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Enhancing Cardiopulmonary Resuscitation Training with Mixed Reality: Improving Cardiopulmonary Resuscitation Performance and Enjoyment

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Abstract

Cardiac arrests stand as a leading cause of mortality worldwide. When performed timely, cardiopulmonary resuscitation (CPR) can significantly improve a person's chance of survival during a cardiac arrest. Given that the majority of cardiac arrests happen outside of hospitals, it becomes crucial to equip as many laypeople as possible with CPR skills. Recently, mixed reality has garnered attention as a potential tool for CPR training. This study, with a randomized controlled trial (RCT), tested the effectiveness of a mixed reality CPR training compared to traditional training among laypeople ($N = 59$). Results revealed that participants in the mixed reality training either showed similar (i.e., compressions per minute, exam scores) or better (i.e., compression depth) CPR performance compared to participants that received the traditional training. Furthermore, the mixed reality training was perceived as more enjoyable than the traditional training. Finally, across conditions, participants reported comparable levels of presence, indicating a similar sense of being in a CPR situation. Based on these findings, we conclude that mixed reality CPR training can serve as a viable alternative for traditional CPR training. Especially, the enjoyable nature of mixed reality can boost motivation and encourage more people to follow or refresh previous CPR training.

Keywords: cardiopulmonary resuscitation, CPR training, mixed reality, enjoyment, presence

Introduction

Cardiovascular diseases stand as the leading cause of mortality worldwide, with sudden and unexpected cardiac death accounting for 17 million deaths every year.[1,2] Cardiac arrest occurs when the heart stops beating and circulation of oxygenated blood ceases. The first moments in a cardiac arrest are crucial, as without immediate medical attention, permanent brain damage and cardiac death may occur in a few minutes. Cardiopulmonary resuscitation (CPR) is a time-tested emergency procedure that involves chest compressions and sometimes artificial ventilation (e.g., mouth-to-mouth resuscitation) which aims to restore the flow of oxygenated blood and prevent tissue damage. When performed timely, CPR significantly improves survival chances during cardiac arrests.[1] Since majority of these emergencies occur outside of hospitals, the presence of trained bystanders capable of accurately administering CPR is crucial.[3]

Despite its importance, there are still several ongoing notable issues with CPR performed by bystanders. First, the number of trained individuals remain extremely low in comparison to people at risk.[4] Second, survival rates following bystander CPR is not high, signaling a lack of proficiency in performing CPR or following official guidelines.[5,6] Third and relatedly, CPR skill retention tends to be short with showing declines 3 months after the training.[7] Ultimately, it becomes crucial to find solutions that can increase the number of CPR-trained bystanders, improve CPR skills, and motivate trainees to retain and refresh their skills with follow-up trainings.

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A novel solution to address challenges regarding bystander CPR is trainings that utilize mixed reality tools (also sometimes referred to as MR). Mixed reality along with other immersive technologies that utilize spatial computing—like virtual reality (VR) and augmented reality (AR)—has gained attention as a promising medium for health care practice and education.[8–14] Training with mixed reality can offer potential benefits, including increased trainee numbers due to cost-effectiveness, enhanced learning outcomes through improved feedback, and greater follow-up participation by providing more enjoyable experiences. While studies employing immersive media-based medical trainings show promising results,[15] so far there has been limited research in the field of CPR training that focus on knowledge and skill acquisition and application, with most of the studies examining VR-based trainings.[15–18]

In this study, we aim to bridge this gap and examine the effectiveness of mixed reality CPR training by conducting a randomized controlled trial (RCT) that compares mixed reality training with traditional CPR training (with an instructor) on application of CPR skills. To determine the effectiveness of the training, we consider standardized outcome measures, such as compressions per minute (CPM) and compression depth. Additionally, we also consider the psychological measures enjoyment and presence to gain a comprehensive understanding of the training experience.

