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Effectiveness of extended reality-based cardiopulmonary resuscitation training for healthcare students: A systematic review

John Raymund P. Suazo[1,2], Grasiela Piuvezam[3,4,5], Isac Davidson Santiago Fernandes Pimenta[4,5], Lucía López Ferrándiz[6], Manuel Pardo Ríos[6], Rafael Castro-Delgado[1,7,8]*

[1]Department of Medicine, University of Oviedo, Oviedo, Asturias, Spain, [2]Department of Global Public Health, Karolinska Institute, Stockholm, Sweden, [3]Department of Public Health, Federal University of Rio Grande do Norte, Natal, Brazil, [4]Graduate Program in Health Science, Federal University of Rio Grande do Norte, Natal, Brazil, [5]Systematic Review and Meta-Analysis Laboratory (Lab-SYS) Research and Health Innovation, Federal University of Rio Grande do Norte, Natal, Brazil, [6]Faculty of Nursing, Catholic University of Murcia, Murcia, Spain, [7]Research Group on Prehospital Care and Disasters (GIAPREDE), Health Research Institute of the Principality of Asturias, Oviedo, Spain, [8]SAMU-Asturias, Health Service Principality of Asturias, Oviedo, Spain
*Corresponding author

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ORCID:
JRPS: 0009-0003-1112-5706
GP: 0000-0002-2343-7251
IDSFP: 0000-0002-8246-0603
LLF: 0009-0001-7990-8497
MPR: 0000-0001-7965-0134
RCD: 0000-0001-9520-656X

Address for correspondence:
Prof. Rafael Castro-Delgado, Department of Medicine, University of Oviedo. Faculty of Medicine and Health Sciences, Julián Clavería, 6, 33006, Oviedo, Spain.
E-mail: castrorafael@uniovi.es

Abstract:

BACKGROUND: Cardiopulmonary resuscitation (CPR) is a lifesaving intervention where timely, effective actions improve survival. However, traditional Basic and Advanced Life Support (BLS and ALS) training often lacks realism, limiting preparedness among healthcare students. Extended Reality (XR) technologies, including Virtual, Augmented, and Mixed Reality, offer promising tools to enhance CPR training. The aim is to assess the effects of XR on CPR training outcomes among healthcare students.

METHODOLOGY: Following the Preferred Reporting Items for Systematic Reviews and Meta-Analysis Protocols guidelines, PubMed/MEDLINE, EMBASE, CINAHL, Cochrane, Web of Science, and Scopus were searched for randomized controlled trials and quasi-experimental studies. Two reviewers independently extracted data, with disagreements resolved by a third. Risk of bias was evaluated using Cochrane ROB 2 and ROBINS-I. Due to heterogeneity, findings were synthesized narratively.

RESULTS: Eight studies from six countries were included. Evidence showed mixed outcomes: XR improved confidence and reduced anxiety in Basic Life Support and ALS training, but results on technical performance, including CPR knowledge and quality, were inconsistent. Variability in study design and concerns about bias limited generalizability.

CONCLUSION: XR shows potential as a valuable complement to traditional CPR training, particularly in blended learning approaches aligned with modern pedagogy. However, inconsistent findings highlight the need for standardized assessments, evaluation of long-term outcomes, and integration of haptic torso simulators to improve technical skills and clarify XR's role in resuscitation education.

Keywords:

Basic and advanced life support, cardiopulmonary resuscitation, extended reality, healthcare education, virtual reality

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Box-ED Section

- Extended Reality-based cardiopulmonary resuscitation training is a valuable complement to combine with more traditional training.
- Results on technical performance are inconsistent, and more in-depth research is needed for a better combination of both strategies.
- Extended reality technologies also showed potential in reducing anxiety, but results are again heterogeneous.

Introduction

Sudden cardiac arrest (SCA) is responsible for approximately 20% of deaths in North America and Western Europe,[1,2] highlighting the importance of effective cardiopulmonary resuscitation (CPR) in improving survival rates.[3] Despite widespread Basic Life Support (BLS) and Advanced Cardiac Life Support (ACLS) training, SCA remains a leading cause of death, with a resuscitation success rate of around 10%,[4,5] emphasizing the need for improved educational strategies.[6,7]

Healthcare professionals must be skilled in performing CPR promptly, yet studies suggest that CPR proficiency is not always guaranteed after undergraduate education.[8] A common misconception is that healthcare professionals are fully capable of performing CPR after completing undergraduate education.[6] However, global studies have raised concerns about the CPR competencies of medical and healthcare students.[9,10] In Europe, for instance, a lack of BLS courses in medical students' undergraduate education has been linked to insufficient CPR competencies.[6] Additionally, many students fail to master the necessary knowledge and skills for CPR despite BLS training.[11]

Traditional manikin-based CPR training has limitations, including its inability to replicate real-life resuscitation scenarios, which reduces confidence in performing CPR.[12] Furthermore, it faces scalability challenges, such as costs and resource constraints related to time, personnel, and equipment.[13] This training method also has drawbacks, such as physical risks to participants and repeatability in training, limiting its effectiveness.[14] Manikin-based training struggles to simulate the stress and complexity of real cardiac arrest situations,[7] often emphasizing didactic learning over hands-on skill development[15] and failing to provide immediate, objective feedback on CPR quality metrics like compression depth and rate.[7] Additionally, it does not adequately prepare students for the team dynamics of actual resuscitation efforts.[16] As a result, many students experience a deterioration in knowledge and skills within 3-6 months.[7]

