the dispatcher count together with the bystander using a metronome. Making the metronome both visual and auditory didn't change the compression rate compared to an auditory metronome used for telephone-CPR.
The second CPR quality factor that we measured is the compression depth. As expected, Hololens-CPR improves the compression depth compared to telephone-CPR. The overall compression depth average was closer to the optimal range for Hololens-CPR compared to telephone-CPR. We think this improvement can be explained the fact that the dispatcher, using ARC, can visually observe the bystander and therefore has access to information about the compression depth. With this information the dispatcher can give feedback that was otherwise not possible. Both conditions show an improvement of compression depth after the first set. After the fifth set this improvement is no longer present. If we look at Figure 6.14, we see that especially in the telephone-condition there is a large standard deviation for the 6th, 7th and 8th set. A larger

standard deviation suggests a larger difference in performance between participants. In Figure 6.13 we can see that this deviation is towards a compression depth below the optimum. It could be that some participants started to get tired and performed shallower compressions from this point onward, while other participants maintained the same compression depth. Looking at the figures, it seems that this effect is mostly present for telephone-CPR. However, no significant difference was found between both conditions for these last few sets. Future research should look further into this observation, because we think that the presence of a virtual dispatcher could have a positive influence on how well a bystander can maintain a good compression depth while getting physically tired.

The third CPR quality factor that we measured is the hand position. As expected, Hololens-CPR improves the hand position compared to telephone-CPR. The results match with our expectations that the ability of the dispatcher to observe the bystander and use visuals to explain chest compressions can improve the hand position. The fact that 7 out of 15 participants using telephone-CPR didn't perform the chest compressions as instructed, suggests that it is more difficult for bystanders to learn the correct hand position when only given verbal instructions. These 7 participants also didn't improve their hand position at any point during all eight sets, which suggest that telephone-CPR does not allow for feedback regarding hand position. We think that Hololens-CPR has solved both problems and has the potential to further improve hand position by looking at different ways to make use of visuals for feedback. Further research is required to investigate the individual effect of giving the dispatcher the ability to see the bystander and the use of visuals.

The final CPR quality factor that we measured is the number of compression interruptions. As expected, Hololens-CPR does not increase the number of interruptions. We observed less and shorter interruptions for Hololens-CPR compared to telephone-CPR. Though further research is required to investigate if the number of interruptions can significantly decrease when using Hololens-CPR. We think that the effect of Hololens-CPR on interruptions during real-world CPR should also be investigated during future research, as the pressure experienced by the bystander is different to the pressure experienced in an experimental setting. We think that bystanders are less likely to interrupt compressions for any reason if they are performing CPR on a real person.

Chapter 7

Conclusion

We have designed and created ARC, a system that makes use of Augmented Reality to facilitate a dispatcher who one-shot teaches a bystander to perform CPR. ARC provides a new way to teach lay bystanders of a cardiac arrest victim to quickly learn how to perform CPR while emergency services are on the way. ARC has been designed to improve the ways a dispatcher can give instructions and feedback to the bystander and to provide the dispatcher with more information about the performance of the bystander. After ARC was created, we conducted an experiment to compare Hololens-CPR (using ARC) to telephone-CPR. In the rest of this chapter we conclude the answers to the two main research questions: **RQ1** *How to create a VR application for one-shot teaching dispatcher assisted CPR?* and **RQ2** *How does ARC compare to telephone-CPR?* The conclusions to these research questions are reported in this chapter.