Theoretical Framework

Mixed reality

Mixed reality refers to immersive experiences that integrate virtual or digital content within the user's physical environment. Users wear a pass-through visor which projects holographic overlays in the real environment. Typically, users can interact with these digital objects by directly using their hands. In mixed reality, real-life objects can be integrated into the digital experience. For example, in the case of CPR training, a physical manikin can be integrated with a holographic overlay. This combination allows for the provision of real-time digital performance feedback while also enhancing the mannequin's appearance to resemble an actual person.[19–21] Therefore, by combining digital information with the actual physical environment, mixed reality applications provide unique immersive experiences in an unintrusive way.

Mixed reality and CPR performance

Performing CPR effectively (i.e., applying proper depth and rate in chest compressions, correct automated external defibrillator [AED] use, following steps in the right order) is crucial for increasing survival rates during cardiac arrests.[22] Innovative training methods aim to improve CPR outcomes and to ultimately save more lives.[23] Previous studies testing the effectiveness of immersive media-based medical training have shown promising learning outcomes.[17,18,24,25] For instance, VR-based CPR trainings were shown to improve compression performance,[24] CPR self-efficacy, and knowledge.[18] Specifically, in a feasibility trial health care professionals reported high levels of satisfaction with a mixed reality CPR training with the system.[26] In addition to finding the experience realistic and helpful, CPR performance met the criteria for good quality CPR.

One key reason training with mixed reality can enhance learning is due to superior feedback possibilities.[27] Traditional CPR training lasts 90 minutes and consists of 1 trainer with a group of up to 10 trainees which can limit continuous individual feedback opportunities.[28] Additionally, in these settings, feedback is typically based on corrective information (i.e., telling the trainee if they performed a step right or wrong). In contrast, mixed reality allows the user to learn at their own pace and provides continuous and tailored audiovisual explanatory feedback (e.g., why chest compressions were incorrect). Explanatory feedback, as opposed to corrective feedback, has been linked to richer learning experience and better performance.[29,30] Given that mixed reality provides continuous explanatory feedback we hypothesize:

H1: The mixed reality CPR training will lead to higher CPR performance in comparison to the traditional CPR training.

Mixed reality CPR training and enjoyment

The knowledge gained during CPR trainings typically diminishes after 3 months.[6] To ensure quality of CPR, it is important that trainees are motivated to refresh their learnings after completing their initial training. One way of increasing motivation in education is through creating enjoyable learning experiences. Enjoyment is a crucial component for fostering intrinsic motivation. When people are intrinsically motivated to perform a task, they show higher levels of engagement, better performance, and show longer-term interests and commitment.[31] Similarly, in the context of education, when students find the learning experience enjoyable, they show increased intrinsic motivation for continued learning.[32]

Immersive media technologies can deliver highly enjoyable experiences due to a combination of affordances and qualities such as high interactivity and engagement, rich sensory stimulation, novelty, and by delivering a sense of presence.[33–36] Previous research into VR-based basic life support training has been found to enhance intrinsic motivation and enjoyment.[37] Therefore, we hypothesize that

H2: The mixed reality CPR training will lead to higher enjoyment in comparison to the traditional CPR training.

Mixed reality CPR training and presence

Presence, in the context of immersive media, refers to the subjective perception of the media user that they are a part of the mediated experience. It can refer to a physical sensation of ''being there,'' where individuals perceive themselves as physically located in the virtual space, or they may feel the presence of digital social actors.[38] Presence is a key underlying process that influences how immersive media is experienced and has been shown to affect outcomes such as enjoyment, emotional intensity, and memory.[39–44]

In a mixed reality setting, users engage with a CPR scenario that involves interactions with a human body (represented as a holographic overlay on a physical manikin) and an AED. This distinguishes mixed reality from traditional training methods, where trainees typically only work with a resuscitation manikin.[28] Additionally, mixed reality based training enables users to progress individually and seamlessly as they master each skill which eliminates potential distractions from the outside world, ensuring continuous and complete user engagement. In contrast, traditional training environments, often involve multiple students in a classroom setting, leading to individual discussions with a trainer for each step, resulting in interruptions and breaks in immersion during the training experience. Therefore, we hypothesize that

H3: The mixed reality CPR training will lead to higher sense of presence compared to the traditional CPR training.

