EFFECTIVENESS OF EXTENDED REALITY-BASED CARDIOPULMONARY RESUSCITATION TRAINING FOR HEALTHCARE STUDENTS: A SYSTEMATIC REVIEW

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Statement

I hereby certify that this thesis entitled "Effectiveness of Extended Reality-Based Cardiopulmonary Resuscitation Training for Healthcare Students: A Systematic Review" is my own work. All the sources of information reported by others are indicated in the list of references according to the guidelines.

I, **John Raymund P. Suazo**, approve the thesis for submission.

ABSTRACT

Background: Emergency medical services play a crucial role in providing initial lifesaving care and transport of victims to definitive care facilities. Among these interventions, cardiopulmonary resuscitation (CPR) is critical in saving lives during emergencies. Despite its importance, traditional CPR training methods often fail to replicate real-life scenarios, leading to gaps in preparedness among healthcare students. Recent advances in Extended Reality (XR) technologies, including Virtual Reality, Augmented Reality, and Mixed Reality offer promising new methods to enhance CPR training among healthcare students.

Aim: This systematic review aimed to identify the effects of using extended reality in training healthcare students in cardiopulmonary resuscitation.

Methods: This study follows PRISMA guidelines for systematic review. Databases searched include PubMed/MEDLINE, EMBASE, CINAHL, Cochrane, Web of Science, and Scopus. Eligible studies were randomized controlled trials and quasi-experimental studies on XR-based CPR training. Two reviewers independently extracted data, with discrepancies resolved by a third. The Cochrane ROB 2 tool and ROBINS-I were used to assess the risk of bias. A narrative synthesis was used to present results, however, meta-analysis was no longer conducted due to the heterogeneity of the findings.

Results: Eight studies from six countries were included, reflecting the growing interest in XR for CPR training among healthcare students. The findings revealed mixed results. Some studies indicated that XR could enhance learners' confidence and reduce anxiety during CPR training, but the impact on technical skills, such as CPR knowledge and CPR quality, was inconsistent. The variability in study outcomes, coupled with concerns about bias, limited the generalizability of the results.

Conclusion: The results suggest that XR technologies hold promise for enhancing CPR training. However, due to inconsistencies in the findings further research is necessary to fully understand the impact of XR in resuscitation training. Future studies should focus on standardizing assessment tools and investigating long-term outcomes to provide clearer guidance on integrating XR technologies effectively into healthcare education.

Keywords: Extended Reality, Cardiopulmonary Resuscitation, Healthcare Education

PROSPERO Registration number: CRD42024528709.

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LIST OF ABBREVIATIONS

ACLS	Advanced Cardiac Life Support
AED	Automated External Defibrillator
AR	Augmented Reality
BLS	Basic Life Support
CPR	Cardiopulmonary Resuscitation
EMS	Emergency Medical Services
HFS	High Fidelity Simulation
HMD	Head-Mounted Display
MCI	Mass Casualty Incident
MESH	Medical Subject Headings
MR	Mixed Reality
PICO	Population, Intervention/Exposure, Comparison, and Outcome
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analysis
PROSPERO	International Prospective Register of Systematic Reviews
QCRI	Qatar Computing Research Institute
ROB 2	Cochrane Risk of Bias version 2
ROBINS-I	Risk of Bias in Non-randomized Studies of Interventions
SCA	Sudden Cardiac Arrest
VR	Virtual Reality
WHO	World Health Organization
XR	Extended Reality

CHAPTER 1: INTRODUCTION

Due to the increasing frequency and magnitude of both man-made and natural disasters, the need to better respond to these incidents have become paramount. According to the World Health Organization (WHO), a disaster is an event wherein the normal conditions of existence in a locality are disrupted and the level of suffering exceeds the capacity of the community exposed to the hazard can respond to (1). Based on this definition, disasters overwhelm local response capabilities and necessitates external assistance (2).

Mass Casualty Incidents (MCI), on the other hand, are more common than disasters and can place significant pressure on local resources, particularly medical resources (1). MCIs are characterized by the quantity, severity, and diversity of injuries and medical conditions, which can quickly overwhelm the ability of the local health system to provide comprehensive and definitive care (3,4). Local resources under such conditions are not necessarily overwhelmed but demand more organization of available resources to respond and provide the needed prehospital care (5). Consequently, the imbalance between demand and availability of resources can stress the system, influencing not only those directly affected by the incident but also the local community (4).

In either scenario, emergency medical services (EMS) play a crucial role in providing initial care, triage, and transportation of victims to definitive care facilities. EMS is a critical part of the healthcare system which provides the arrangement of personnel, facilities and equipment for the effective, coordinated and timely delivery or pre-hospital care to victims of injury or sudden illness (6). The effectiveness of the emergency response relies on the ability to quickly assess the situation, allocate available resources efficiently, and implement life-saving interventions (4).

Among these life-saving interventions, Cardio-Pulmonary Resuscitation (CPR) stands out as a critical skill that can significantly impact patient outcomes (7). When professional medical help may be delayed or overwhelmed, pre-hospital CPR can be the difference between life and death for victims of cardiac arrest. Timely application of CPR can maintain blood flow to vital organs, potentially preserving neurological function and improving the chances of survival until more advanced medical care becomes available (8). The importance of CPR in high pressure environments underscores the need for widespread training and preparedness among both medical professionals and the general public, leading international guidelines to strongly advocate for widespread CPR education (7).

Furthermore, considering the rising global mortality from sudden cardiac arrest (SCA), which accounts for about 20% of deaths in North America and Western Europe (9), it is crucial to recognize the effectiveness of CPR in increasing survival rates from cardiac arrest, both in-hospital and out-of-hospital (10). However, despite the efforts to promote Basic Life Support (BLS) or Advanced Cardiac Life Support (ACLS) training, SCA remains a leading cause of death, with a resuscitation success rate of only around 10% (11,12). This underscores the need for continued optimization of education strategies as noted by European Resuscitation Council (13) and American Heart Association (7).

To effectively respond to cardiac arrest incidents, it is important for health workers to possess the skill to administer CPR promptly (14). However, this proficiency is not always given, one misconception is the assumption that healthcare professionals are capable of providing effective CPR after completing undergraduate education (13). Yet, global reports have raised concerns about the CPR competencies of medical and other healthcare students (15,16). Studies in Europe, for example, documented a lack of CPR competencies among medical students due to the absence of basic life support courses in their undergraduate education (13). Another study revealed that many students are unable to master the required knowledge and skills for CPR despite having undergone BLS training (17).

Furthermore, traditional manikin-based CPR training often fails to replicate the real-life scenarios that healthcare professionals face during actual resuscitations, which impacts confidence to initiate CPR (18). This training method also faces significant challenges, including scalability issues due to costs and resource constraints related to time, personnel, equipment, and other logistical support (19). Additionally, traditional instructor-led manikin training poses physical risks to participants and often lacks consistency and repeatability in training contexts, further limiting its efficacy (20). These courses have shown to fail to simulate the stress and complexity of real cardiac arrest incidents (7), emphasizing didactic learning over hands-on skill development (21), lacking immediate, objective feedback on CPR quality metrics like compression depth and rate (7), and inadequately preparing students for the team dynamics involved in real resuscitation efforts (22). As a result, there are significant gaps in preparedness, with many students unable to retain the required knowledge and psychomotor skills, experiencing deterioration often within 3-6 months (7).

In recent years, Extended Reality (XR) technologies, including Virtual Reality (VR), Augmented Reality (AR), and Mixed Reality (MR) have emerged as innovative tools in training CPR. The difference between these technologies is that VR allows user to interact with and immerser themselves in a computer generated environment, experiencing a fully immersive experience with or without using head-mounted display (HMD) devices (23). AR, on the other hand, overlays digital content onto the real world, enhancing the user's view of their physical surroundings enabling users to experience both realities at the same time (23). However, MR combines elements of both VR and AR, creating an environment where physical and digital objects to coexist and interact (23). These technologies create immersive and interactive learning environments that can simulate real-life scenarios in safe environments.

The advent of XR has revolutionized medical education, offering immersive and cost-effective alternatives (24). Virtual Reality-based resuscitation training, for instance, has proven useful in bridging the gap left by face-to-face teaching disruptions amid the COVID-19 pandemic (25). Studies have demonstrated that VR simulations not only provide a safe environment for trainees to practice procedural skills but also offer a platform for developing soft skills, including stress management, crucial in real-life emergencies (11). Additionally, VR's high level of immersion shows that it can enable users to feel actively engaged, akin to real-life scenarios, enhancing learning outcomes (26).

In addition, studies across various clinical settings, including orthopaedic and laparoscopic surgery, have demonstrated the efficacy of VR in improving surgical performance and accuracy, subsequently reducing operation times (27,28). As the demand for scalable and accessible medical training solutions grows, extended reality technology, with its ability to simulate real-world scenarios, stands at the forefront of innovation in CPR training.