7.1 Research questions

RQ1 *How to create a VR application for one-shot teaching dispatcher assisted CPR?* A literature study was conducted to determine how CPR is taught and what factors contribute to the CPR quality. We looked at other systems that use Augmented Reality to teach CPR, like Holo-BLSD (Bottino et al., 2018) and CPReality (Almodovar et al., 2017). These systems augment information to the person performing CPR to help with learning CPR. We found that current AR research only focuses on teaching CPR in a CPR course setting. We also found that AR has a real potential for teaching CPR in a dispatcher assisted scenario. Therefore we decided to design the ARC system that helps a dispatcher to teach CPR to a cardiac arrest victim bystander. The bystander in this scenario does not know how to perform CPR and will learn how to do so on the first try. The goal of this system is to make learning CPR easier for the bystander and help with teaching CPR by enabling the dispatcher to give specific and detailed instructions and feedback to the bystander. To achieve this, the dispatcher needs to be able to observe the bystander. We used the OpenIMPRESS system to allow the dispatcher to be virtually present with the bystander (Harmsen, 2018). The bystander wears a Hololens and can see the dispatcher virtually. The dispatcher uses immersive VR and can see the victim

and bystander in a virtual 3D environment that is reconstructed from depth cameras on the Hololens and Kinect cameras at the location of the bystander. ARC allows the dispatcher to use multiple communication channels when giving instructions and feedback, in an attempt to make learning CPR easier. This follows Mayer's principles of Multimedia (R. Mayer, 2002). Visual aids were created so the dispatcher can make use of the visual communication channel. These aids consist of instruction videos showing how to perform different tasks that are required when performing CPR, arrows pointing to where to place the hands that are linked with the instruction videos and lastly the hands of the dispatcher virtually represented by a 3D model in real-time. The visual aids were also designed to reduce the spatial and temporal distance between the CPR tasks and the information provided to the bystander, this follows Mayer's Spatial and Temporal Contiguity principles.

RQ2 *How does ARC compare to telephone-CPR?* Because the dispatcher is virtually present with ARC, the dispatcher can observe the performance of the bystander. This creates new possibilities for feedback about hand positioning, technique and compression depth. ARC also allows instructions and feedback to be given to the bystander not only verbally, but also visually. The dispatcher can use their own hands to help explain a task, for example by placing their hand where the bystander needs to place a hand. The dispatcher can also use video instructions that show how a task is performed that can be used as an aid when explaining the tasks or place a visual metronome. These features of ARC resulted into a lower *Mental Demand* perceived by the bystander, though we did not find if the overall *task load* is perceived the same. ARC also increases the *Perceived message understanding* for the bystander. We could not find if the *Social presence* is perceived the same or if the *Co-presence* is also increased. We think that the lower *Mental Demand* and increased *Perceived message understanding* support that ARC makes learning CPR easier for the bystander. By conducting the experiment, we found an improvement of CPR quality when using ARC. The results of the experiment showed that the average compression depth deviation from the optimal 5-6 cm range is lower when using ARC instead of a telephone. ARC does not change the compression rate and we could not find a difference in variance between compression sets for both compression depth and rate. The improvement of compression depth can be explained by the fact that the dispatcher can observe the bystander when using ARC and therefore can provide the bystander with feedback about this factor. We found that the ability to give visual instructions and feedback about hand positioning and technique translates into actual improved CPR quality. This is supported by our findings that ARC improves the hand position and does not increase the number of compression interruptions. All observed bystanders using ARC used the technique as explained by the dispatcher, while almost half of the bystanders using telephone-CPR used a different technique or even completely misplaced their hands, rendering the compression useless.

7.2 Future work

In this research we tested the ARC system as a whole. The improvements that ARC provide for teaching CPR, compared to telephone-CPR, come from different parts of the system. Future research should identify the individual contribution of each part.

We mentioned in section 2.1.2 that visual feedback can be distracting for the person performing CPR. ARC uses visual feedback like the visual metronome and video instructions. Future research should investigate when such visual tools can best be used and if they cause distraction. To investigate this, we propose a similar experiment were lay bystanders are taught CPR using ARC. Each experimental condition should only include one of the visual aids and no visual aids in the control condition. Having a better understanding of individual parts of the system will help with creating a system that can be used for real bystander CPR.
We believe that this research has created valuable insights into how to further improve bystander CPR using AR technology and would like to see future research that focuses on how to implement this technology in the real world. Currently, a system like ARC requires state of the art technology and is not yet practical outside of experimental use. With AR capable device emerging, such as dual camera smart phones and smart glasses, we believe that a system like ARC will become viable in the near future.