In response to these challenges, extended reality (XR) technologies – such as virtual reality (VR), augmented reality (AR), and mixed reality (MR) – have emerged as innovative solutions in medical education, offering immersive, scalable, and cost-effective alternatives to traditional training.[17] VR-based resuscitation training has proven valuable in compensating for face-to-face teaching disruptions during the COVID-19 pandemic.[18] Research has shown that VR simulations provide a safe environment for practicing procedural skills and developing soft skills, such as stress management, which are crucial in real-life emergencies.[5] The immersive nature of VR also helps users feel actively engaged, similar to real-life scenarios, enhancing learning outcomes.[19]

Despite growing interest in XR-based CPR training, its effectiveness in enhancing student competence remains insufficiently examined. Existing research has predominantly focused on laypersons or professionals, leaving its effectiveness among healthcare students understudied. Notably, no prior synthesis has systematically evaluated how XR interventions influence key CPR training outcomes within this specific population. This study addresses this gap by presenting the first systematic review dedicated to the use of extended reality (XR) for CPR training among healthcare students. It would consolidate available evidence, outline the reported advantages and limitations of XR-based approaches, and identify areas requiring methodological and outcome standardization. By assessing the impact of XR technologies on CPR-related competencies in this group, the review offers direction for future research and guidance for educators considering XR-enhanced training strategies. If XR proves effective, its adoption may support wider implementation and contribute to the development of a more standardized CPR curriculum. Thus, the objective of this study is to evaluate the effects of extended reality (XR) technologies on CPR training outcomes among healthcare students.

Methodology

Study design

This systematic review followed the Preferred Reporting Items for Systematic Reviews and Meta-Analysis Protocols (PRISMA) guidelines [Supplementary Table 1].[20] 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.

Data collection

Literature searches were conducted in PubMed/MEDLINE, EMBASE, CINAHL, Cochrane, Web of Science, and Scopus. The search strategy combined

MeSH and free-text terms related to "cardiopulmonary resuscitation," "augmented reality," "virtual reality," and "students." The search strategy and retrieval counts are provided in Table 1. All searches were performed on May 8, 2024, covering all records from database inception up to that date. References from included studies were also examined.

Eligibility criteria

Eligible studies were peer-reviewed full-text articles on extended reality in CPR training for healthcare students, based on the Population, Intervention/Exposure, Comparison, and Outcome (PICO) framework [Table 2]. CPR quality is a focused outcome as it is a standardized measure, while other technical and nontechnical skills were included to capture the full range of competencies needed for effective CPR, including procedural proficiency, confidence, and team behaviors.

The research did not include studies where XR technology is not used as an intervention in CPR training. Additionally, studies involving lay persons and healthcare professionals, including those undergoing postgraduate education, were excluded. There were no restrictions concerning the language, year of publication, publication status, or the locale of the study's conduct.

Search outcome

An initial systematic search was conducted across various databases, followed by manual selection. All studies were uploaded to the Rayyan QCRI tool for study selection, and duplicates were removed.[21] In the first screening phase, two reviewers (JRS and IDP) independently assessed article relevance based on titles and abstracts. The same reviewers then read the full texts to determine eligibility, excluding studies that did not meet the inclusion criteria or fell under the exclusion criteria. Discrepancies were resolved with the help of a third reviewer (MPR).

Quality appraisal

Quality appraisal of eligible studies was performed using established tools: The Cochrane Risk of Bias version 2 (ROB 2) for randomized trials[22] and the Risk of Bias in Nonrandomized Studies of Interventions (ROBINS-I) for nonrandomized and quasi-experimental studies with a control group.[23] Studies were categorized based on predefined criteria, including low, some concerns, or high risk of bias.

Data abstraction

Data extraction was carried out independently by two reviewers using an adapted version of the Cochrane Extraction form.[24] Extracted information included study identification, participant characteristics (sex, age, course, and year), intervention details (XR technology, simulation type), and outcomes (CPR quality, knowledge, skills retention, perception). Authors were contacted for missing data, and any unreceived information was excluded from analysis, with this limitation addressed in the discussion.

Synthesis

A narrative synthesis approach was used to present results, emphasizing study characteristics and key findings. Due to significant heterogeneity, a meta-analysis was not performed. Dichotomous outcomes were presented as risk ratios with 95% confidence intervals (CI), and continuous outcomes as mean differences with 95% CI. The *P* value of the results was also evaluated. For proportions, data conversion was performed by calculating the total correct answers divided by the possible correct answers. Data were summarized in tables, detailing study characteristics and results.

Results

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 [Figure 1].

Study characteristics

This study reviewed eight articles published between 2022 and 2024, reflecting a recent increase in research on XR technologies for CPR training in healthcare students. Geographically, the studies were conducted in six countries, predominantly in high-income settings, with Türkiye as the only upper-middle-income country represented. Spain and Germany contributed the most studies, with two articles each.

Sample sizes ranged from 29 to 241 participants, with a predominance of female participants (average 70% across six studies specifying sex distribution). Half of the studies involved first-year healthcare students, though two did not specify the participants' year level. The focus was largely on nursing (3 articles; 37.5%) and medical students (3 articles; 37.5%), with two studies (25%) including mixed disciplines such as nursing, medicine, psychology, and health sciences.