Despite the growing interest in XR-based cardiopulmonary resuscitation training, its effectiveness in enhancing student competence still needs to be evaluated to determine their potential to enhance both learning and performance. Although some literature has explored the use of XR technology in training professionals or laypersons, the impact on healthcare students has not been adequately addressed. The findings from this systematic review could reveal gaps in literature, particularly in the standardization of outcome measures and XR technology applications in CPR training. Highlighting these gaps will not only guide future research but also inform policy makers in education and healthcare about the potential and limitations of XR technologies. Should XR-based training be found effective for resuscitation simulations, it could lead to broader adoption and possibly standardized curricula incorporating XR technologies.

1.1 Aim

The aim of this study is to identify the effects of using extended reality in training healthcare students in cardiopulmonary resuscitation.

1.2 Research Questions

The review would like to answer the following specific questions:

1. What are the different types of extended reality technologies used in training cardiopulmonary resuscitation among healthcare students?
2. What are the different measures used to evaluate the effect of extended reality in enhancing cardiopulmonary resuscitation training outcomes among healthcare students?

CHAPTER 2: METHODOLOGY

2.1 Study Design

This systematic review followed the Preferred Reporting Items for Systematic Reviews and Meta-Analysis Protocols (PRISMA) guidelines (29). For transparency and completeness, the details of the protocol for the study were registered in the International Prospective Register of Systematic Reviews (PROSPERO) with registration number CRD42024528709 on April 19, 2024.

2.2 Data Collection

Literature searches were conducted in PubMed/MEDLINE, EMBASE (Excerpta Medica Database), CINAHL, Cochrane, Web of Science, and Scopus. A systematic search strategy was employed using the following MESH terms: "cardiopulmonary resuscitation", "augmented reality", "virtual reality", and "students". The search strategy conducted for this review can be viewed in **Supplementary Table S2**. We also considered the references of the included studies as a source of information to find more studies that were not captured in the initial searches.

2.3 Eligibility Criteria

Eligible studies included peer-reviewed full-text articles, irrespective of language or geographic location, that explored the application of extended reality in training healthcare students for cardiopulmonary resuscitation. The criteria were established using the Population, Intervention/Exposure, Comparison, and Outcome (PICO) framework. Details of the inclusion criteria are provided in **Table 1**.

The protocol did not include studies where XR technology is not used as intervention in CPR training. Additionally, studies involving laypersons and healthcare professionals, including those undergoing post-graduate education, were excluded. There were no restrictions concerning the language, year of publication, or the locale of the study's conduct.

Table 1. Details of the inclusion criteria of the systematic review.

	Criteria for Inclusion
Population	We considered studies conducted with healthcare undergraduate students from any area or specialty.
Intervention	We included studies that report CPR training or simulations that utilize extended reality (XR) interventions, including augmented reality (AR), virtual reality (VR), and mixed reality (MR).
Comparison	Studies on CPR training that compare XR interventions to traditional manikin-based training or no training at all, were included.
Outcome	The primary outcome of focus were CPR quality (encompassing chest compression fraction, compression rate, compression depth, and no excessive ventilation) and CPR knowledge. Secondary outcomes post-intervention considered were technical skills, such as skills retention, and non-technical skills, such as confidence, communication, leadership, decision-making.
Study	Studies employing randomized controlled trials and quasi-experimental methods were considered.

2.4 Search Outcome

After the initial systematic search across the different databases and portals, manual selection was conducted. All studies gathered were uploaded to Rayyan QCRI (Qatar Computing Research Institute) tool to perform study selection aided by this platform (30). Duplicate detection in the records was then performed, followed by their proper removal. In the first screening phase, relevance of the article based on the titles and abstract was assessed independently by two reviewers (JRS and IDP) from the research team. Following this, the same pair of researchers read the full text of the studies to determine their eligibility, excluding those that do not meet the predefined inclusion criteria and those that fall under the exclusion criteria. Should discrepancies arise between the two reviewers at any stage, a third reviewer was consulted to facilitate resolution (MPR). The selection process is summarized in the flowchart presented in **Figure 1**.

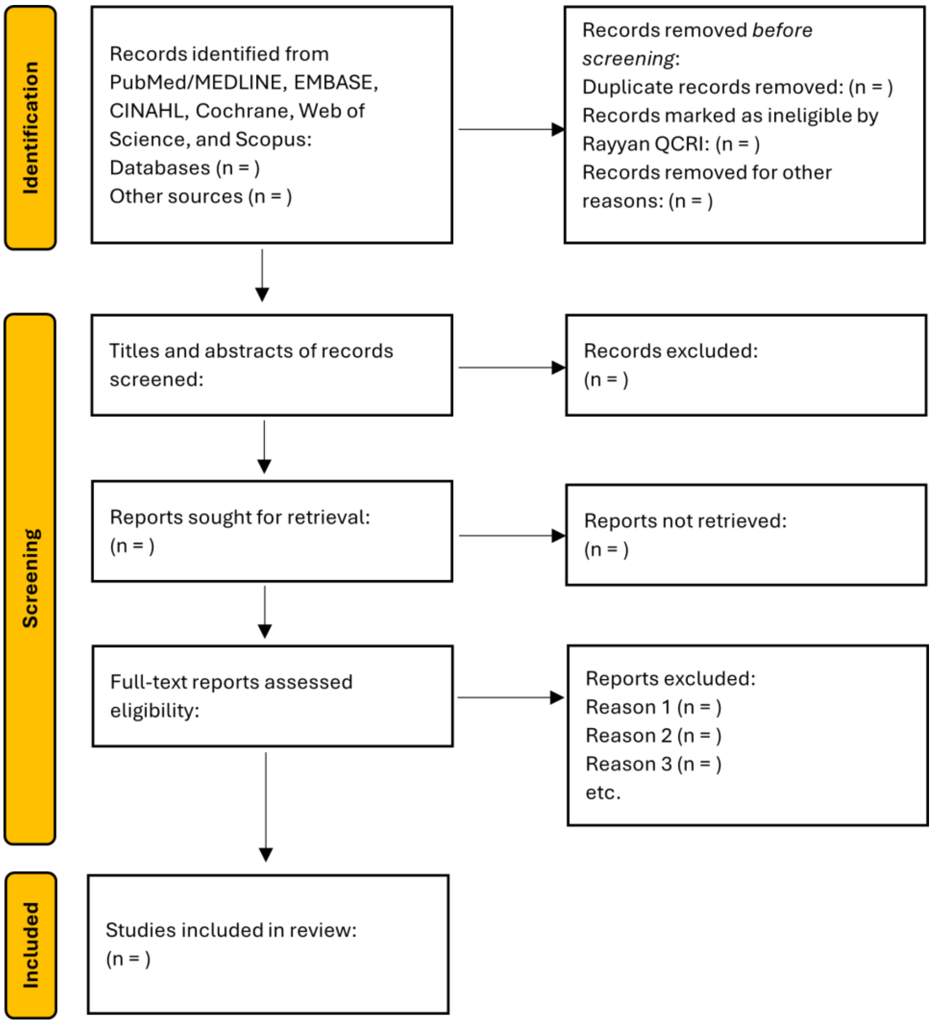

Figure 1. Systematic Review process flow based on Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA).

2.5 Quality Appraisal

Quality appraisal of eligible studies was carried out using established assessment tools, including the Cochrane Risk of Bias version 2 (ROB 2) for randomized clinical trials (31), or the Risk of Bias in Non-randomized Studies of Interventions (ROBINS-I) for non-randomized clinical trials and quasi-experimental studies with a control group (32). The assessment of bias involved categorization based on predefined criteria, including levels such as: low, some concerns or high risk.

2.6 Data Abstraction

Data were extracted by two reviewers independently, using an adapted version of the Cochrane Extraction form (33). The information extracted from the articles will include the following: study identification (title, authors, journal, year, country), characteristics of the participants (sex, mean age, course, year or level), intervention (type of XR technology used, type of simulation), and outcomes (CPR quality, CPR knowledge, skills retention, perception, etc.). If essential data were missing from the studies, the authors were contacted by email for additional clarification. Should we have failed to obtain the information from the authors, the data were excluded from the analysis and this limitation will be discussed in the discussion section.

2.7 Synthesis

The results were presented using a narrative synthesis approach, highlighting key characteristics and findings from the eligible studies. While a meta-analysis was initially considered, it was ultimately not conducted due to the significant heterogeneity of the results. Dichotomous outcomes were presented as risk ratios with 95% confidence intervals, while continuous outcomes were expressed as mean differences with 95% CI. The p-value of the results was also evaluated. For the outcomes that presented the data as proportions of correct answers for each of the questions, but not for the whole questionnaire, data conversion was conducted by calculating the proportions of right answers as a sum of all right answers in the scale, divided by the number of all possible correct answers. For the average of means, we multiplied the means for the size of the sample, then divided them from the total sample. Data from the studies were summarized in tables based on study characteristics and results of each studies.

CHAPTER 3: RESULTS

3.1 Selection of Articles

The selection process from six different databases initially identified 614 articles. After the removal of duplicates, 347 articles underwent title and abstract screening based on the predefined inclusion and exclusion criteria. Twenty-three articles eventually underwent review in full text. In the end, eight articles were deemed suitable for inclusion in this systematic review as detailed in **Figure 2**.

