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## Contents

### Reviews

- Immersive Virtual Reality for Health Promotion and Primary Prevention in Psychology: Scoping Review  
([e49923](#))  
Solenne Bonneterre, Oulmann Zerhouni, Marilisa Boffo. . . . . 2
- Applications of Augmented Reality for Prehospital Emergency Care: Systematic Review of Randomized  
Controlled Trials ([e66222](#))  
Rayan Harari, Sara Schulwolf, Paulo Borges, Hamid Salmani, Farhang Hosseini, Shannon Bailey, Brian Quach, Eric Nohelty, Sandra Park, Yash  
Verma, Eric Goralnick, Scott Goldberg, Hamid Shokoohi, Roger Dias, Andrew Eyre. . . . . 18

### Original Papers

- Understanding the Views of Health Care Professionals on the Usability and Utility of Virtual Reality  
Multidisciplinary Team Meetings: Usability and Utility Study ([e60651](#))  
Maryam Almashmoum, Antony Payton, Emily Johnstone, James Cunningham, John Ainsworth. . . . . 31
- Augmented Reality in Enhancing Operating Room Crisis Checklist Adherence: Randomized Comparative  
Efficacy Study ([e60792](#))  
Rayan Ebnali Harari, Abdullah Altaweel, Erik Anderson, Charles Pozner, Rafael Grossmann, Andrew Goldsmith, Hamid Shokoohi. . . . . 47

# Immersive Virtual Reality for Health Promotion and Primary Prevention in Psychology: Scoping Review

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## Abstract

**Background:** Virtual reality (VR) has emerged as a promising tool in health promotion and prevention psychology. Its ability to create immersive, engaging, and standardized environments offers unique opportunities for interventions and assessments. However, the scope of VR applications in this field remains unclear.

**Objective:** This scoping review aims to identify and map the applications of VR in health promotion and prevention psychology, focusing on its uses, outcomes, and challenges.

**Methods:** A systematic search was conducted across 3 electronic databases (PubMed, PsycINFO, and Scopus) for studies published between 2010 and 2024. Eligibility criteria included empirical studies using immersive VR for health promotion and prevention, while studies using nonimmersive VR, lacking health-related applications, or focusing on clinical interventions were excluded. The review followed PRISMA-ScR (Preferred Reporting Items for Systematic Reviews and Meta-analyses extension for Scoping Reviews) guidelines, and 4295 records were initially identified, with 51 studies included after screening. Data were synthesized qualitatively to identify key applications, limitations, and emerging trends.

**Results:** VR was primarily used in three areas: (1) delivering interventions (eg, pilot testing, skills training), (2) exploring fundamental research questions, and (3) assessing outcomes such as behavioral or psychological responses. Although VR demonstrated potential for enhancing user engagement and replicating ecological scenarios, its effectiveness compared to nonimmersive methods varied. Most studies were pilot or feasibility studies with small, nonrepresentative samples, short follow-up periods, and limited methodological standardization.

**Conclusions:** VR offers a versatile and promising tool for health promotion and prevention but its applications are still in the early stages. The evidence is limited by methodological weaknesses and variability in outcomes. Future research should prioritize replication, longitudinal designs, and standardized methodologies to strengthen the evidence base and expand the applicability of VR interventions.

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## KEYWORDS

virtual reality; health psychology; prevention psychology; health promotion

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## Introduction

### Background

Health and prevention psychology aims to address health-related issues to either prevent individuals from starting or continuing an unhealthy behavior (ie, primary prevention), help them to detect or reduce illness in early stages (ie, secondary prevention), or support individuals in their journey against consequences of heavier injuries or diseases (ie, tertiary prevention, [1]). Although secondary and tertiary prevention are more individual-based depending on the illness or signs or symptoms individuals need to learn to cope with, primary prevention is

broader and aimed at a larger audience. Therefore, primary or universal prevention is designed to prevent individuals from the general population from getting injured or sick and aims to enable people to live a sustainable and healthy lifestyle [2,3].