Most studies (75%) were randomized controlled trials, while 25% were quasi-experimental. Outcomes predominantly assessed both technical and nontechnical skills. Table 3 summarizes the study characteristics

Table 1: Search strategy used to conduct the review (Search date: May 8, 2024)

Serial number	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

Contd...

Table 1: Contd...

Serial number	Search terms
	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

Table 2: 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 XR interventions, including AR, VR, and 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 outcomes were CPR quality (including chest compression fraction, rate, depth, and avoidance of excessive ventilation) and CPR knowledge
	Secondary outcomes included other technical skills, such as skill retention, and nontechnical skills, such as confidence, communication, leadership, and decision-making
Study	Studies employing randomized controlled trials and quasi-experimental methods were considered

XR: Extended reality, AR: Augmented reality, VR: Virtual reality, MR: Mixed reality, CPR: Cardiopulmonary resuscitation

of the included articles, with extended details in Supplementary Table 2.

Quality assessment of articles

The risks of bias (ROB 2) of the included articles and their outcomes are summarized in Table 4 and Figure 2. 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. These results suggest that although many studies attempted to follow robust methodologies, limitations in randomization and outcome reporting may compromise the reliability of the reported effects.

Similarly, the summarized results of ROBINS-I are presented in Table 5. Among the nonrandomized studies, Yang *et al*. displays notable methodological consistency and a low risk of bias,[25] whereas those by Rushton *et al*. reveal considerable concerns,[26] as several domains were not reported, reducing certainty in their outcomes. Overall, the prevalence of high-risk and some-concern outcomes implies that the findings of this review should be interpreted with caution.

Effect of extended reality

The studies reviewed various forms of XR technologies to train CPR among healthcare students. VR was the most common, used in five (62.5%) of the articles.[18,19,25,27,28] Augmented reality (AR) was utilized in two studies (25%), while one combined VR and MR.[26] No studies exclusively utilized MR technology. Most studies employed smart glasses or headsets for BLS or multiple scenarios, often incorporating feedback mannequins,[18,19,26,28] except for one that used an immersive simulation room with video technology.[26]

Due to substantial heterogeneity in outcome definitions, measurement tools, and statistical reporting across the included studies, a meta-analysis was not conducted. Although several studies assessed similar outcomes (e.g., CPR quality, technical skills, knowledge, confidence, and BLS performance), they used different measurement tools, scoring systems, and scales. In addition, comparable outcomes were analyzed using varying statistical approaches (e.g., means vs. medians, raw scores vs. change scores, nonparametric tests vs. ANCOVA/GLM), making effect sizes noncomparable and preventing calculation of statistical heterogeneity. Given these inconsistencies, the results were synthesized narratively.

Effect on technical skills

Cardiopulmonary resuscitation knowledge

The results regarding CPR knowledge were varied. Two studies reported nonsignificant decrease,[27,29] while two others demonstrated higher scores among the XR group,[25,28] including a significant improvement in neonatal CPR knowledge with VR.[25] Regarding BLS performance, the results were similarly contradictory. One study noted a nonsignificant decline in the XR group,[27] while another observed a significant improvement.[18]