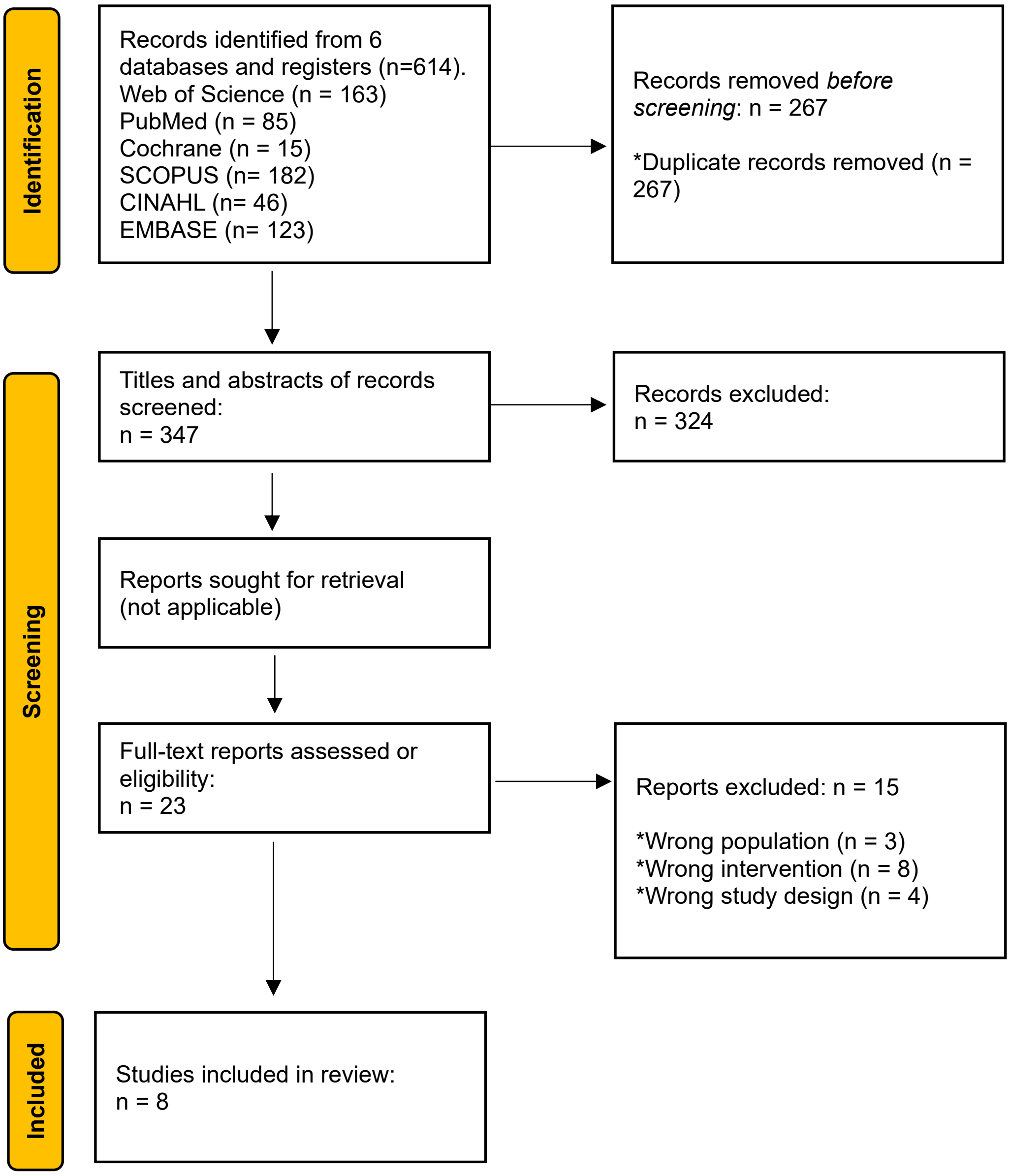

Figure 2. Article selection flow based on Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA).

3.2 Study Characteristics

This study reviewed eight articles published between 2022 and 2024 investigating the impact of XR technologies on training CPR to healthcare students indicating a recent increase in research activity on using XR in CPR training. Geographically the studies were conducted in six countries, majority of which are in high-income countries with only one study conducted in Turkey, an upper middle-income country. It is noted that Spain and Germany contributed the most, with 2 studies coming from each of these countries.

The sample sizes varied, ranging from 29 participants to 241 participants. Sex distribution across the studies showed a predominance of female participants, with an average of 70% female participation among 6 articles that specified the number of male or female participants. The studies predominantly involved early-stage learners, with first-year healthcare students accounting for 50% of the samples. It should be noted that in two articles the year level of the participants was not specified. There was also a significant focus on nursing (3 articles; 37.5%) and medical students (3; 37.5%) among the overall sample with 2 articles involving mixed disciplines (25%) such as nursing, medicine, psychology or health sciences students.

Among the articles selected for review, six (75%) were randomized controlled trials, and two (25%) were quasi-experimental studies. The studies focused on various outcomes, primarily assessing both technical and non-technical skills of participants. **Table 2** summarized the study characteristics of the included articles.

Table 2. Characteristics of the articles included in the systematic review.

Author	Year Country	Study Design	Sample Size		Female	Course	Year Level	Type of XR used	Control Group Intervention	Experimental Group Intervention
			CG	EG						
Castillo J, et al.	2023 Spain	RCT	116	125	74.7% (180/241)	Nursing, Medicine, Psycology	1st year	Virtual Reality	The control group (CG) received traditional BLS–AED training from the ERC, following a 4-step methodology	Used a VR application developed by LUDUS® that allowed interaction with a 3D virtual environment, the software contains six scenarios (one per student, identical to the CG)
Yang SY, et al.	2022 South Korea	QE	26	VR: 29; HFS: 28	83.1% (69/83)	Nursing students	Not specified (Undergrads)	Virtual Reality	Control group: only received the NRP lecture	VR group: the program included a URL to a Neonatal Resuscitation Program (NRP) lecture (30 minutes) in the first week and an immersive VR gamification program (50 minutes) in the second week. Simulation group: received the same NRP lecture in the first week and a high-fidelity simulation using a premature simulator in the second week.
Issleib M, et al.	2021 Germany	RCT	104	56	53.12% (85/160)	Medicine	1st year	Virtual Reality	Control group received a classic BLS course that included a 45-minute lecture and a 1-hour practical training session using the Laerdal® QCPR Mannequin.	Intervention group received an individual 35-minute VR Basic Life Support (BLS) course and a basic skill training
Rushton MA, et al.	2020 UK	QE	55	VR: 73; MR: 80	Not Specified	Nursing students	2nd year	Virtual Reality and Mixed Reality	The basic skills room had no added technology; it has hospital beds and lockers and imitates a ward environment.	The immersive simulation room uses video technology, set up to present an outdoor urban environment that included streets, houses, and associated distractions and dangers such as road traffic. The Octave suite provides high-end simulation, integrating nurse training and associated props with a realistic visual and aural sensation of an outdoor urban environment that included streets, houses, and associated distractions and dangers such as road traffic.
Gazzelloni A, et al.	2023 Italy	RCT	48	48	71.88% (69/96)	Nursing students	1st year	Augmented Reality	Control group watched a standard 2D video	The 360-degree video group used a Head Mounted Display (HMD) to

									demonstrating the CPR procedure on an adult victim, displayed on a 2D screen inside the Head Mounted Display (HMD) with no possibility to interact with the video.	experience the video, they watched a video demonstrating the CPR procedure on an adult victim.
Moll-Khosrawi, et al.	2022 Germany	RCT	42	46	70.45% (62/88)	Medicine	1st year	Virtual Reality	A 60-minute seminar on Basic Life Support (BLS) conducted by one instructor, covering learning objectives as per the European Resuscitation Council (ERC) Guidelines 2021.A 120-minute online demonstration of BLS by two instructors using the Resusci Anne QCPR mannequin. One instructor demonstrated the BLS sequence and common mistakes, while the second instructor provided commentary. Students practiced cardiopulmonary resuscitation on pillows at home. Did not receive the VR training but also took the three-minute SCE within the same time span after the web-based training.	The intervention group received the same web-based training as the control group, with an additional Virtual Reality (VR) BLS training within three days after the web-based session. The VR training included a 20-minute introduction to the VR module and a 35-minute training session. After the VR training, students performed a three-minute structured clinical examination (SCE) on BLS using the Resusci Anne QCPR mannequin. VR Training Details: Section 1: A virtual teacher demonstrated and explained a correct BLS scenario. Participants managed and guided a BLS scenario with a virtual colleague performing chest compressions. Section 2: Participants practiced chest compressions on the mannequin while the virtual colleague provided bag-mask ventilation. This was followed by a real-life emergency scenario where participants performed BLS without assistance. Features of the VR System: Connected to a small CPR mannequin for practicing chest compressions. Provided visual feedback on the quality of chest compressions. Included virtual implementation of