In this sense, health promotion campaigns have started to integrate technological innovations such as virtual reality (VR). We refer to VR as a type of human-computer interface immersing users into a computer-generated 3D virtual environment (VE) they can interact with in a naturalistic fashion, usually via an avatar (ie, representation of the user in the VE [4]). More pragmatically, we labeled as VR any type of device that has the ability to sensorily detach the user from the outside

world (at least sight, but also sounds, smell, and touch in some cases). This includes the use of a cave automatic VE (users are surrounded by walls displaying the VE) or a head-mounted display (HMD), which blocks the user's field of view outside of the VE and from which the user cannot turn away by simply looking away (ie, computer screens or 360° videos will not be considered VR in this definition).

The main aim of VR is to recreate a realistic, ecological context and experience while keeping some degree of experimental control over it [5-7]. Systematic reviews have reported promising results from VR-based interventions in other disciplines (eg, clinical psychology [8] and social psychology [9,10]). However, to our knowledge, there has been no review of the use of VR technologies for primary health promotion and prevention. Therefore, instead of focusing on specific research questions related to a topic, outcome, or population, the goal of this review was to map the current state of the art of the use of VR in such areas and identify gaps and future directions.

## Rationale

### *Virtual Reality: Operating Principles*

The VR literature highlights 2 essential concepts, immersion and presence, both of which are critical to the user's experience in VEs [7,11]. Immersion refers to the technological ability of a VR system to fully engage the user by replacing real-world sensory inputs with virtual stimuli. The more immersive the device, the less interface there is between the user and the virtual world. High immersion includes naturalistic interactions, such as the use of body suits to track movement, which increases the sense of realism [7]. Immersive systems create a sense that the virtual world is an actual experience rather than a mediated one. However, presence depends on the user's psychological response to the VE. It is the subjective feeling of "being there" in the virtual world, interacting with it as if it were real [12]. This sense of presence increases engagement and leads to more vivid, memorable experiences [13]. Notably, presence can be felt in both immersive and nonimmersive media, such as movies or books, as it is influenced by individual factors and not just the technological features of the medium [14].

Although immersion and presence are often related, they are not the same. Higher levels of immersion tend to enhance feelings of presence, but immersion is not a necessary condition for presence [15]. Thus, immersion can be viewed as a moderator that enhances presence but does not guarantee it [16].

### **Why Use VR in Health Promotion and Prevention Psychology?**

VR technology has emerged as a promising tool in health promotion and prevention psychology, allowing for immersive experiences that can enhance user engagement and motivation [17,18]. VR enables researchers to create safe, ecological, and standardized VEs, where health promotion interventions can be effectively delivered and evaluated. VR presents key advantages as a tool for research and intervention in health promotion and primary prevention [7].

First, VR can be combined with devices aimed at mimicking more natural movements (eg, the use of handheld controllers

or haptic devices instead of a mouse and keyboard) and can encompass the integration of full-body motor and haptic feedback when using a bodysuit. This freedom and wholeness of movement can help enhance learning through direct practice, visualization, and ultimately embodied cognition (ie, cognition linked to the body [7,19]). Hence, VR can be a relevant tool to create interventions aimed at learning health-related behaviors that require practicing skills (eg, detecting testicular disorders [20]).

Second, due to its ability to elicit embodiment, VR is well suited to elicit and enhance perspective-taking and empathy [7,21]. For example, embodying an obese avatar could enhance taking the perspective of being overweight, leading to a more effective learning of the consequences of obesity and, in turn, a greater intention to take care of individual health (ie, reduce the attitude-intention-behavior gap). Through the feeling of presence, individuals can visualize themselves in a specific situation, hence allowing a deeper sense of self-reflection [20], potentially leading to more persistent changes in behavior. VR can recreate ecological situations and environments in which users can embody an avatar and act in the virtual world as if it were real, through the feeling of presence [12].

## Objective

Our goal was to identify and map how VR has been used in the field of health promotion and primary prevention. In this scoping review, we addressed three broad research questions:

1. What are the uses of VR technology in primary prevention and health promotion (ie, an overview of the goals and research questions addressed through the use of VR)?
2. What do we know so far about the effects of using VR in these fields (ie, a summary of the results)?
3. What are the challenges and limitations, if any, encountered so far?

Based on the findings of the scoping review, we drafted a list of recommendations and perspectives for the use of VR in health promotion and primary prevention.