Methods

Design and participants

To test our hypotheses, we conducted a RCT (Type of training: Mixed reality vs. traditional). The study received ethical approval (2022-YME-14809) from the Ethics Review Board of University of Amsterdam.

A total of 60 people participated in the study in return for course credit or 25 euros. Participation was limited to people without a professional medical background. One participant was omitted from the final data analyses for being an outlier on the CPM outcome variable. Omitting this participant did not affect the results. The final sample ($N = 59$) consisted of 41 women and 18 men ($M_{age} = 21.71$, standard deviation $[SD]_{age} = 3.23$, range 18–32 years old).

Procedure

Participants were randomly assigned to either mixed reality or traditional CPR training conditions. Both types of training consisted of the same stages: registration, CPR training with practice sessions on a physical manikin, examination, filling out a questionnaire, and breaks. Trainings lasted for ~ 150 minutes (±2.5 hours). After the training, participants went through an in-person evaluation of their CPR performance and filled in a questionnaire. The questionnaire started with measuring previous experience with CPR and mixed reality, followed by questions about the enjoyment and presence during the CPR training, and finally demographics.

Traditional CPR training. The traditional CPR training session began with a presentation from a CPR trainer and a guided practice. During the guided practice, participants received verbal feedback from the trainer if they made a mistake, could ask for help, and received live visual feedback via a Bluetooth application that displayed whether their rate and depth of chest compressions were correct. Afterward, participants took part in an unguided practice wherein they did not receive any feedback unless they were stuck (e.g., if they remained idle or made a mistake). The trainings were conducted in small groups of about five people as they would happen in real training settings.[28]

Mixed reality CPR training. In the mixed reality CPR condition, we used a setup with Microsoft HoloLens 2 mixed reality devices and CPR+ software for the training. The training software was an off-the-shelf mixed reality CPR application developed by Velicus (https://velicus.nl). Similar to a human trainer, the application delivers auditory and visual tips on the steps to follow when conducting CPR, alerts users if they make a mistake, provides live feedback for chest compression depth and rate, and offers the option to watch a tutorial about a step they made a mistake on (e.g., if a user performs chest compressions incorrectly, they can choose to watch an instructional video).

Before the training, participants were asked to use the Microsoft HoloLens Tips application for about 10 minutes to get acquainted with the device. This application is a tutorial that engages users to interact with holograms such as tapping on gems and enlarging objects. During the training, participants watched a prerecorded holographic CPR lesson and took part in a guided practice using a physical manikin with a holographic overlay (Fig. 1). Finally, participants took part in an unguided practice, where the system only gave tips if participants remained idle for 10 seconds or if they performed an incorrect step.

Measures

In addition to the variables reported here, we measured several control variables. An overview of these variables (including randomization checks) can be found in the Appendix A1.

FIG. 1. Mixed Reality Training. *Note*. This figure shows participants during the mixed reality training. A video of the CPR+ mixed reality training can be found here: https://www.youtube.com/watch?v=ICDQPrG-sP8 CPR, cardiopulmonary resuscitation.

Table 1. Group Means and Test Statistics per Outcome Variable

Variables	Type of training: Mixed reality	Traditional	t	df	CI	Hedges's g
CPR performance						
CPM	113.03	111.70	–9.64	57	–5.51 to 2.84	–0.16
Depth (inch.)	2.31	2.05	5.15**	57	–0.36 to –0.16	–1.32
Enjoyment	4.05	3.51	–2.73*	57	–0.93 to –0.14	–0.70
Presence	3.59	3.36	1.18	57	–0.61 to 0.16	–0.30

*$p < 0.05$; **$p < 0.001$.
CI, confidence interval; CPM, compressions per minute; CPR, cardiopulmonary resuscitation.