										bag-mask ventilation and AED use, without actual haptic handling.
Aranda-Garcíaa, et al.	2024 Spain	RCT	31	29	75% (unspecified /60)	Health Sciences and Nursing students	Not Specified	Augmented Reality	Face-to-face training with individual sessions by a certified European Resuscitation Council instructor. The sessions were 6-8 minutes long, using aesusci Anne QCPR simulator and AED Trainer 2. Instructor explained, demonstrated, and corrected techniques in person. Training sequence was conducted in four blocks. Training Sequence: Four blocks ABC Assessment: Safety, consciousness check, airway opening, and breathing check. Emergency Alert: Dial 112, set up AED, and follow instructions. Chest Compressions (CC): Proper compression point, rhythm with metronome, depth, and compression-decompression ratio. Complete Protocol: Students performed the entire BLS protocol with instructor corrections.	Training Session: 6-8 minutes individual session via smart glasses (Vuzix Blade AR) linked to the instructor via wifi. Equipment: Same as control group. Training Sequence: Same four blocks as the control group. Method: Instructor explained techniques verbally and provided supporting animated images through the smart glasses. Corrections were made by the instructor based on real-time feedback from what was seen and heard through the smart glasses. The instructor was located at a control post some distance away from the training area.
Aksoy, et al.	2023 Turkey	RCT	15	14	Not Specified	Medicine (Anestesiology)	2nd Year (3rd semester)	Virtual Reality	All participants read educational material. Both groups completed a pretest form consisting of multiple-choice questions aligned with the ALS curriculum and ERC guidelines. Participants attended an interactive lecture with instructors.	All participants read educational material. Both groups completed a pretest form consisting of multiple-choice questions aligned with the ALS curriculum and ERC guidelines. Participants took part in a VR familiarization session.

									The lecture duration matched the time spent on VR training by the intervention group. Participants engaged in a skills training session using a CPR manikin (CPR Lilly Pro+, 3BScientific GmbH) to learn effective CPR and ventilation techniques. Both groups participated in a simulation-based ALS scenario using a patient simulator (Apollo Patient Simulator, CAE Healthcare). Participants were divided into Code Blue teams of 5. The scenario content and flow were identical to the VR-based ALS serious gaming module. Sessions were video-recorded for evaluation by two independent instructors using the same scoring criteria as the VR module. All participants completed a posttest identical to the pretest. Control group participants were given the opportunity to try the VR module after the study. VR group participants did not need to attend a classroom-based lecture after the study since they already attended such lectures in their standard program.	Played 1 round of VR beginner training mode followed by 1 round of VR advanced training mode. Total time spent on VR training equaled the time of the interactive lecture for the control group. Participants engaged in a skills training session using a CPR manikin (CPR Lilly Pro+, 3BScientific GmbH) to learn effective CPR and ventilation techniques. Both groups participated in a simulation-based ALS scenario using a patient simulator (Apollo Patient Simulator, CAE Healthcare). Participants were divided into Code Blue teams of 5. The scenario content and flow were identical to the VR-based ALS serious gaming module. Sessions were video-recorded for evaluation by two independent instructors using the same scoring criteria as the VR module. All participants completed a posttest identical to the pretest. Control group participants were given the opportunity to try the VR module after the study. VR group participants did not need to attend a classroom-based lecture after the study since they already attended such lectures in their standard program.

Note: CG=control group, EG=experimental group, HFS=high fidelity simulation, RCT=Randomized control trial, QE=Quasi-experimental.

3.3 Quality Assessment of Articles

The risks of bias (ROB 2) of the included articles and their outcomes are summarized in **Table 3** and **Figure 3**. The randomized articles demonstrated variability in adherence to robust randomization, with 31.3% of the study outcomes showing low risk, 37.5% raising some concerns, and 31.3% at high risk. Most studies (81.3%) maintained a low risk regarding deviations from intended interventions, and all studies managed missing outcome data effectively with no risk identified. In terms of outcome measurement, 53.1% of the outcomes were categorized as low risk, with 9.4% arousing mild concerns, and 37.5% rated as high risk. There were substantial concerns in the selection of reported results, with 93.8% of study outcomes exhibiting some concerns, suggesting potential reporting biases. Overall, 59.4% of the study outcomes were deemed to have some concerns, and 40.6% were categorized as high-risk, indicating susceptibility to biases that could affect the validity of the findings.

The summarized results of ROBINS-I are presented in **Table 4**. Among the nonrandomized studies, Yang et al. (2022) displays notable methodological consistency and a low risk of bias (34), whereas those by Rushton et al. (2020) reveal considerable concerns, as it did not report many of the domains (35).

Table 3. Risk of bias (ROB 2) summary of included articles.

Unique ID	Study ID	Experimental	Comparator	Outcome	Weight	D1	D2	D3	D4	D5	Overall
Castillo 1	NA	VR training	Traditional training	CPR Knowledge	1	!	!	+	+	!	!
Castillo 2	NA	VR training	Traditional training	CPR Quality - Manekin	2	!	!	+	+	+	!
Castillo 3	NA	VR training	Traditional training	CPR Pratical Skills - Instructor	3	!	!	+	-	!	-
Issleib 1	NA	VR training	Lecture	No flow time	1	+	+	+	+	!	!
Issleib 2	NA	VR training	Lecture	BLS learning gains	2	+	+	+	+	!	!
Gazzeloni	NA	VR training	Lecture + video	CPR Knowledge	1	+	+	+	+	!	!
Khosrawi 1	NA	VR training	Lecture	No flow time	1	+	+	+	+	!	!
Khosrawi 2	NA	VR training	Lecture	BLS Knowledge	2	+	+	+	+	!	!
Khosrawi 3	NA	VR training	Lecture	BLS Learning gain	3	+	+	+	+	!	!
Aksoy 1	NA	VR training	Lecture	Learning gain	1	-	+	+	+	!	-
Aksoy 2	NA	VR training	Lecture	Crew resource management	2	-	+	+	-	!	-
Aksoy 3	NA	VR training	Lecture	Technical skills	3	-	+	+	-	!	-
Aksoy 4	NA	VR training	Lecture	Overall performance	4	-	+	+	-	!	-
Aranda García 1	NA	VR training	Simulation	BLS Knowledge	1	!	+	+	+	!	!
Aranda García 2	NA	VR training	Simulation	BLS performance	2	!	+	+	+	!	!
Aranda García 3	NA	VR training	Simulation	BLS Response time	3	!	+	+	!	!	!

+ Low risk ! Some concern - High risk

D1 Randomisation process
D2 Deviations from the intended interventions
D3 Missing outcome data
D4 Measurement of the outcome
D5 Selection of the reported result

Figure 3. Risk of bias (ROB 2) graph of included articles.

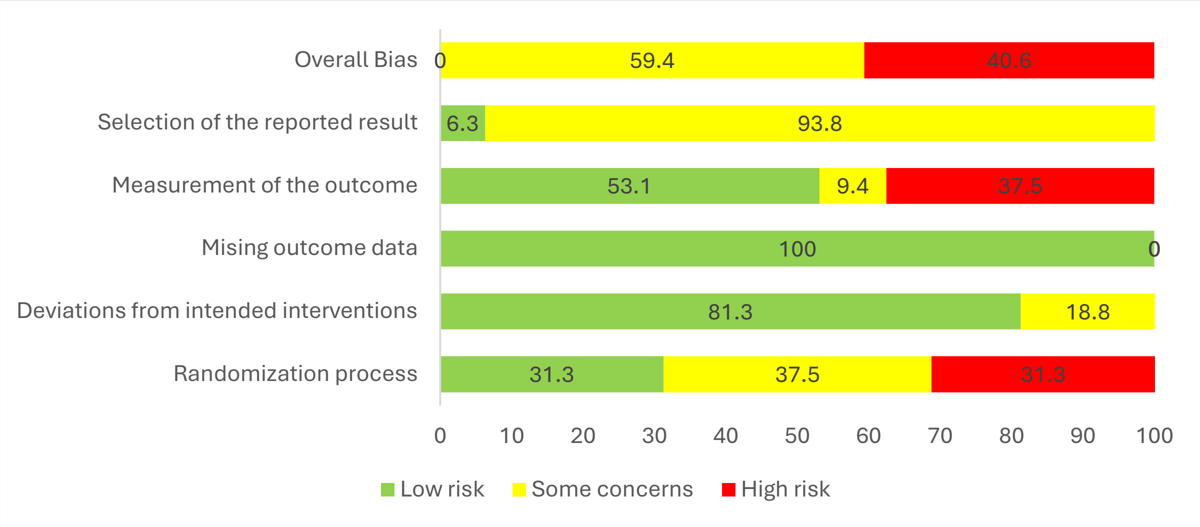

Table 4. Risk Of Bias in Non-randomized Studies of Interventions (ROBINS I) summary.