## Methods

### **Protocol and Registration**

The scoping review protocol was drafted according to the PRISMA-ScR (Preferred Reporting Items for Systematic Reviews and Meta-analyses extension for Scoping Reviews) checklist [22,23]. We also conducted a synthesis without meta-analysis [24] (Checklist 1).

### **Eligibility Criteria**

We included any peer-reviewed and published empirical article, written in English, that described a study conducted on human subjects deploying any kind of immersive VR device (eg, HMD, cave automatic VE), including 360° videos when used in a VR setup, focusing on any research question in the field of health promotion or primary prevention, from January 1, 2010, to September 16, 2024. We chose to limit the search to the last 14 years in order to generate a recent state-of-the-art overview of the field. We excluded studies conducted on nonhumans or focused on secondary or tertiary prevention interventions, such

as psychotherapeutic treatments (eg, VR exposure therapy) and medical interventions (eg, rehabilitation), or specialized educational programs unrelated to prevention (eg, skills improvement for health practitioners). Pilot studies were not excluded from this review because of their critical role in assessing the feasibility and acceptability of interventions that may inform future primary, secondary, or tertiary prevention efforts. We excluded studies using the term “virtual reality” that described computer-based VEs involving a virtual world (eg, Second Life) or computer-related or motion-sensing devices (eg, Kinect, joystick) when they were associated with a nonimmersive VR setup (eg, non-VR video or serious game). We also used the population-concept-context framework to define our inclusion criteria. The population includes adolescents, young adults, and specific populations at risk for health issues (eg, individuals with anxiety or those at risk for substance use). The concept focuses on the application of VR technology to promote health behaviors, enhance knowledge, and improve emotional well-being. The context refers to contextual factors including the environments where VR interventions are delivered, such as schools, community centers, or health care facilities.

### Information Sources and Search Process

We searched 3 databases from January 1, 2010, until September 16, 2024 (PubMed and PsycINFO). For each database, we combined 2 sets of keywords; the first set focused on health promotion and prevention psychology. For PubMed, the search strings were (“health prevention” OR “health promotion” OR “health risk communication” OR “health communication” OR “preventive psychology” OR “behavior change” OR “attitude change”) AND (“virtual reality” OR “immersive virtual reality” OR “immersive virtual environment”). For PsycINFO, the search strings were (“health prevention” OR “health promotion” OR “health risk communication” OR “health communication” OR “preventive psychology” OR “behavior change” OR “attitude change”) AND (“virtual reality” OR “immersive virtual reality” OR “immersive virtual environment”).

### Selection of Sources of Evidence

Studies that did not employ VR technology, were not peer-reviewed, were reviews or meta-analyses, or lacked empirical data were excluded from the review. The screening process was conducted in 2 stages to enhance the rigor of the selection. In the first stage, titles and abstracts of the identified studies were reviewed to determine their relevance based on the inclusion criteria. This initial screening allowed the authors to eliminate studies that were clearly outside the scope of the review. In the second stage, full-text articles of the remaining studies were assessed to confirm their eligibility for inclusion. The extraction process was conducted independently by multiple reviewers to enhance reliability and minimize bias. Any discrepancies in data extraction were resolved through discussion and consensus among the reviewers. This meticulous approach to data extraction allowed the authors to synthesize findings across studies effectively and draw meaningful conclusions regarding the efficacy and feasibility of VR interventions in health promotion and primary prevention.

### Data Charting Process

The data charting process involved collecting information on study characteristics, intervention details, measured outcomes, user experience, type of materials, and sample characteristics (see [Multimedia Appendix 1](#)). Of note, approximately 63% of the studies included in the review were categorized as pilot or feasibility studies. We also recorded the type of VR technology used (eg, immersive headsets, desktop VR), the duration of the intervention, and the focus of the VR content (eg, health education, behavior change). On average, participants spent approximately 12.8 (SD 11.1) minutes using VR. We focused on health-related outcomes such as knowledge acquisition, behavioral intentions, and psychological well-being. User experience was assessed through qualitative data that provided insights into participants’ enjoyment, ease of use, and perceived effectiveness of the VR interventions. Many studies found that participants found the VR experience both enjoyable and engaging, which in turn led to higher participation rates compared to non-VR interventions.