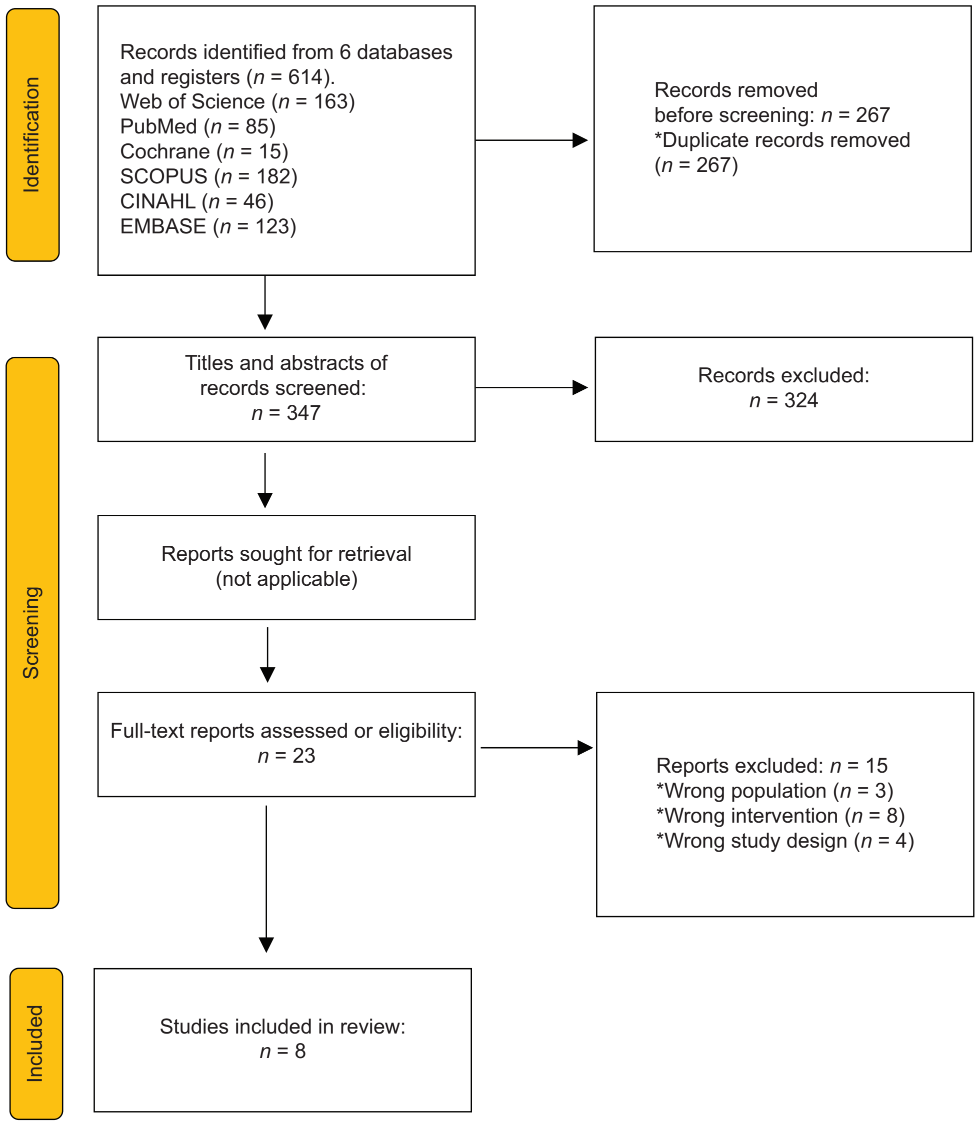

Figure 1: Article selection flow based on Preferred Reporting Items for Systematic Reviews and Meta-Analysis

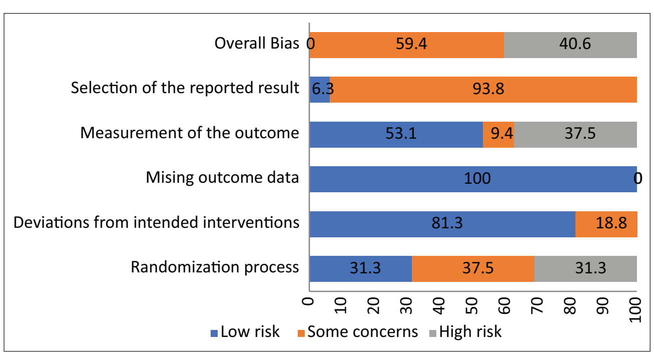

Figure 2: Risk of Bias 2 graph of included articles

Cardiopulmonary resuscitation knowledge Quality

The findings related to various components of CPR quality were also inconsistent across studies. Regarding hand positioning, results ranged from no difference[30] to lower scores in the XR group, with one study showing a significant difference.[26,28] Compression depth findings were mixed, with some studies reporting nonsignificant lower scores[28,30] and others significantly higher scores.[26] Similarly, chest recoil results ranged from nonsignificant decreases[28] to significant improvements.[30] Ventilation outcomes were inconclusive.[26]

For no-flow time, one study showed a significant decrease in the VR group,[18] while another reported an increase.[19] In the overall assessment of technical skills, two studies reported declines in XR groups,[19,28] including a significant decrease in one,[27] whereas another study noted a significant improvement.[26]

Effect on nontechnical Skills

Confidence and anxiety

Majority of the studies made assessments on the impact of XR on nontechnical skills in CPR. Assessing the

Table 3: Summary of study characteristics, interventions, and key outcomes of articles included in the systematic review

Author	Year and Country	*n*	Course	Design	XR Type	*P*	Main findings (vs. Cohort)
Castillo J *et al.*[28]	2023, Spain	241	Nursing, Medicine, Psychology	RCT	VR	MWU	Technical skills: Nonsignificant decrease CPR knowledge: Nonsignificant increase Practical skills overall score: Significant decrease
Yang SY *et al.*[25]	2022, S. Korea	83	Nursing	QE	VR	ANCOVA, $P<0.01$	Knowledge: Significant increase in VR Confidence: Significant increase in VR Anxiety: Significant decrease in HFS
Issleib M *et al.*[19]	2021, Germany	160	Medicine	RCT	VR	CSA/Likert	Confidence: Nonsignificant increase
Rushton *et al.*[26]	2020, UK	NS	Nursing	QE	VR and MR	ANOVA, $P<0.05$	Technical skills: Significant increase in VR, significant decrease in MR Proper hand positioning: Significant decrease in VR and MR Confidence in assessing responsiveness: Nonsignificant decrease in VR, nonsignificant increase in MR
Gazzelloni *et al.*[29]	2023, Italy	96	Nursing	RCT	AR	*t*-test, $P=0.117$	CPR knowledge: Nonsignificant decrease
Moll-Khosrawi *et al.*[18]	2022, Germany	88	Medicine	RCT	VR	GLM, $P=0.001$	BLS performance: Significant increase Confidence: Nonsignificant increase
Aranda-García *et al.*[30]	2024, Spain	60	Health Sciences and Nursing	RCT	AR	MWU/*t*-test	Chest recoil: Significant increase AED response time: Significantly slower
Aksoy *et al.*[27]	2023, Türkiye	NS	Medicine (Anaesthesiology)	RCT	VR	MWU/GLM	Technical skills: Significant decrease BLS performance: Nonsignificant decrease Crew resource management skills: Nonsignificant increase