CPR performance. CPR performance was measured by CPM, compression depth, and an exam score. CPM and compression depth (in inches) were measured in absolute numbers. For each participant, we also coded (0 = score not within range, 1 = score within range) whether they met the basic life support guidelines for CPM (100–120) and compression depth (between 2 and 2.4 inches).[45] These benchmarks are universally accepted.[46–49]

For the exam score, we used an 11-item examination checklist used by a major first aid training and certification organization in Netherlands (www.hetoranjekruis.nl). The items include following the correct steps for calling emergency services, correct placement of electrodes for the AED, and a proper number of seconds counted for checking breathing. In a regular CPR examination, the final evaluation is graded upon full completion of all steps in the correct order. Any mistake is marked as a failure of the CPR training. In line with the regular CPR examination, we coded (0 = fail, 1 = pass) for each participant to see whether they passed the exam.

Enjoyment. We measured enjoyment ($M = 3.78$, $SD = 0.79$, Cronbach's $\alpha = 0.85$) on a three item (e.g., ''I thought the CPR training was enjoyable'') 5-point Likert scale, ranging from 1 (not at all) to 5 (extremely). The scale was adopted from previous research.[50]

Presence

Presence ($M = 3.47$, $SD = 0.74$, Cronbach's $\alpha = 0.82$) was measured with an eight-item (e.g., ''I felt like I was actually in the environment of an actual CPR experience'') 5-point Likert scale, ranging from 1 (strongly disagree) to 5 (strongly agree). This scale was adapted from the spatial presence experience scale.[51]

Results

Main findings

To test our hypotheses, we performed several *t* tests (Table 1) and chi-square tests (Table 2).

The effect of mixed reality CPR training on CPR performance. The results showed that people in both conditions were equally likely to pass the CPR exam ($p = 0.705$, Table 1). Furthermore, we found a nonsignificant effect of mixed reality training on CPM ($p = 0.525$) and a significant effect on compression depth ($p < 0.001$). This means that the mixed reality and traditional CPR training led to comparable performance in terms of CPM, though that mixed reality training outperformed the traditional training in terms of compression depth. A visualization of the effects can be found in Figure 2.

In addition, we also tested whether people who followed mixed reality (vs. traditional) training were more likely to hit the basic life support benchmarks.[45,49] Here, the results (in Table 2) showed a nonsignificant effect for CPM ($p = 0.797$) and a significant effect for depth ($p = 0.015$). This means that people who followed the mixed reality training were equally likely to fulfill the CPM benchmark, though were more likely to reach the recommended compression depth. In sum, the data partially supports H1.

The effect of mixed reality CPR training on enjoyment. The results showed a significant effect of mixed reality on enjoyment ($p = 0.008$, Table 1 and Fig. 3). Participants in the mixed reality CPR training perceived it as more enjoyable than the traditional training, thereby supporting H2.

The effect of mixed reality CPR training on presence. Finally, we found a nonsignificant effect of the type of training on presence ($p = 0.242$, Table 1 and Fig. 3). This means that perceived presence is comparable between the mixed reality and traditional CPR training experiences. H3 was not supported.

Discussion

The aim of the study was to examine the effects of mixed reality CPR training. In terms of CPR performance, we found that participants in the mixed reality training either showed

Table 2. Cardiopulmonary Resuscitation Performance Scores

Variables	Type of training: Mixed reality (percent)	Traditional (percent)	χ	df	Goodman Kruskal λ
Exam score	72.4	80.0	0.14	1	0.07
CPM	82.8	76.7	0.07	1	0.03
Depth	93.1	63.3	5.97*	1	0.28

Note. Chi-square coefficients are estimated with Yates' continuity correction. *$p < 0.05$.