### Data Items

Primary variables included study characteristics such as authorship, year of publication, study design, and sample size, which provided context for the research findings. Participant demographics, including age, gender, and health status, were also collected to understand the populations included in the studies. Intervention details were documented, focusing on the type of VR technology used, the duration of the intervention, and the specific health issues addressed. Measured outcomes were categorized into primary outcomes, such as knowledge acquisition and behavioral intentions, and secondary outcomes, including user engagement and satisfaction. User experience data were collected to assess participants’ enjoyment, ease of use, and any challenges encountered during the VR interventions. In addition, limitations of the studies were noted, including issues such as small sample sizes and methodological limitations, which are critical for contextualizing the findings. It is important to note that while immersion and presence are key concepts in understanding the effectiveness of VR, these variables were not measured consistently across studies, which may affect the interpretation of results. The data elements collected were intended to provide a structured review of the existing literature, as well as identify trends, gaps, and implications for future research in the field of VR-based health interventions.

### Critical Appraisal of Individual Sources of Evidence

We found that approximately 37% of the included studies were pilot or feasibility studies. These studies primarily focused on evaluating the usability and acceptability of VR interventions, which are critical for assessing the feasibility of larger-scale research. Although pilot studies provide valuable insights into user experiences and preliminary results, their small sample sizes and limited generalizability limit the ability to draw firm conclusions about the effectiveness of VR-based interventions. Mixed results have been found when comparing VR interventions to traditional methods, suggesting that VR does not always offer a clear advantage in achieving health outcomes. Key variables such as immersion and presence, which are critical

to understanding how VR might influence health behaviors, have not been systematically evaluated. We found a lack of focus on larger, more diverse samples and aim to replicate existing studies to strengthen the evidence supporting the use of VR in health promotion efforts.

### Study Selection Procedure

All search results were stored in Zotero, an open-source reference manager, and duplicates were removed. Titles and abstracts were screened first, removing articles that clearly did not match eligibility criteria. Second, full texts of the remaining articles were downloaded to define final eligibility for inclusion. For each step, 2 reviewers conducted the screening independently and compared and discussed these discrepancies until a full consensus was reached.

### Data Extraction Process and Synthesis of Results

Data extraction was done by 1 reviewer, who extracted the following items from the included articles: (1) title and authors, (2) goal(s) of the study, (3) design of the study, (4) study sample characteristics, (5) VR device used, (6) main results, and (7) limitations reported by the authors. A second reviewer verified that all data were correctly extracted. Following the data extraction, we conducted a narrative analysis and synthesis of the results. Results and implications of the data extracted from