RCT: Randomized controlled trial, QE: Quasi - experimental study, *n*: Sample size, VR: Virtual reality, AR: Augmented reality, MR: Mixed reality, HFS: High-fidelity simulation, NS: Not specified, CSA: Comparative self: assessment, BLS: Basic life support, CRM: Crew resource management, MWU: Mann–Whitney *U*-test, GLM: General linear model, ANCOVA: Analysis of covariance, CPR: Cardiopulmonary resuscitation, XR: Extended reality, ES: Effect Size, AED: Automated external defibrillator, UK: United Kingdom

level of confidence was a recurring theme among the studies. The majority reported higher confidence in the intervention group compared to controls.[18,19,25,26] One study noted significantly higher confidence in the VR group compared to high-fidelity simulation and lecture groups.[25] Another study comparing MR, VR, and control groups found lower confidence in the VR group but higher confidence in the MR group compared to controls.[26]

Anxiety reduction showed mixed results. One study reported a minimal but significant decrease in the VR group, though the high-fidelity simulation group showed greater anxiety reduction.[25]

Other nontechnical skills

No significant difference was observed in crew resource management between the VR group and the control.[27]

In terms of overall practical skills, one study indicated that the XR group scored significantly lower in overall practical skills compared to other groups.[28] Summary results on the different nontechnical skills outcomes are presented in Supplementary Table 3.

Discussions

This systematic review aimed to assess the effects of XR technologies on CPR training outcomes among healthcare students. The review highlighted that VR is the most used XR technology for CPR training, with most participants being female first-year students. However, many of the studies included in this review were susceptible to bias, which compromised the validity and reliability of their reported outcomes. Additionally, the findings showed considerable variability in both technical and nontechnical skills outcomes, further limiting the ability to draw definitive conclusions about the overall effectiveness of XR in CPR training.

Effect on technical skills

Cardiopulmonary resuscitation knowledge

The review yielded mixed results for CPR knowledge. Some studies reported improvements in posttraining CPR knowledge,[25,28] while others did not,[27,29] creating contradictory findings. These findings partially align with recent systematic reviews reporting that VR training improves CPR knowledge among healthcare professionals and adolescents.[31-34] One study even showed good retention of CPR knowledge 6 months

Table 4: Risk-of-bias summary of included articles (D1 Randomisation process, D2 Deviations from the intended interventions, D3 Missing outcome data, D4 Measurement of the outcome, D5 Selection of the reported result)

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

+ Low risk ! Some concerns - High risk, BLS: Basic life support, CPR: Cardiopulmonary resuscitation, VR: Virtual reality

Table 5: Risk of bias in nonrandomized studies of interventions (Mod: Moderate, NR: Not reported 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

CPR: Cardiopulmonary resuscitation

after XR training.[12] A major issue in this domain is the lack of standardized knowledge assessment tools. In this review, only the study by Yang *et al*. used a standardized questionnaire, which focused on neonatal CPR.[25] This highlights the need for validated, standardized questionnaires to enable reliable comparisons across studies.

Cardiopulmonary resuscitation quality

Findings on CPR quality were inconsistent, aligning with prior reviews. Recent studies focusing on laypersons and another on healthcare professionals showed VR improved chest compression rate and depth, suggesting its potential for skill enhancement.[34,35] However, another review showed that XR often failed to achieve the guideline-recommended compression depth of 50–60 mm.[12] A meta-analysis examining XR among mixed populations found no significant differences in chest compression quality.[33] These outcomes suggest XR simulations, while valuable, lack the physical feedback critical for mastering manual CPR skills.[35] The immediate correction and personalized feedback provided by instructors during traditional training also appear to play a role in improving learning outcomes.[32] With this, it is recommended to incorporate the presence of an instructor and the use of haptic torso mannequins in XR simulations.

Ventilation skills

Ventilation quality was another area where findings were inconclusive. One study included in the review lacked clear results,[26] but prior research indicated that XR with real-time feedback helps maintain appropriate ventilation rates.[36] Given the persistent challenges in achieving the necessary compression and ventilation parameters, regular refresher training is advised as long-term XR effects remain uncertain.[32]

Overall, the findings on CPR quality were contradictory, mirroring inconsistencies in previous reviews on XR's effectiveness compared to face-to-face training.[32,33,35] There is a need for further research to establish more reliable conclusions regarding XR's impact on CPR quality.

Effect on nontechnical skills

Confidence and anxiety

Enhancing confidence was a recurring theme in many of the included studies,[18,19,25,26] with mixed reality (MR) showing greater confidence boosts than VR or traditional methods.[26] This aligns with recent reviews noting that VR training positively impacts CPR confidence[36] and willingness to perform CPR.[12] However, current evidence is limited to short-term outcomes, necessitating further research on the longevity of these effects.

Extended reality technologies also showed potential in reducing anxiety, though with minimal effects.[25] High-fidelity simulations were more effective in alleviating anxiety, likely due to their ability to better replicate real-life emergency pressures.[25] Prior studies support this, noting less positive emotional responses, including anxiety, with XR.[37] This finding points to the potential benefit of integrating XR with high-fidelity simulations to achieve optimal training outcomes for CPR.

Other nontechnical skills

In terms of other nontechnical skills, XR's impact on rapid decision-making and team-building under pressure remains underexplored.[34] These skills are crucial in real-world CPR scenarios, limiting the current applicability of XR in this aspect. On usability, however, XR technology in CPR training received a positive reception, indicating its potential as a viable training tool.[12]

Considerations and implications

This review did not address potential side effects of XR technology, but prior studies have noted temporary issues such as dizziness, blurred vision, and headaches, which may disrupt training sessions.[33] Additionally, inexperienced users may require extra time to adapt to XR environments, potentially affecting early training efficiency.[33] These challenges highlight the need for careful implementation to maximize XR's benefits.