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Appendices

Appendix A1; Consent form

INFORMED CONSENT FORM (ICF)

Before agreeing to participate in this research study, it is important that you read the following explanation of this study. This statement describes the purpose, procedures, risks, discomforts, and precautions of the experiment. If you encounter a term or expression that you do not understand please ask the experimenter for clarification. Before accepting to participate in this study, you are free to consult with anyone to feel comfortable about this research. If you want, you can take a full copy of this consent form with you.

Title of research: Augmented Learning for teaching Cardiopulmonary Resuscitation (CPR)

Investigator: Sander Giesselink

Purpose of the research:

This experiment investigates how the use of VR technology can improve the learning of CPR.

Explanation of procedures, duration and risks

First you will be instructed about the experiment, then the experiment follows. During the experiment you will be taught how to perform CPR on a doll. Your task is to try to follow the instructions given by the instructor and follow them to the best of your ability. After the experiment a short questionnaire follows. Performing CPR can be hard work, so please let the experimenter know if you are experiencing any physical problems. Please also inform the experimenter if you have ever experienced a real cardiac arrest/CPR situation. You are free to quit with the experiment at any time, the experimenter can also decide to stop the experiment if they believe it is in the best interest of the participant. The total time required is about 15-20 minutes.

Confidentiality

You will be filmed and data is recorded. All recorded data will be used for this research only, with the purpose to gather data about your CPR performance. Any questions concerning the research and/or in the case of issues, you can contact the researcher via s.j.giesselink@student.utwente.nl

I have read the foregoing information, or it has been read to me. I have had the opportunity to ask questions about it and any questions I have asked have been answered to my satisfaction. I consent voluntarily to be a participant in this study.

Participant name:	Date of signing:
Participant signature:	

I confirm that the participant was given an opportunity to ask questions about the study, and all the questions asked by the participant have been answered correctly and to the best of my ability. I confirm that the individual has not been coerced into giving consent, and the consent has been given freely and voluntarily.

Experimenter name:	Date of signing:
Experimenter signature:	

Appendix A2; Experiment protocol

Experiment protocol

Tasks for the bystander that are instructed by the dispatcher:

Try to wake victim

  Talk to victim
  Sit on knees next to victim
  Gently shake shoulders

Check for signs of breathing

  Perform chin lift
  Hold ear above mouth and nose while looking at chest movement (10 sec)

Perform 8x 30:2 CPR (~4 min)

  Combine hands and press on chest with stretched arms, force should come from the hips
  Press 30 times at a rate of 100 times a minutes
  Perform chin lift
  Blow air in mouth for 1 second, breath in while looking at chest, blow air in mouth for 1 second (this should not take more than 10 sec, if it fails don’t try an extra breath)
  Repeat from start until 8 cycles are complete

Control condition:

- No use of VR/AR, only auditory communication via telephone
- Instructor can make use of audio tools, such as a metronome.

Experimental condition:

- Learner wears Hololens, instructor uses HTC Vive
- Audiovisual communication. In addition to speech, the learner can see the position of the instructor and their hands, while the instructor has a 3D virtual view on the learner
  - Instructor can virtually observe the learner with images from the Kinect
  - Learner can see a virtual representation of the instructor's head and their hands, either by using Leap Motion or Vive controllers
- Instructor can place visual tools for the learner
- Instructor can see data about the quality of CPR in a virtual graph
  - This information should help the instructor to give better and more accurate feedback

Appendix A2; Experiment protocol

Instructions for control condition (telephone-CPR):
Instructions and feedback only given in this condition are marked orange
Situation: Bystander is alone with a person that is not responding.