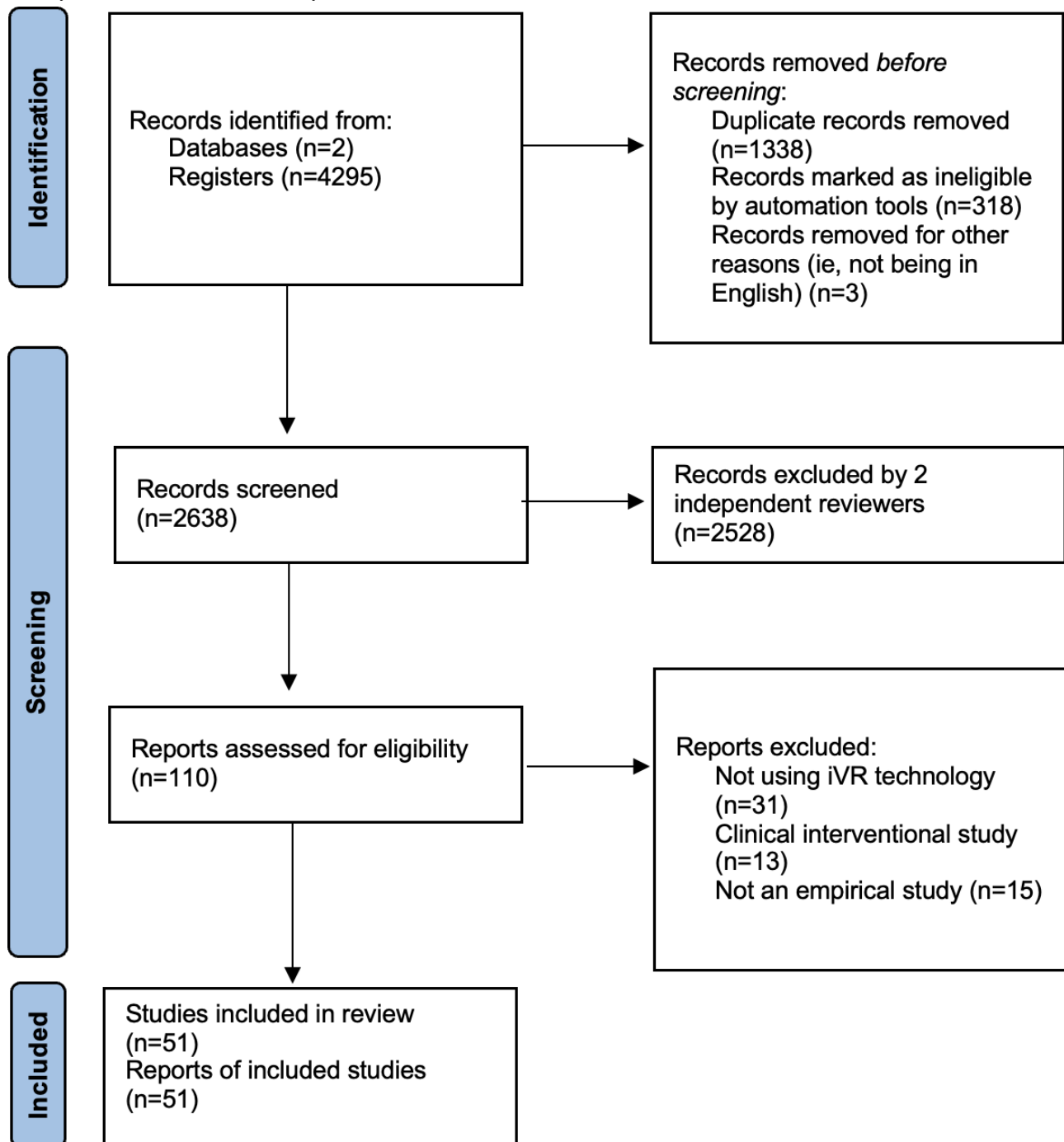
the included studies were discussed by 2 reviewers in relation to the 3 research questions of the scoping review.

## Results

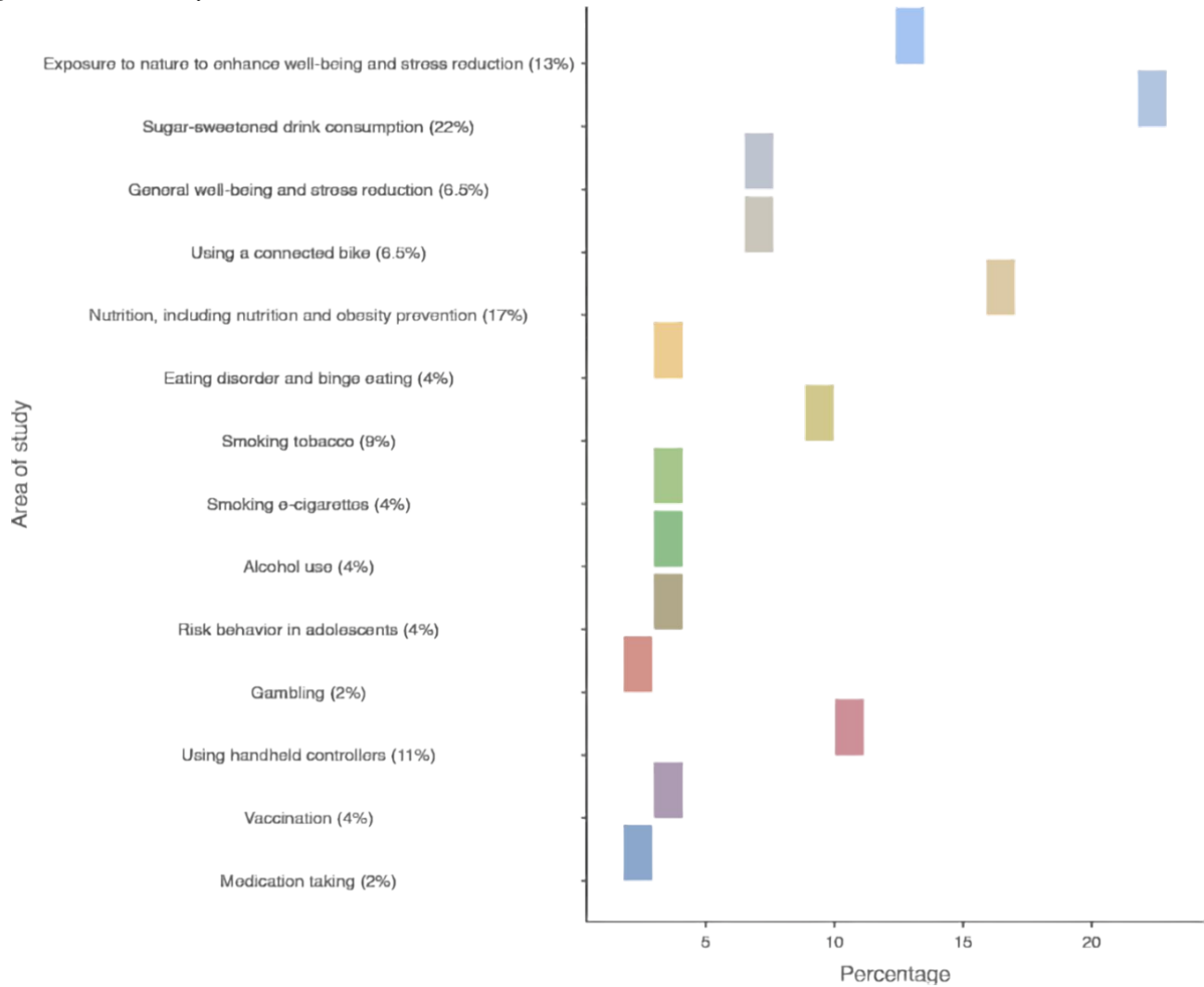
### Study Selection and Characteristics of Included Studies