Study	Outcome	Bias due to confounding	Bias in selection of participants into the study	Bias in classification of interventions	Bias due to deviations from intended interventions	Bias due to missing data	Bias in measurement of outcomes	Bias in selection of the reported result	Overall bias
Yang et al.	Knowledge	Low	Low	Low	Low	Low	Low	Low	Low
Yang et al.	Non-technical skills	Low	Low	Low	Low	Low	Low	Low	Low
Rushton et al	CPR Quality	Mod	NR	NR	Low	NR	Low	Mod	Critical
Rushton et al	Non-technical skills	Mod	NR	NR	Low	NR	Low	Mod	Critical

Note: Mod – moderate, NR – not reported

3.4 Types of Extended Reality Used

The studies reviewed various forms of XR technologies to train CPR among healthcare students. Virtual reality was the most commonly used XR technology, employed in five (62.5%) of the articles, highlighting its popularity (25,26,34,36,37). Augmented Reality was used in two (25%) of the articles (35,38), while one study employed a combination of VR and Mixed Reality (35). No studies exclusively utilized MR technology. All the studies used smart glasses or headsets showing a BLS scenario or multiple training scenarios, except for one study which used immersive simulation room with video technology (35). Many of the studies also utilized feedback mannequins in their set-up (25,26,35,36).

3.5 Effect on Technical Skills

The results regarding CPR knowledge were varied. Two studies reported non-significant decrease in CPR knowledge scores in the XR group (37,38). Conversely, two other studies demonstrated higher scores among the XR group (34,36), with one study focusing on neonatal CPR revealing significantly higher scores for the VR group (34).

The results regarding BLS performance were similarly contradictory. One study found a non-significant decrease in BLS performance within the VR group (37), whereas another study reported a statistically significant improvement (25).

The findings related to various components of CPR quality were inconsistent across studies. For no-flow time, which measures interruptions between chest compressions, one study observed a significant decrease in the VR group (25), while another reported a significant increase (26). Regarding correct hand positioning, one study found no difference (39), while two studies showed lower scores in the XR group (35,36), with one study noting a significant difference (35). In terms of compression depth, two studies reported non-significant lower scores in the XR group (36,39), yet another study demonstrated significantly higher scores in this group (35). As for chest recoil, one study found non-significant lower scores in the XR group (36), whereas another reported significantly higher scores (39). One study evaluated adequate ventilation but yielded inconclusive results (35). Additional findings on the various components of CPR quality are summarized in **Table 5**.

In the overall assessment of technical skills, two studies indicated a decrease in technical skills among the VR group (36,37), with Ashok et al. (2023) reporting a significant decrease (37). However, another study found a significant increase in technical skills competence (35), highlighting the inconsistency in findings regarding the overall impact on technical skills.

3.6 Effect on Non-technical Skills

Majority of the studies made assessments on the impact of XR on non-technical skills in CPR. Assessing level of confidence was a recurring theme among the studies. A majority of the studies found that participants in the intervention group reported higher confidence levels than the control (25,26,34,35). Notably, one study reported that the VR group had significantly higher confidence compared to both the high-fidelity simulation and lecture groups (34). In a study comparing MR, VR, and control groups, it was found that while the VR group exhibited lower confidence than the control group, the MR group demonstrated higher confidence than the control group (35).

Regarding anxiety reduction, one study reported a minimal yet significant decrease in anxiety within the VR group. However, the high-fidelity simulation group experienced a substantially greater reduction in anxiety compared to both the control and XR groups (34). Lastly, there was no significant improvement in crew resource management scores across any of the groups (37).

In terms of overall practical skills, one study indicated that the XR group scored significantly lower in overall practical skills compared to other groups (36). Summary results on the different non-technical skills outcome are presented in **Table 5**.

Table 5. Summary of key CPR outcome findings in the reviewed articles.

Author	Outcome	Measurement	Scale	Control	Intervention	p value	Analysis
TECHNICAL SKILLS							
Castillo J, et al.	Technical skills Overall Score	Feedback mannequin (%)	Mean and SD	67.86 (SD=24.99)	64.54 (SD=28.85)	0.34	MWU
Rushton MA, et al.	Competence skills score	Laerdal SimPad QCPR manikin scores	Mean	46.6	VR: 46.9 MR: 37.1	**0.0407**	ANOVA
Aksoy, et al.	Technical skills	Evaluation of the users actions in time and order. A higher score is better. Range from 0 to 70 points. Assess by the simulator.	Mean and SD	60.20 (SD=8.13)	53.80 (SD=7.63)	**0.03**	MWU
1. CPR Knowledge							
Castillo J, et al.	CRP Knowledge	Multiple choice questions (0-10). A higher score indicates a better kwnoledge.	Mean and SD	8.21 (SD=1.41)	8.44 (SD=1.65)	0.24	MWU
Yang SY, et al.	Knowledge - Neonatal resuscitation Knowledge	Neonatal resuscitation nursing knowledge measurement tool standardized by Yoo, 2013 (0-30)	Mean change of scores and SD (a=VR, b=HFS, c=CG)	1.04 (SD=5.53)	VR: 5.48 (SD=4.13) HFS: 3.00 (SD=6.96)	**3.83 (0.004) a.b.>c.**	ANCOVA
Gazzelloni A., et al.	CPR Knowledge	Ten item CPR knowledge test (0-10).	Mean and SD	6.97 (SD=1.5)	6.31 (SD=1.78)	0.117	T test
Aksoy, et al.	Learning gains	Questionnare developed by the authors. The higher the score the better.	Mean and SD	64.20 (SD=9.96)	53.79 (SD=14.01)	**0.01**	MWU
2. BLS Performance							
Moll-Khosrawi, et al.	BLS performance	The Basic Life Support scoring system was adapted from Graham and Lewis (2000), using penalty points ranging from 0 to 125, with higher scores indicating worse outcomes. Each section was recorded and rated by two blinded assessors	Mean	29.19 (SD = 16.31)	13.75 (SD = 9.66)	**0.001**	GLM
Aksoy, et al.	Overall performance in BLS	Sume of points of CRM and Technical skills. Assessed by the software. 0 to 100, a higher score is better.	Mean and SD	71.53 (SD=9.89)	68.25 (SD=8.81)	0.53	MWU
3. CPR Quality							
Aranda-Garcíaa, et al	Quality of CPR	Assessed by the simulator software	Percentage	66 (34–84)	49 (11-76)	0.10a	MWU
3.1 Minimizing interruptions							
Issleib M, et al	CPR Quality - No flow time	Measured during practical examination in seconds.	Mean	82.031	92.963	**0.00**	

Moll-Khosrawi, et al.	CPR Quality - No-flow time until three minutes	Mean time of no-flow in seconds	Mean	11.05 (SD = 14.89)	6.46 (SD = 3.49)	**0.009**	GLM
3.2 Correct hand positioning							
Castillo J, et al.	CPR Quality - Correct hand positioning (%)	Feedback mannequin (%)	Mean and SD	97.73 (SD=11.03)	97.68; (SD=9.94)	0.97	MWU
Rushton MA, et al.	CPR Quality - Compression Hand Position	Laerdal SimPad QCPR manikin scores	Mean	92.5	VR: 83.5 MR: 72.7	**0.0011**	ANOVA
Aranda-Garcíaa, et al	CPR Quality - with correct position of hands (%)	Assessed by the simulator software	Percentage	100 (100−100)	100 (100−100)	0.07a	MWU
3.3 Depth of Chest Compression							
Castillo J, et al.	CPR Quality - Median depth (%)	Feedback mannequin (mm)	Mean and SD	47.1 (SD=7.27)	45.98 (SD=7.70)	0.24	MWU
Rushton MA, et al.	CPR Quality - Mean Compression Depth	Laerdal SimPad QCPR manikin scores	Mean	41.2	VR: 48 MR: 41.4	**0**	ANOVA
Aranda-Garcíaa, et al	CPR Quality - Mean depth (mm)	Assessed by the simulator software	Median and IQR in mm	48 (39–58)	43 (34–54)	0.06b	T-test
Aranda-Garcíaa, et al	CPR with adequate depth (%)	Assessed by the simulator software	Percentage	30 (1–53)	16 (0–61)	0.44a	MWU
3.4 Recoil of Chest Compression							
Castillo J, et al.	CPR Quality - Complete Chest Recoil (%)	Feedback mannequin (%)	Mean and SD	70.52 (SD=34.04)	71.56 (SD=32.28)	0.8	MWU
Aranda-Garcíaa, et al	CPR Quality - adequate recoil (%)	Assessed by the simulator software	Percentage	32 (6–85)	85 (37–100)	**0.008a (ES = 0.34)**	MWU
3.5 Rate of Chest Compression							
Castillo J, et al.	CPR Quality - Compression Rate (%)	Feedback mannequin (%)	Mean and SD	61.86 (SD=30.6)	60.33 (SD=34.94)	0.71	MWU
Castillo J, et al.	CPR Quality - Correct compressions (%)	Feedback mannequin (%)	Mean and SD	43.4 (SD=35.99)	41.14 (SD=34.66)	0.62	MWU
Rushton MA, et al.	CPR Quality - Compression score	Laerdal SimPad QCPR manikin scores	Mean	35.9	*VR: 43.4* *MR: 30.9*	0.0589	ANOVA
Rushton MA, et al.	CPR Quality - Number of cycles	Laerdal SimPad QCPR manikin scores	Mean	1.9	VR: 1.8 MR: 1.8	0.7123	ANOVA
Rushton MA, et al.	CPR Quality - Number of compressions	Laerdal SimPad QCPR manikin scores	Mean	83	VR: 81.7 MR: 83.7	0.6031	ANOVA
Aranda-Garcíaa, et al	Total number of CPR	Assessed by the simulator software	Number of CC per group	237 (219–250)	249 (223–263)	0.25b	T-test
Aranda-Garcíaa, et al	CPR Quality - CPR/decompression ratio	Assessed by the simulator software	Median and IQR	0.92 (0.79–1.04)	1.00 (0.77–1.18)	0.29a	MWU