While cost-effectiveness was outside this study's scope, prior research indicates that XR systems, though initially expensive, may be more economical than traditional CPR training at the organizational level.[34] The scalability of XR also supports more frequent and accessible training sessions, particularly where physical resources and instructors are limited.[33]

Strengths and limitations

To the best of our knowledge, this review is the first systematic assessment of XR technologies in CPR training for healthcare students. It followed a robust methodological framework adhering to PRISMA guidelines, capturing a broad range of studies from various databases, which enhances the comprehensiveness and generalizability of the findings. The absence of temporal or geographic limits allowed for a global perspective. However, several limitations should be considered when interpreting the findings. The included studies revealed outcomes rated as high-risk or having some concerns, indicating methodological weaknesses in randomization, outcome reporting, and bias control. Additionally, the overall certainty of the evidence was not assessed using the GRADE approach, which could have strengthened the interpretation of findings given the proportion of studies with methodological concerns. Furthermore, the heterogeneity in XR technologies and outcome measures across studies posed challenges in data synthesis, limiting the ability to draw definitive conclusions about XR's effectiveness. Although this heterogeneity prevented a meta-analysis, alternative strategies such as calculating Standardized Mean Differences or applying the Synthesis Without Meta-analysis guidelines were not used and may have provided a more structured synthesis. Several XR-specific sources of bias may also have influenced study results. The novelty effect may have temporarily enhanced engagement, while unfamiliarity with XR devices could have hindered skill execution initially. These issues, combined with generally small sample sizes, reduce confidence in the reported effects of XR on CPR outcomes. Additionally, language limitations and the exclusion of grey literature may introduce publication bias.

Despite these limitations, the review highlights critical gaps in evidence and underscores the potential of XR as a complementary tool in CPR training. Future research should prioritize larger, rigorously designed trials, standardized outcome measurement, and structured orientation periods to address device unfamiliarity. Strengthening these areas will be essential for developing robust, evidence-informed XR-enhanced CPR training programs for healthcare learners.

Conclusion

This systematic review analyzed eight studies on the impact of extended reality (XR) technologies in CPR training for healthcare students, conducted across six countries. Key findings include:

- Virtual reality (VR) was the most used XR technology for CPR training
- The effect of XR on technical CPR skills was mixed, with studies showing both improvements and declines in outcomes
- Some evidence suggested XR could boost learners' confidence and reduce anxiety, though findings on other nontechnical skills were inconsistent
- Outcome variability and bias concerns highlight the need for caution in generalizing these results.

Given these mixed outcomes, XR appears to be a useful tool within a blended learning methodology, aligning with current pedagogical trends, but should not be considered a standalone method. Its strengths appear most relevant for enhancing engagement, and supplementing hands-on practice rather than replacing traditional methods. Future research should strengthen methodological consistency by using standardized assessment tools for technical CPR skills, conduct long-term follow-up studies to determine retention of skills acquired through XR, and investigate the role of haptic torsos to enhance technical skill acquisition. These efforts will help clarify XR's educational value in CPR training and guide evidence-based implementation into healthcare education.

Author contribution statement

JRS: Conceptualization, data curation, formal analysis, investigation, methodology, writing – original draft, writing – review and editing; GP: Data curation, formal analysis, investigation, methodology, validation, writing – review and editing; IDP: Data curation, formal analysis, investigation, methodology, validation, writing – review and editing; LLF: Data curation, formal analysis, investigation, validation, writing – review and editing; MPR: Conceptualization, investigation, project administration, resources, supervision, validation, writing – review and editing; RC: Conceptualization, funding acquisition, investigation, project administration, resources, supervision, validation, writing – review and editing.

Conflicts of interest

None Declared.

Ethical approval

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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Supplementary Table 1: Preferred Reporting Items for Systematic Reviews and Meta-Analysis Checklist for the systematic review

Section and Topic	Item number	Checklist item	Location where item is reported
		Title	
Title	1	Identify the report as a systematic review	1
		Abstract	
Abstract	2	See the PRISMA 2020 for Abstracts checklist	1
		Introduction	
Rationale	3	Describe the rationale for the review in the context of existing knowledge	4
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	6
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	7
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	6
	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	6
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	6
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	7
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))	7
	13b	Describe any methods required to prepare the data for presentation or synthesis, such as handling of missing summary statistics, or data conversions	7
	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), method(s) to identify the presence and extent of statistical heterogeneity, and software package(s) used	NA
	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)	6
Certainty assessment	15	Describe any methods used to assess certainty (or confidence) in the body of evidence for an outcome	NA

Contd...

Supplementary Table 1: Contd...

Section and Topic	Item number	Checklist item	Location where item is reported
		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	7
	16b	Cite studies that might appear to meet the inclusion criteria, but which were excluded, and explain why they were excluded	7
Study characteristics	17	Cite each included study and present its characteristics	8
Risk of bias in studies	18	Present assessments of risk of bias for each included study	8
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	8
Results of syntheses	20a	For each synthesis, briefly summarise the characteristics and risk of bias among contributing studies	8
	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	9
	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	8
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	11
	23b	Discuss any limitations of the evidence included in the review	14
	23c	Discuss any limitations of the review processes used	14
	23d	Discuss implications of the results for practice, policy, and future research	14
		Other information	
Registration and protocol	24a	Provide registration information for the review, including the register name and registration number, or state that the review was not registered	1
	24b	Indicate where the review protocol can be accessed, or state that a protocol was not prepared	1
	24c	Describe and explain any amendments to information provided at registration or in the protocol	NA
Support	25	Describe sources of financial or nonfinancial support for the review, and the role of the funders or sponsors in the review	Title Page doc
Competing interests	26	Declare any competing interests of review authors	Title Page doc
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	Supplemental table doc.