The initial search identified 4295 unique articles, which were reduced to 51 eligible articles (see the PRISMA flowchart in [Figure 1](#)). Included studies were conducted in Asia (11 studies, 22%), Europe (18 studies, 35%), the Middle East (1 study, 2%), and North America (21 studies, 41%). The total sample size across all studies was 4647 participants, with an average of 91.1 participants per study. Study samples included slightly more women, with 2651 women (53%) and 1958 men (42.7%). The mean age of participants across the studies was 31.6 (SD 5.45) years. Studies primarily included adults, with 29 studies (57%) focused on adults, followed by 14 studies (28%) focused on adolescents, 7 studies (14%) focused on senior adults, and 1 study (2%) focused on children. Specific populations studied included students (7 studies, 29%), people with cognitive impairment (3 studies, 12%), and people with obesity (3 studies, 12%). Other populations studied included former smokers (1 study, 4%), NHS staff (1 study, 4%), parents (2 studies, 8%), smokers (2 studies, 8%), adults who had been in lockdown (1 study, 4%), and unvaccinated adults (1 study, 4%, see [Figure 2](#) for details).

**Figure 1.** Flowchart of the study selection process following PRISMA guidelines. A total of 4295 articles were initially identified across 3 databases. After removing duplicates and applying eligibility criteria, 51 studies were included. iVR: immersive virtual reality; PRISMA: Preferred Reporting Items for Systematic Reviews and Meta-analyses.



**Figure 2.** Overview of key outcomes from the intervention studies.



**Characteristics of Sources of Evidence**

The 51 included studies focused on various health-related topics (Table 1), the most predominant ones being nutrition (17%) and risky behaviors (4%). All studies used HMD, except for Lemieux et al [25], where the device used was not mentioned. HMDs were mainly Oculus (Quest, Go, or Rift, 24%), HTC Vive (17%), or Samsung Gear VR (15%). Almost half of the

studies (43%) were coupled with 1 or 2 handheld controllers. Most studies (56%) included an active interaction with the VE by using 1 or 2 handheld controllers or the bodysuit to interact with the VE. About 49% of VR exposure lasted a maximum of 10 minutes, including 22% of studies with under 5 minutes of VR exposure. We estimated an average time of 12.8 (SD 11.1) minutes spent using VR, according to the information given in the articles.