Aranda-Garcíaa, et al	CPR Quality - Mean rhythm (CC/min)	Assessed by the simulator software	Median and IQR in CC/min	120 (110–128)	126 (112–132)	0.32b	T-test
3.5 Adequate Ventilation							
Rushton MA, et al.	CPR Quality -Ventilation score	Laerdal SimPad QCPR manikin scores	Mean	92.2	*VR: 93.6* *MR: 87.1*	0.0795	ANOVA
Rushton MA, et al.	CPR Quality - Total Ventilation	Laerdal SimPad QCPR manikin scores	Mean	3.7	*VR: 3.8* *MR: 3*	0.0687	ANOVA
Rushton MA, et al.	CPR Quality - Mean Ventilation Volume	Laerdal SimPad QCPR manikin scores	Mean	502.4	VR: 439 MR: 449.6	0.2922	ANOVA
6. Time to start CPR							
Aranda-Garcíaa, et al	Time performing CPR	Assessed by the simulator software	Percentage	100 (100−100)	100 (100−100)	0.18a	MWU
7. Response times by groups on AED							
Aranda-Garcíaa, et al	From start to setup of AED (s)	Time in seconds	Median and IQR	30 (21–46)	38 (30–47)	**0.041a (ES = 0.26)**	MWU
Aranda-Garcíaa, et al	From setup of AED to discharge (s)	Time in seconds	Median and IQR	67 (58–75)	65 (56–71)	0.36a	MWU
Aranda-Garcíaa, et al	From start to discharge (s)	Time in seconds	Median and IQR	96 (80–116)	102 (86–119)	0.38a	MWU
Aranda-Garcíaa, et al	From discharge to start of CC (s)	Time in seconds	Median and IQR	10 (8–11)	10 (8–13)	0.69b	T-test
Aranda-Garcíaa, et al	From start to first CC (s)	Time in seconds	Median and IQR	102 (88–125)	116 (99–127)	0.29a	MWU
NON-TECHNICAL SKILLS							
Castillo J, et al.	Practical Skills Overall Score	Instructor evaluation (0-16 points)	Mean and SD	9.10 (SD=1.2)	8.61 (SD=1.48)	**0.05**	MWU
1. Confidence							
Yang SY, et al.	Self-confidence	Self-Confidence in Neonatal Resuscitation Scale (SCNRS). Scores range from 15 to 75	Mean change of scores and SD (a=VR, b=HFS, c=CG)	4.38 (SD=16.52)	VR: 16.03 (SD=9.77), HFS: 6.57 (SD=15.76)	**6.53 (<0.001) a.>b.c.**	ANCOVA
Issleib M, et al	Confidence (in providing BLS, detect cardiac arrest, breathing, etc.)**	Comparative self-assessment (CSA). Likert scale from 1 to 6 (1 = mostly applies, 6 = mostly does not apply). Calculated the mean of the mean learning gains and the mean percentages	Mean of total learning gain and mean of percentage	2.92 (74.24%)	3.22 (83.80%)	-	
Rushton MA, et al.	Overall Confidence in assessing responsiveness, pulse, etc. (control vs VR)**	Confidence questionnaire (%)	Mean of means	19.73	12.31	-	

Rushton MA, et al.	Overall Confidence in assessing responsiveness, pulse, etc. (control vs MR)**	Confidence questionnaire (%)	Mean of means	19.73	27.83	-	
Moll-Khosrawi, et al.	Comparative self assessment: Confidence in provide BLS**	Comparative self-assessment (CSA). Percentage of learning gains expressed by CSA gain (%)= (CSApre—CSApost) / (CSApre—1)×100.	Percentage	21.41	47	-	
Moll-Khosrawi, et al.	Comparative self assessment: Confidence in provide BLS**	Comparative self-assessment (CSA). Percentage of learning gains expressed by CSA gain (points)= CSApre—CSApost.	Mean	2.23	2.98	-	
2. Degree of anxiety							
Yang SY, et al.	Degree of anxiety	State-Trait Anxiety Inventory (STAI). Scores range from 15-75, wherein a score of <or=30 indicates low or no degree of anxiety, and a score of =or>31 indicates a high degree of anxiety.	Mean change of scores and SD (a=VR, b=HFS, c=CG)	-1.12 (SD=9.63)	VR: -2.42 (SD=10.29), HFS: -8.96 (SD=11.59)	**16.14 (<0.001) b.>a.c.**	ANCOVA
3. Others							
Aksoy, et al.	Crew Resource Management skills	Evaluation of the users actions in time and order. A higher score is better. Range from 0 to 30 points. Assessed by the simulator.	Mean and SD	11.33 (SD=5.37)	14.45 (SD=1.23)	0.23	MWU

Note: SD=Standard Deviation, IQR=Interquartile Range, CG= Control group, VR=Virtual reality, MR=Mixed reality, HFS=High fidelity simulation, MWU=Mann-Whitney U test, ANOVA=Analysis of Variance, ANCOVA=Analysis of Covariance, GLM=General Linear Model.
**Conversion of results (e.g. mean of means, etc.)

CHAPTER 4: DISCUSSIONS

This systematic review sought to identify the effects of using extended reality in training healthcare students in cardiopulmonary resuscitation. The review highlighted that virtual reality (VR) is the most commonly employed technology for CPR training among healthcare students. Majority of the participants involved in the studies were female and first year students. However, many of the studies included in the review exhibited susceptibility to bias, which could affect the validity and reliability of the reported outcomes. Additionally, the findings revealed considerable heterogeneity in the impact of XR on both technical and non-technical skills related to CPR. This variability suggests that caution should be exercised when making generalized conclusions about the effectiveness of XR technologies in CPR training.

4.1 Effect on Technical Skills

The primary outcome focused on this review is on the technical skills related to CPR knowledge and CPR quality. Regarding the impact of XR on post-training CPR knowledge among healthcare students, the review presented mixed findings. Some studies reported improvements in CPR knowledge (34,36), while others did not (37,38), leading to contradictory results. This inconsistency differs with previous systematic reviews that demonstrate improved CPR knowledge following VR training among mixed populations, healthcare professionals and adolescents (40–43). On the other hand, a review focused on laypersons found no significant difference in CPR knowledge but reported an improvement in automated external defibrillator (AED) knowledge (44). Another study did show good retention of CPR knowledge after six months of XR training (45). A critical issue identified in this domain is the lack of standardization in knowledge assessment questionnaires across many studies. In this review for example, only the study by Yang, et al. (2022) employed a standardized questionnaire, though it focused on neonatal CPR (34). To ensure more reliable comparisons in future research, the adoption of standardized tools for assessing CPR knowledge is recommended.

The evaluation of various components of cardiopulmonary resuscitation (CPR) quality has produced inconsistent results, a finding consistent with previous reviews. For example, reviews focusing on laypersons and another on healthcare professional indicated that VR training significantly improved the rate and depth of chest compressions, suggesting that VR may be an effective tool for enhancing CPR (40,44). However, another study identified limitations with XR training noting that it may not consistently achieve the optimal compression depth required by current CPR guidelines, with mean compression depths often falling short of the recommended 50-60 mm (46). Moreover, a meta-analysis examining the effectiveness of XR technology among mixed population found no significant differences in chest compression rate, depth, or the proportion of participants meeting the established CPR depth criteria (41). In these measures, technological simulations may have limitations, particularly since VR utilizes haptic controls to simulate chest compressions. These findings suggest that while XR simulations offer valuable training experiences, they may not fully replicate the physical feedback provided by traditional manikin-based training, which is crucial for mastering the manual skills required in CPR (44). The immediate correction and personalized feedback provided by instructors during traditional training also appear to play a role in improving learning outcomes (42). With this, it is recommended to incorporate the presence of an instructor alongside the use of a feedback-enabled manikin in XR simulations.

Ventilation quality during CPR was another area where findings were inconclusive. While one study in this review did not provide clear results on ventilation effectiveness (35), previous research found that XR training, particularly when combined with real-time feedback, helps learners maintain appropriate ventilation rates, thereby preventing excessive ventilation (47). The variability in outcomes highlights the challenges in ensuring consistent CPR quality when using XR technology. For both compression depth and ventilation, regular refresher training is suggested to address these challenging skills (42), especially since the long-term effect is not established.