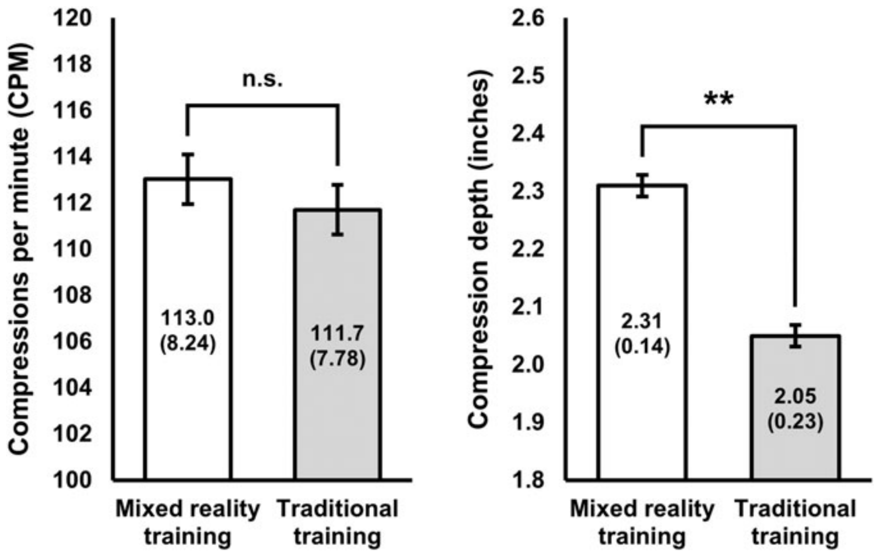

FIG. 2. Effects of Mixed Reality Training on CPR Performance. *Note.* This figure shows the effect of mixed reality (vs. traditional) training on CPR performance indicators: CPM and compression depth. Means (standard deviations) and error bars (standard error) are shown per training condition. $^{**}p < 0.001$. CPM, compressions per minute.

similar performance or outperformed people who followed the traditional training. Where CPM were found to be comparable between the mixed reality and traditional CPR training, we found deeper compression depths in the mixed reality training condition and saw that people were more likely to meet the basic life support guidelines for compression depth. Finally, we found that people who attended mixed reality (vs. traditional) CPR training experienced higher levels of enjoyment and equal levels of presence. Based on these results, three conclusions can be drawn.

The effects of mixed reality CPR training

Mixed reality CPR training and CPR performance. First, we found that, overall, the mixed reality CPR training was more effective than the traditional training. Depending on the performance indicators that are considered, people who participated in the mixed reality CPR training showed comparable (i.e., CPM and exam) or better (i.e., compression depth) performance than those who were in the traditional training. Notably, the nonsignificant effects on CPM and the exam score could be explained as ceiling effects, since in both conditions over 75 percent of people hit the CPM benchmark and 72 percent passed the exam. These findings extend previous research on the effects of mixed reality CPR refresher training among health care professionals, which showed no difference in CPR performance between mixed reality and traditional CPR trainings.[52] This means that, despite the still unclear potential for training health care professionals, mixed reality training seems effective for training laypeople.

Mixed reality CPR training and enjoyment. Second, we found that the mixed reality CPR training was considered more enjoyable than the traditional training. This is important because training that is considered enjoyable is expected to be more likely to be followed in the future due to increased intrinsic motivation and intent.[53,54] At the same time, higher chances of surviving cardiac arrest can be accomplished with better performance through frequent and innovative training.[6] Increasing enjoyment of learning and motivating people to train more often can thus ultimately improve survival rates of out-of-hospital cardiac arrest patients.