**Table .** Characteristics of sources of evidence.

Area of study	Studies
Nutrition, including nutrition and obesity prevention (17%)	Blom et al [26]; Isgin-Atici et al [27]; Ledoux et al [28]; Marcum et al [29]; McBride et al [30]; Persky et al [31,32]; Verhulst et al [33]
Eating disorder and binge eating (5%)	Ferrer-Garcia et al [34]; Lemieux et al [25]
Sugar-sweetened drink consumption (10%)	Blom et al [26]; Ledoux et al [28]; Marcum et al [29]; McBride et al [30]
Smoking tobacco (8%)	Borrelli et al [35]; Ferrer-García et al [36]; García-Rodríguez et al [37]; Bonnetterre et al [17]
Smoking e-cigarettes (5%)	Weser et al [38,39]
Alcohol use (5%)	Guldager et al [40]; Ma [41]
Risk behavior in adolescents (4%)	Hadley et al [42,43]
Gambling (2%)	Detez et al [44]
Exposure to nature to enhance well-being/stress reduction (14%)	Alyan et al [45]; Beverly et al [46]; Brimelow et al [47,48]; Browning et al [49]; Calogiuri et al [50]
General well-being/stress reduction (10%)	Afifi et al [51]; Adhyaru et al [52]; Kim et al [53]; Riva et al [54]; Ko et al [55]; Kiper et al [56]
Using handheld controllers (7%)	Eisapour et al [57]; Fang and Huang [58]; Farič et al [59]
Using a connected bike (7%)	Bird et al [60]; Zeng et al [61,62]
Vaccination (4%)	Mottelson et al [63]; Nowak et al [64]
Medication-taking (2%)	Niki et al [65]

## Results of Individual Sources of Evidence: Detailed Results

### Main Identified Research Goals

We identified three main goals for using VR: (1) as a tool to deliver an intervention, with 35 articles focusing on either (1a) pilot testing or testing the feasibility of using VR materials or procedures or (1b) using VR to deliver an actual intervention (eg, skills learning, comparing VR vs other intervention modalities) to test its relative efficacy; (2) as a tool to address fundamental research questions, with 6 studies aimed at recreating ecological settings to address physiological and psychological changes when exposed to certain situations (eg, cravings elicitation); or (3) as an assessment tool, with 5 studies investigating food choices with a food buffet created in VR.

### Pilot Studies: Ensuring Usability and Enjoyability

Many studies included in the scoping review were pilot or feasibility studies (about 37%, Table 2) from which we distinguished two main purposes: (1) testing VR usability for future research and seeing how target outcomes are impacted and (2) assessing users' experience with VR. First, researchers

found that the use of VR in their methods was rather relevant and reached multiple target outcomes such as reducing stress using a short exposure to nature in VR [45-48,51,52,55], even though exposure durations were relatively short (3-10 minutes). The use of VR was also useful to enhance participants' physical and cognitive activity [66,67]. Finally, some studies were focused on prevention and the major advantage of VR use is its ability to involve participants directly in the preventive message, for example through gaming [68] or skill practice (eg, refusing peer pressure to vape [38]). This resulted in improved knowledge on health topics (eg, on smoking in [69]) and intentions to check for diseases (eg, [20]). It also helped to deliver information in a more traditional preventive way (eg, exposure to a preventive video in an HMD in [35] or a FestLab in [40]). Overall, pilot and feasibility studies, even if conducted on small samples, found VR to be enjoyed and accepted by participants, as well as useful and feasible, and found that it impacted target outcomes (eg, enhanced well-being, increased knowledge). These results occurred whether participants only had a one-time exposure (eg, [53,69]) or sessions over a few weeks (eg, [48]) and were found to be sustained at follow-up when measured (eg, participants reduced their tobacco intake over the month following their participation [35]).