The overall findings of this review on CPR quality were contradictory mirroring the inconsistencies reported by previous systematic reviews on laypersons and mixed populations in comparing XR simulations performance to face-to-face training (41,42,44). Similarly, these reviews also noted low confidence in their results, indicating a pressing need for further research to establish more reliable conclusions about XR's effectiveness in enhancing CPR quality.

4.2 Effect on Non-Technical Skills

Enhancement of confidence levels was a consistent theme across the studies included in this review (25,26,34,35). Among the various XR technologies, mixed reality (MR) was found to boost confidence more effectively than VR and traditional training (35). This aligns with the findings of previous systematic review which highlighted that VR training had a positive effect on participants' confidence in performing CPR (44). Moreover, another study suggested that VR training improved willingness to perform CPR (45). However, while the current evidence indicates that XR training holds promise in boosting CPR confidence, further research is required to assess the longevity of this confidence noting that the outcome measured is short-term.

The potential of XR technologies to reduce anxiety during CPR training was also reported, albeit with minimal yet significant reductions in anxiety levels within the XR group (34). However, high-fidelity simulation was found more effective in alleviating anxiety than the VR group (34). Previous findings does support this, revealing that such technology resulted in some participants experiencing less positive emotions, including anxiety (48). This suggests that while XR offers engaging experiences, high-fidelity simulations may better emulate the pressures of real-life emergency scenarios. This finding points to the potential benefit of integrating XR with high-fidelity simulations to achieve optimal training outcomes for CPR.

The findings of this systematic review on non-technical skills only reported impact on CPR confidence and reduction of anxiety. However, previous studies have identified other relevant skills impacted by XR training. For example the impact of VR technology on rapid decision-making and team-building under pressure remains limited (40). The importance of such skills in these high-pressure scenarios cannot be over emphasized, limiting the real-world applicability of XR in this aspect. Also, when it comes to usability, satisfaction and appreciation on the XR in CPR training, the same review showed good general acceptance (40). This demonstrates a positive reception of using XR technology, contributing to its potential as a viable training tool.

4.4 Considerations and Implications

The review did not address potential side effects associated with XR technology that could influence the effectiveness or comfort during training sessions. However, prior research has identified side effects such as dizziness, blurred vision, and headaches, which, although typically temporary, may require breaks and adjustments that disrupt the learning process (41). Furthermore, inexperienced users may need additional time to acclimate to XR environments, potentially hindering the initial efficiency of training (41). These factors suggest that while XR technology offers significant potential, its implementation in training must account for these challenges to optimize outcomes.

Although the cost-effectiveness of XR simulations was beyond the scope of this study, existing research has explored this aspect. While some XR systems can be expensive and may pose accessibility challenges in resource-limited settings (41), organizational-level cost-benefit analyses have shown that VR training can be more economical than traditional CPR training methods (40). Moreover, XR training offers scalability, enabling more widespread and frequent training sessions without the constraints of physical resources and instructor availability.

4.5 Strengths and Limitations

To the best of our knowledge, this is the first systematic review to examine the impact of extended reality technologies on CPR training for healthcare students. This review followed a robust methodological framework that adheres to PRISMA guidelines and employs standard quality assessment tools. This strategy is designed to capture a broad range of studies from various databases, ensuring comprehensive coverage of available literature and aiming to reduce publication bias while increasing the generalizability of the findings. Another strength of this review is the absence of temporal or geographic limits, which facilitates a comprehensive global perspective.

Despite these strengths, the review anticipates several limitations. The heterogeneity in the types of XR technologies and outcome measures across studies could pose challenges in data synthesis and interpretation. This variability may limit the ability to draw definitive conclusions regarding the overall effectiveness of XR-based CPR training. Furthermore, while efforts will be made to include studies in multiple languages, the potential language limitations could introduce bias, particularly if relevant studies are excluded due to a lack of translation resources. The exclusion of grey literature may also introduce publication bias limiting the inclusivity of the review.

The findings from this systematic review could reveal gaps in literature, particularly in the standardization of outcome measures and XR technology applications in CPR training. Identifying these gaps will not only guide future research but also inform policy makers in education and healthcare about the potential and limitations of XR technologies. This could pave the way for its broader adoption and the potential development of standardized curricula that incorporate XR technologies into CPR training programs.

CHAPTER 5: CONCLUSION

The systematic review analyzed eight studies to assess the impact of extended reality technologies on CPR training among healthcare students. These studies, conducted across six different countries, reflect the growing interest in using XR technologies such as virtual reality, augmented reality, and mixed reality in educational settings. The key findings are summarized as follows:

- Virtual reality was the most commonly used XR technology for training healthcare students in CPR.
- The effect of XR on technical CPR skills was mixed, with some studies showing improvements while others noted declines.
- While some studies suggested that XR technologies could enhance learners' confidence and reduce anxiety during CPR training, the overall impact on non-technical skills was inconsistent.
- The variability in study outcomes, coupled with concerns about bias, underscores the need for caution when generalizing these findings.

Given these mixed results, it is clear that more research is needed to fully understand the potential of XR technologies in CPR training. Future studies should prioritize the standardization of assessment tools to allow for more reliable comparisons across studies. Furthermore, there is a need to explore the long-term impact of XR on CPR performance, as most of the reviewed studies focused on short-term outcomes. As the popularity of the use of XR technology grows, it is essential that future research addresses these gaps to provide clear guidance on how best to integrate these technologies into healthcare education.

AUTHOR STATEMENT

Data sharing statement:

All data used in this systematic review are secondary and sourced from the original published studies. Data derived from the narrative synthesis will be made available upon publication, either in the manuscript or in the Supplementary Material. Additional information can be obtained from the corresponding author upon reasonable request.

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The authors declare that they have no competing interests.

Ethical considerations:

This study examines previously published studies that do not contain personally identifiable information about participants, rendering ethical approval unnecessary from a research committee.

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ANNEXES

Supplementary Table S1: PRISMA Checklist for the systematic review.

Section and Topic	Item #	Checklist item	Location where item is reported
TITLE			
Title	1	Identify the report as a systematic review.	i
ABSTRACT			
Abstract	2	See the PRISMA 2020 for Abstracts checklist.	iv
INTRODUCTION			
Rationale	3	Describe the rationale for the review in the context of existing knowledge.	3
Objectives	4	Provide an explicit statement of the objective(s) or question(s) the review addresses.	4
METHODS			
Eligibility criteria	5	Specify the inclusion and exclusion criteria for the review and how studies were grouped for the syntheses.	5
Information sources	6	Specify all databases, registers, websites, organisations, reference lists and other sources searched or consulted to identify studies. Specify the date when each source was last searched or consulted.	5
Search strategy	7	Present the full search strategies for all databases, registers and websites, including any filters and limits used.	5
Selection process	8	Specify the methods used to decide whether a study met the inclusion criteria of the review, including how many reviewers screened each record and each report retrieved, whether they worked independently, and if applicable, details of automation tools used in the process.	6
Data collection process	9	Specify the methods used to collect data from reports, including how many reviewers collected data from each report, whether they worked independently, any processes for obtaining or confirming data from study investigators, and if applicable, details of automation tools used in the process.	6
Data items	10a	List and define all outcomes for which data were sought. Specify whether all results that were compatible with each outcome domain in each study were sought (e.g. for all measures, time points, analyses), and if not, the methods used to decide which results to collect.	8
	10b	List and define all other variables for which data were sought (e.g. participant and intervention characteristics, funding sources). Describe any assumptions made about any missing or unclear information.	8
Study risk of bias assessment	11	Specify the methods used to assess risk of bias in the included studies, including details of the tool(s) used, how many reviewers assessed each study and whether they worked independently, and if applicable, details of automation tools used in the process.	7
Effect measures	12	Specify for each outcome the effect measure(s) (e.g. risk ratio, mean difference) used in the synthesis or presentation of results.	8
Synthesis methods	13a	Describe the processes used to decide which studies were eligible for each synthesis (e.g. tabulating the study intervention characteristics and comparing against the planned groups for each synthesis (item #5)).	8
	13b	Describe any methods required to prepare the data for presentation or synthesis, such as handling of missing summary statistics, or data conversions.	8
	13c	Describe any methods used to tabulate or visually display results of individual studies and syntheses.	NA
	13d	Describe any methods used to synthesize results and provide a rationale for the choice(s). If meta-analysis was performed, describe the model(s),	NA