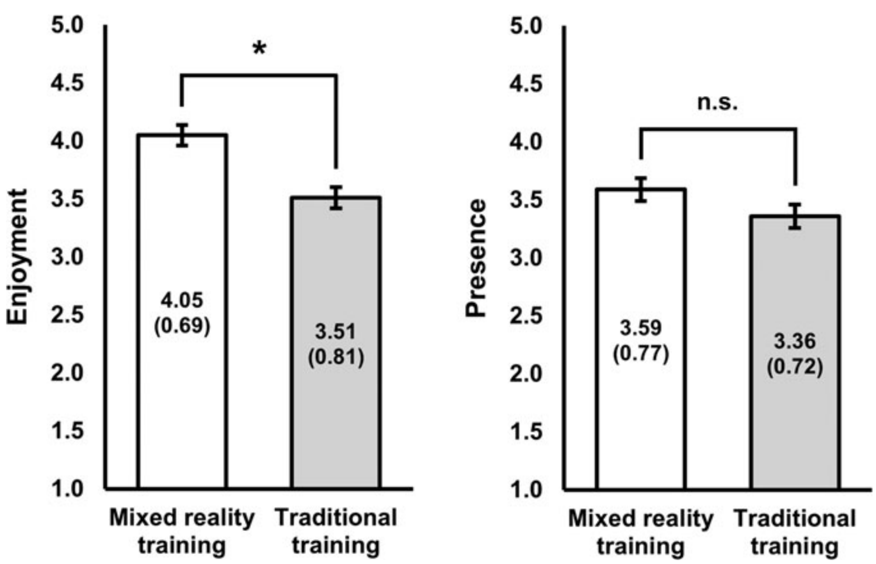

FIG. 3. Effects of Mixed Reality Training on Enjoyment and Presence. *Note.* This figure shows the effect of mixed reality (vs. traditional) training on psychological measures of enjoyment and presence. Means (standard deviations) and error bars (standard error) are shown per training condition. $^{*}p < 0.05$.

Notably, an area for which these findings might be particularly relevant is CPR training in schools. Several studies have indicated that one of the main reasons for resistance toward CPR training at schools is the fact that they are considered ''uninteresting'' by students.[55,56] Using mixed reality to make these trainings more enjoyable could potentially alleviate these concerns and improve engagement.

Mixed reality CPR training and presence. Third, we found that using mixed reality in CPR training does not necessarily lead to a more immersive experience. These findings corroborate previous research,[52] which found comparable levels of perceived presence of health care professionals in a mixed reality versus traditional CPR refresher training context. A potential explanation for this could be the use of a practice dummy. We measured presence in terms of feeling like ''being in a CPR situation.'' It is possible that the practice dummy was enough to simulate a CPR situation and the holographic overlay on the dummy did not enhance this feeling further.

Limitations and suggestions for future research

Despite offering valuable insights, this study also has limitations. An important limitation of our study is that the majority of our participants had no previous experience with mixed reality. The novelty of the experience may have affected our findings such that participants might have felt excitement with the opportunity to interact with holograms. Future research needs to investigate the potential role of ''novelty effect''[57] to assess the stability of positive outcomes.

Also, our participants were relatively young, which may not fully represent the typical scenario of cardiac arrests occurring at home. Research has shown that older adults are more likely to both witness[58] and experience[3] a cardiac arrest at home. Exploring the effectiveness of mixed-reality in teaching cardiac arrest response to a more age-diverse population would therefore be invaluable in broadening the applicability of our findings.

Author Disclosure Statement

During data collection, L.M.G. was an intern at Velicus (the company that developed the mixed reality application used in this study). She did not receive any financial support from Velicus for her services. There are no additional conflicts of interest to share.

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Appendix A1

Control Variables

In addition to the main variables of this study, we also measured several control variables: Prior experience with cardiopulmonary resuscitation (CPR) training (yes/no), prior experience with performing CPR (yes/no), and extent of previous experience with mixed reality. We found that 26.7 percent of participants had followed CPR training before, and 7.3 percent of participants had prior experience with performing CPR. Majority (78.0 percent) indicated they had no experience with mixed reality.

Randomization Check

To test whether the sample data were distributed equally across conditions, we performed randomization checks on age, gender, and the control variables. We found no issues with the distribution of the sample data across conditions for age, $t(57) = -0.67$, 95 percent confidence interval: -2.26 to 1.12, Hedge's $g - 0.17$, gender, $\chi^2(1) = 2.25$, $p = 0.134$, prior experience with CPR training, $\chi^2(1) = 0.92$, $p = 0.338$, prior experience with performing CPR, $\chi^2(1) = 0.95$, $p = 0.330$, nor for prior experience with mixed reality, $\chi^2(1) < 0.01$, $p = 1.000$. These results indicated that participants were successfully randomly assigned to the different conditions.