1. Bystander calls with a smartphone and tells there is someone on the ground not responding.
2. Instructor: Where are you, what's the address?
3. Instructor: Are your surroundings safe?
4. Instructor: Put your phone on speaker mode and put it next to the victim
5. Instructor: Can you talk to the victim?
6. Instructor: Can you gently shake to shoulders to see if the victim responds?
7. Instructor: Can you see if the person is breathing?
    a. Do this by kneeling next to the person
    b. Put two fingers under the chin and lift the chin up, use your other hand to pull back the back of the head. Put your ear close to the nose and mouth and watch the chest to see if it moves
    c. Do this for 10 seconds.
8. Instructor: Help is on the way, I'm going to help you perform CPR, do you know how to do that?
9. Instructor:
    a. Kneel next to the person at the height of the upper arm
    b. Place the heel of one hand in the center of the chest (leave clothes on)
    c. Place the heel of the other hand on top of the first one
    d. Interlace the fingers of both hands and stretch your arm (no flat fingers)
    e. Position yourself vertical above your hands and press the chest 5-6cm down
    f. Let the chest fully come up and keep contact with the chest
    g. Repeat this until help arrives
    h. You are doing great, keep going at a rate of 2 compressions per second, I'm counting with you
    i. Instructor counts out loud together with the bystander to indicate the correct tempo if necessary
10. After every 30 chest compressions the bystander is instructed to perform 2 rescue breaths
    a. Instructor: Perform a chin lift like you have done before by lifting the chin with two fingers, use your other hand to pinch to nose.
    b. Make sure the chin is up and blow two times for one second into the mouth
    c. After the second breath go straight back to chest compressions

Instructions for experimental condition (Hololens-CPR):
Situation: Bystander is alone with a person that is not responding.
Instructions and feedback only given in this condition are marked blue

1. Bystander calls with a Hololens and tells there is someone on the ground not responding.
2. Instructor: Where are you, what's the address?
3. Instructor: Are your surroundings safe?

Appendix A2; Experiment protocol

4. Instructor: Can you talk to the victim?
5. Instructor: Can you gently shake to shoulders to see if the victim responds?
6. Instructor: Can you see if the person is breathing?
    a. Instructor places the chin lift instruction video in front of the bystander
    b. Do this by kneeling next to the person
    c. Put two fingers under the chin and lift the chin up, use your other hand to pull back the back of the head. Instructor uses their hands to hold two fingers below the chin and the other hand at the back of the head. Put your ear close to the nose and mouth and watch the chest to see if it moves
    d. Do this for 10 seconds.
7. Instructor: Help is on the way, I'm going to help you perform CPR, do you know how to do that?
8. Instructor:
    a. Instructor places chest compression video in front of the bystander
    b. Kneel next to the person at the height of the upper arm
    c. Place the heel of one hand in the center of the chest (leave clothes on)
    d. Place the heel of the other hand on top of the first one
    e. Instructor places their hands on the victim to show how and where the hands should be placed
    f. Interlace the fingers of both hands and stretch your arm (no flat fingers)
    g. Position yourself vertical above your hands and press the chest 5-6cm down
    h. Let the chest fully come up and keep contact with the chest
    i. Repeat this until help arrives
    j. You are doing great, keep going at a rate of 2 compressions per second, I'm counting with you
    k. Instructor places a visual metronome to indicate the correct tempo if necessary
9. After every 30 chest compressions the bystander is instructed to perform 2 rescue breaths
    a. Instructor places rescue breath video in front of the bystander
    b. Instructor: Perform a chin lift like you have done before by lifting the chin with two fingers, use your other hand to pinch to nose.
    c. Instructor places two fingers under the chin and pinches the nose with the other hand to show where the bystander should place their hands.
    d. Make sure the chin is up and blow two times for one second into the mouth
    e. After the second breath go straight back to chest compressions

Notes: the chest compression and rescue breath instruction videos are only placed during the first two times the bystander has to perform these tasks. The visual metronome is only placed after the second set if the bystander has difficulty with the correct compression rate.