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. NA: Not available

Supplementary 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	CG intervention	EG intervention
			CG	EG						
Castillo J *et al.*[28]	2023, Spain	RCT	116	125	74.7% (180/241)	Nursing, Medicine, Psycology	1st year	VR	The 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.*[25]	2022, South Korea	QE	26	VR: 29; HFS: 28	83.1% (69/83)	Nursing students	NS (Undergrads)	VR	CG: Only received the NRP lecture	VR group: the program included a URL to a NRP lecture (30 min) in the 1st week and an immersive VR gamification program (50 min) in the 2nd week Simulation group: received the same NRP lecture in the first week and a high-fidelity simulation using a premature simulator in the 2nd week
Issleib M *et al.*[19]	2021, Germany	RCT	104	56	53.12% (85/160)	Medicine	1st year	VR	CG received a classic BLS course that included a 45-min lecture and a 1-h practical training session using the Laerdal® QCPR Mannequin	Intervention group received an individual 35-min VR BLS course and a basic skill training
Rushton *et al.*[26]	2020, UK	QE	55	VR: 73; MR: 80	NS	Nursing students	2nd year	VR and MR	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 *et al.*[29]	2023, Italy	RCT	48	48	71.88% (69/96)	Nursing students	1st year	AR	CG watched a standard 2D video demonstrating the CPR procedure on an adult victim, displayed on a 2D screen inside the HMD with no possibility to interact with the video	The 360° video group used a HMD to experience the video, they watched a video demonstrating the CPR procedure on an adult victim

Contd...

Supplementary Table 2: Contd...

Author	Year, country	Study design	Sample size		Female	Course	Year level	Type of XR used	CG intervention	EG intervention
			CG	EG						
Moll-Khosrawi *et al.*[18]	2022, Germany	RCT	42	46	70.45% (62/88)	Medicine	1st year	VR	A 60-min seminar on BLS conducted by one instructor, covering learning objectives as per the ERC Guidelines 2021.A 120-min 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 VR BLS training within three days after the web-based session. The VR training included a 20-min introduction to the VR module and a 35-min training session. After the VR training, students performed a 3-min 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-García *et al.*[30]	2024, Spain	RCT	31	29	75% (unspecified/60)	Health Sciences and Nursing students	NS	AR	Face-to-face training with individual sessions by a certified European Resuscitation Council instructor. The sessions were 6–8 min long, using aesusci Anne QCPR simulator and AED Trainer 2. Instructor explained, demonstrated, and corrected techniques in person.	Training Session: 6–8 mins individual session via smart glasses (Vuzix Blade AR) linked to the instructor via wifi Equipment: Same as CG Training sequence: Same four blocks as the CG

Contd...

Supplementary Table 2: Contd...

Author	Year, country	Study design	Sample size CG	Sample size EG	Female	Course	Year level	Type of XR used	CG intervention	EG intervention
									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 CC: Proper compression point, rhythm with metronome, depth, and compression-decompression ratio Complete Protocol: Students performed the entire BLS protocol with instructor corrections	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.*[27]	2023, Türkiye	RCT	15	14	NS	Medicine (Anestesiology)	2nd year (3rd semester)	VR	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 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)	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 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

Contd...

Supplementary Table 2: Contd...

Author	Year, country	Study design	Sample size		Female	Course	Year level	Type of XR used	CG intervention	EG intervention
			CG	EG						
									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	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 CG 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

EG: Experimental group, CG: Control group, ERC: European Resuscitation Council, VR: Virtual reality, AR: Augmented reality, MR: Mixed reality, NRP: Neonatal resuscitation program, BLS: Basic life support, HMD: Head Mounted Display, CPR: Cardiopulmonary resuscitation, QCPR: Quantitative CPR, SCE: structured clinical examination, CC: Chest compressions, ALS: Advanced life support, RCT: Randomized controlled trial, HFS: High- fidelity simulation, NS: Not specified, ES: Effect size, AED: Automated external defibrillator

Supplementary Table 3: Summary of key cardiopulmonary resuscitation outcome findings in the reviewed articles

Author	Outcome	Measurement	Scale	Control	Intervention	P	Analysis
Technical skills							
Castillo J *et al.*[28]	Technical skills overall score	Feedback mannequin (%)	Mean and SD	67.86 (SD=24.99)	64.54 (SD=28.85)	0.34	MWU
Rushton *et al.*[26]	Competence skills score	Laerdal SimPad QCPR manikin scores	Mean	46.6	VR: 46.9 MR: 37.1	0.0407	ANOVA
Aksoy *et al.*[27]	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.*[28]	CRP Knowledge	Multiple choice questions (0–10). A higher score indicates a better knowledge	Mean and SD	8.21 (SD=1.41)	8.44 (SD=1.65)	0.24	MWU
Yang SY *et al.*[25]	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 *et al.*[29]	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.*[27]	Learning gains	Questionnaire 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.*[18]	BLS performance	The BLS 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.*[27]	Overall performance in BLS	Sum 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-García *et al.*[30]	Quality of CPR	Assessed by the simulator software	Percentage	66 (34–84)	49 (1176)	0.10a	MWU
3.1 Minimizing interruptions							
Issleib M *et al.*[19]	CPR Quality - No flow time	Measured during practical examination in seconds	Mean	82.031	92.963	0.00	
Moll-Khosrawi *et al.*[18]	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.*[28]	CPR Quality - Correct hand positioning (%)	Feedback mannequin (%)	Mean and SD	97.73 (SD=11.03)	97.68; (SD=9.94)	0.97	MWU
Rushton *et al.*[26]	CPR Quality - Compression Hand Position	Laerdal SimPad QCPR manikin scores	Mean	92.5	VR: 83.5 MR: 72.7	0.0011	ANOVA
Aranda-García *et al.*[30]	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.*[28]	CPR Quality - Median depth (%)	Feedback mannequin (mm)	Mean and SD	47.1 (SD=7.27)	45.98 (SD=7.70)	0.24	MWU