Section and Topic	Item #	Checklist item	Location where item is reported
		method(s) to identify the presence and extent of statistical heterogeneity, and software package(s) used.	
	13e	Describe any methods used to explore possible causes of heterogeneity among study results (e.g. subgroup analysis, meta-regression).	NA
	13f	Describe any sensitivity analyses conducted to assess robustness of the synthesized results.	NA
Reporting bias assessment	14	Describe any methods used to assess risk of bias due to missing results in a synthesis (arising from reporting biases).	7
Certainty assessment	15	Describe any methods used to assess certainty (or confidence) in the body of evidence for an outcome.	NA
RESULTS			
Study selection	16a	Describe the results of the search and selection process, from the number of records identified in the search to the number of studies included in the review, ideally using a flow diagram.	9
	16b	Cite studies that might appear to meet the inclusion criteria, but which were excluded, and explain why they were excluded.	9
Study characteristics	17	Cite each included study and present its characteristics.	10
Risk of bias in studies	18	Present assessments of risk of bias for each included study.	15
Results of individual studies	19	For all outcomes, present, for each study: (a) summary statistics for each group (where appropriate) and (b) an effect estimate and its precision (e.g. confidence/credible interval), ideally using structured tables or plots.	19
Results of syntheses	20a	For each synthesis, briefly summarise the characteristics and risk of bias among contributing studies.	17
	20b	Present results of all statistical syntheses conducted. If meta-analysis was done, present for each the summary estimate and its precision (e.g. confidence/credible interval) and measures of statistical heterogeneity. If comparing groups, describe the direction of the effect.	19
	20c	Present results of all investigations of possible causes of heterogeneity among study results.	NA
	20d	Present results of all sensitivity analyses conducted to assess the robustness of the synthesized results.	NA
Reporting biases	21	Present assessments of risk of bias due to missing results (arising from reporting biases) for each synthesis assessed.	15
Certainty of evidence	22	Present assessments of certainty (or confidence) in the body of evidence for each outcome assessed.	NA
DISCUSSION			
Discussion	23a	Provide a general interpretation of the results in the context of other evidence.	23
	23b	Discuss any limitations of the evidence included in the review.	23
	23c	Discuss any limitations of the review processes used.	26
	23d	Discuss implications of the results for practice, policy, and future research.	26
OTHER INFORMATION			
Registration and protocol	24a	Provide registration information for the review, including register name and registration number, or state that the review was not registered.	5
	24b	Indicate where the review protocol can be accessed, or state that a protocol was not prepared.	5

Section and Topic	Item #	Checklist item	Location where item is reported
	24c	Describe and explain any amendments to information provided at registration or in the protocol.	NA
Support	25	Describe sources of financial or non-financial support for the review, and the role of the funders or sponsors in the review.	28
Competing interests	26	Declare any competing interests of review authors.	28
Availability of data, code and other materials	27	Report which of the following are publicly available and where they can be found: template data collection forms; data extracted from included studies; data used for all analyses; analytic code; any other materials used in the review.	28

From: Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ 2021;372:n71. doi: 10.1136/bmj.n71

Supplementary Table S2. Search strategy used to conduct the review (Search date: May 8, 2024).

S.L.	Search Terms
	PUBMED = 85 records
#1	("Virtual Reality"[Mesh]) OR (Reality, Virtual) OR (Virtual Reality, Educational) OR (Educational Virtual Realit*) OR (Reality, Educational Virtual) OR (Virtual Realities, Educational) OR (Virtual Reality, Instructional) OR (Instructional Virtual Realit*) OR (Instructional Virtual Reality) OR (Realities, Instructional Virtual) OR (Reality, Instructional Virtual) OR (Virtual Realities, Instructional)
#2	("Augmented Reality"[Mesh]) OR (Augmented Realit*) OR (Realities, Augmented) OR (Reality, Augmented) OR (Mixed Realit*) OR (Realities, Mixed) OR (Reality, Mixed)
#3	#1 OR #2
#4	("Cardiopulmonary Resuscitation"[Mesh]) OR (Resuscitation, Cardiopulmonary) OR (CPR) OR (Cardio-Pulmonary Resuscitation) OR (Cardio Pulmonary Resuscitation) OR (Resuscitation, Cardio-Pulmonary) OR (Code Blue) OR (Mouth-to-Mouth Resuscitation) OR (Mouth to Mouth Resuscitation) OR (Mouth-to-Mouth Resuscitations) OR (Resuscitation, Mouth-to-Mouth) OR (Resuscitations, Mouth-to-Mouth) OR (Basic Cardiac Life Support) OR (Life Support, Basic Cardiac)
#5	#3 AND #4
	EMBASE = 123 records
#1	'virtual reality'/exp OR 'virtual reality'
#2	'virtual reality system'/exp OR 'vr interface' OR 'vr system (virtual reality)' OR 'virtual reality interface' OR 'virtual reality system'
#3	'augmented reality'/exp OR 'augmented reality'
#4	'augmented reality system'/exp OR 'augmented reality system'
#5	#1 OR #2 OR #3 OR #4
#6	'resuscitation'/exp OR 'bystander cpr' OR 'bystander-initiated cpr' OR 'cardio pulmonary resuscitation' OR 'cardiopulmonary resuscitation' OR 'chest compression' OR 'reanimation' OR 'resuscitation' OR 'resuscitation orders'
#7	#5 AND #6
	Cochrane = 15 records
#1	MeSH descriptor: [Virtual Reality] explode all trees
#2	MeSH descriptor: [Augmented Reality] explode all trees
#3	#1 OR #2
#4	MeSH descriptor: [Cardiopulmonary Resuscitation] explode all trees
#5	#3 AND #4

	Web of Science = 163 records
#1	(Virtual Reality) OR (Reality, Virtual) OR (Virtual Reality, Educational) OR (Educational Virtual Realit*) OR (Reality, Educational Virtual) OR (Virtual Realities, Educational) OR (Virtual Reality, Instructional) OR (Instructional Virtual Realit*) OR (Instructional Virtual Reality) OR (Realities, Instructional Virtual) OR (Reality, Instructional Virtual) OR (Virtual Realities, Instructional)
#2	(Augmented Reality) OR (Augmented Realit*) OR (Realities, Augmented) OR (Reality, Augmented) OR (Mixed Realit*) OR (Realities, Mixed) OR (Reality, Mixed)
#3	#1 OR #2
#4	(Cardiopulmonary Resuscitation) OR (Resuscitation, Cardiopulmonary) OR (CPR) OR (Cardio-Pulmonary Resuscitation) OR (Cardio Pulmonary Resuscitation) OR (Resuscitation, Cardio-Pulmonary) OR (Code Blue) OR (Mouth-to-Mouth Resuscitation) OR (Mouth to Mouth Resuscitation) OR (Mouth-to-Mouth Resuscitations) OR (Resuscitation, Mouth-to-Mouth) OR (Resuscitations, Mouth-to-Mouth) OR (Basic Cardiac Life Support) OR (Life Support, Basic Cardiac)
#5	#3 AND #4
	SCOPUS = 182 records
#1	(Virtual Reality) OR (Reality Virtual) OR (Virtual Reality Educational) OR (Educational Virtual Realit*) OR (Reality Educational Virtual) OR (Virtual Realities Educational) OR (Virtual Reality Instructional) OR (Instructional Virtual Realit*) OR (Instructional Virtual Reality) OR (Realities Instructional Virtual) OR (Reality Instructional Virtual) OR (Virtual Realities Instructional)
#2	(Augmented Reality) OR (Augmented Realit*) OR (Realities Augmented) OR (Reality Augmented) OR (Mixed Realit*) OR (Realities Mixed) OR (Reality Mixed)
#3	#1 OR #2
#4	(Cardiopulmonary Resuscitation) OR (Resuscitation Cardiopulmonary) OR (CPR) OR (Cardio Pulmonary Resuscitation) OR (Cardio Pulmonary Resuscitation) OR (Resuscitation Cardio Pulmonary) OR (Code Blue) OR (Mouth to Mouth Resuscitation) OR (Mouth to Mouth Resuscitations) OR (Resuscitation Mouth to Mouth) OR (Resuscitations Mouth to Mouth) OR (Basic Cardiac Life Support) OR (Life Support Basic Cardiac)
#5	#3 AND #4
	CINAHL = 46 records
#1	(Virtual Reality) OR (Reality Virtual) OR (Virtual Reality Educational) OR (Educational Virtual Realit*) OR (Reality Educational Virtual) OR (Virtual Realities Educational) OR (Virtual Reality Instructional) OR (Instructional Virtual Realit*) OR (Instructional Virtual Reality) OR (Realities Instructional Virtual) OR (Reality Instructional Virtual) OR (Virtual Realities Instructional)
#2	(Augmented Reality) OR (Augmented Realit*) OR (Realities Augmented) OR (Reality Augmented) OR (Mixed Realit*) OR (Realities Mixed) OR (Reality Mixed)
#3	#1 OR #2
#4	(Cardiopulmonary Resuscitation) OR (Resuscitation Cardiopulmonary) OR (CPR) OR (Cardio Pulmonary Resuscitation) OR (Cardio Pulmonary Resuscitation) OR (Resuscitation Cardio Pulmonary) OR (Code Blue) OR (Mouth to Mouth Resuscitation) OR (Mouth to Mouth Resuscitations) OR (Resuscitation Mouth to Mouth) OR (Resuscitations Mouth to Mouth) OR (Basic Cardiac Life Support) OR (Life Support Basic Cardiac)
#5	#3 AND #4