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Supplementary Table 3: Contd...

Author	Outcome	Measurement	Scale	Control	Intervention	*P*	Analysis
3.3 Depth of chest compression							
Rushton *et al.*[26]	CPR Quality - Mean compression depth	Laerdal SimPad QCPR manikin scores	Mean	41.2	VR: 48 MR: 41.4	0	ANOVA
Aranda-García *et al.*[30]	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-García *et al.*[30]	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.*[28]	CPR Quality - Complete Chest Recoil (%)	Feedback mannequin (%)	Mean and SD	70.52 (SD=34.04)	71.56 (SD=32.28)	0.8	MWU
Aranda-García *et al.*[30]	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.*[28]	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.*[28]	CPR Quality - Correct compressions (%)	Feedback mannequin (%)	Mean and SD	43.4 (SD=35.99)	41.14 (SD=34.66)	0.62	MWU
Rushton *et al.*[26]	CPR Quality - Compression score	Laerdal SimPad QCPR manikin scores	Mean	35.9	VR: 43.4 MR: 30.9	0.0589	ANOVA
Rushton *et al.*[26]	CPR Quality - Number of cycles	Laerdal SimPad QCPR manikin scores	Mean	1.9	VR: 1.8 MR: 1.8	0.7123	ANOVA
Rushton *et al.*[26]	CPR Quality - Number of compressions	Laerdal SimPad QCPR manikin scores	Mean	83	VR: 81.7 MR: 83.7	0.6031	ANOVA
Aranda-García *et al.*[30]	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-García *et al.*[30]	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-García *et al.*[30]	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 *et al.*[26]	CPR Quality -Ventilation score	Laerdal SimPad QCPR manikin scores	Mean	92.2	VR: 93.6 MR: 87.1	0.0795	ANOVA
Rushton *et al.*[26]	CPR Quality - Total Ventilation	Laerdal SimPad QCPR manikin scores	Mean	3.7	VR: 3.8 MR: 3	0.0687	ANOVA
Rushton *et al.*[26]	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-García *et al.*[30]	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-García *et al.*[30]	From start to setup of AED (s)	Time (s)	Median and IQR	30 (21–46)	38 (30–47)	0.041a (ES=0.26)	MWU
Aranda-García *et al.*[30]	From setup of AED to discharge (s)	Time (s)	Median and IQR	67 (58–75)	65 (56–71)	0.36a	MWU
Aranda-García *et al.*[30]	From start to discharge (s)	Time (s)	Median and IQR	96 (80–116)	102 (86–119)	0.38a	MWU
Aranda-García *et al.*[30]	From discharge to start of CC (s)	Time (s)	Median and IQR	10 (8–11)	10 (8–13)	0.69b	t-test
Aranda-García *et al.*[30]	From start to first CC (s)	Time (s)	Median and IQR	102 (88–125)	116 (99–127)	0.29a	MWU
Nontechnical skills							
Castillo J *et al.*[28]	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

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Supplementary Table 3: Contd...

Author	Outcome	Measurement	Scale	Control	Intervention	*P*	Analysis
1. Confidence							
Yang SY *et al.*[25]	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.*[19]	Confidence (in providing BLS, detect cardiac arrest, breathing, etc.)**	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 *et al.*[26]	Overall Confidence in assessing responsiveness, pulse, etc., (control vs. VR)**	Confidence questionnaire (%)	Mean of means	19.73	12.31	-	
Rushton *et al.*[26]	Overall Confidence in assessing responsiveness, pulse, etc., (control vs. MR)**	Confidence questionnaire (%)	Mean of means	19.73	27.83	-	
Moll-Khosrawi *et al.*[18]	CSA: Confidence in provide BLS**	CSA. Percentage of learning gains expressed by CSA gain (%)=(CSApre–CSApost)/(CSApre–1)×100	Percentage	21.41	47	-	
Moll-Khosrawi *et al.*[18]	CSA: Confidence in provide BLS**	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.*[25]	Degree of anxiety	STAI. Scores range from 15 to 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.*[27]	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

**Conversion of results (e.g. mean of means, etc.). VR: Virtual reality, MR: Mixed reality, HFS: High- fidelity simulation, CG: Control group, SD: Standard deviation, CSA: Comparative self-assessment, BLS: Basic Life Support, STAI: State-Trait Anxiety Inventory, CPR: Cardiopulmonary resuscitation, QCPR: Quantitative CPR, CC: Chest compressions, MWU: Mann–Whitney *U*-test, GLM: General linear model, ANCOVA: Analysis of covariance, IQR: Interquartile range, ES: Effect size, AED: Automated external defibrillator