**Table .** Summary of articles and their classification within the scoping review.

Category and study	Descriptives	iVR <sup>a</sup> details	Objective(s)	Study design	Main conclusions
<b>1a: Pilot or feasibility studies</b>					
Adhyaru and Kemp [52]	n=39; mean age 36.6 (SD 10.3) years; 82% women; health care workers	HMD <sup>b</sup> (Oculus Go); 10 minutes	Explore if exposure to nature in iVR can help health care workers de-stress at work.	Before-after exposure; within-subject	iVR reduced anxiety, anger, and heart rate, and enhanced happiness and relaxation.
Affi et al [51]	n=50 older adults with cognitive impairments and their family members	Immersive VR <sup>c</sup> system	Assess whether iVR improves quality of life and social interaction for older adults and their family members.	Feasibility study with pre-post assessments	VR improved social interaction and quality of life for both older adults and their families.
Alyan et al [45]	n=20; mean age 21.8 (SD 2.2) years; 50% women; students	HMD (HTC Vive); 5 minutes	Use iVR to reduce stress via a virtual walk in nature.	2 (environment: realistic vs dreamlike); between-subject	iVR reduced stress and enhanced mental well-being.
Beverly et al [46]	n=102; 72% women; health care workers	HMD (Oculus Go/Pico G2); 3 minutes	Explore if cinematic iVR can reduce stress in health care workers.	Before-after exposure; within-subject	iVR reduced stress, independently of previous iVR use or job type.
Bonnetterre et al [17]	n=121; mean age 19.6 years; 82.5% female; university students	Sensiks Immersive VR system	Evaluate the impact of VR on memorization, attitudes, and craving responses to anti-tobacco posters.	Randomized controlled trial	VR enhanced memorization of prevention messages.
Borelli et al [35]	n=23; mean age 49.8 (SD 13.3) years; 22% women; adult smokers	HMD (Knoxlabs V2 cardboard); 5 minutes	Examine the feasibility and impact of a smoking cessation intervention during dental cleaning.	2 (video type: smoker ready/not ready to quit) × 3 (time: pre/post/follow-up); within-subject	Feasible and accepted by both smokers and dental care providers.
<b>1b: Interventions</b>					
Ahn [5]	n=73; mean age 20.8 (SD 1.1) years; 82% women; students	HMD (NM); 2 minutes	Test efficacy of preventive messages on sugar and sweetened beverage consumption via avatar embodiment.	2 (pamphlet only vs pamphlet plus iVR) × 2 (tailoring: others vs self) × 3 (time: pre/post/follow-up); between-subject	iVR heightened intentions to limit sugar and sweetened beverage consumption; effects were present at follow-up.
Blom et al [26]	n=99; mean age 30.7 (SD 10.9) years; 60% women; general population	HMD (HTC Vive); ≥3 minutes	Study purchase behaviors in an iVR supermarket.	2 (nudge vs control) × 2 (time pressure: 3 minutes vs no pressure); between-subject	iVR revealed changes in healthy food purchases based on nudge type.
<b>2: Fundamental research</b>					
Chittaro et al [70]	n=105; mean age 21.49 (SD 2.43) years; 90.5% women; students	HMD (Sony HMZ-T1); 5 minutes	Investigate links between iVR and persuasion theory, including inducing mortality salience.	2 (environment: iVR park vs cemetery); between-subject	iVR elicited mortality salience, impacted attitudes, and induced greater physiological reactions than traditional mortality salience manipulations.
Ferrer-Garcia et al [36]	n=25; mean age 29.7 (SD 13.4) years; 32% women; smokers	HMD (5DT HMD 800); time not mentioned	Assess iVR's ability to produce cravings toward tobacco smoking.	Before-during exposure to smoking cues	iVR created cravings, correlated with presence.
<b>3: Assessment tool</b>					
Isgin-Atici et al [27]	n=73; mean age 22.2 (SD 4.1) years; 56% women; students	HMD (HTC Vive); 5 - 25 minutes	Evaluate ease of use and efficiency of a virtual cafeteria.	2 (groups: iVR novices vs experienced); between-subject	iVR was user-friendly and effective regardless of prior VR experience.

Category and study	Descriptives	iVR <sup>a</sup> details	Objective(s)	Study design	Main conclusions
Marcum et al [29]	n=221; mean age 38 (SD 5.6) years; 100% women; mothers with obesity	HMD; time not mentioned	Examine microbehaviors influencing food selection in an iVR buffet.	3 (conditions: food safety control vs behavioral risk information vs family-based risk information); between-subject	iVR enabled dynamic assessment of food choice behaviors.

<sup>a</sup>iVR: immersive virtual reality.

<sup>b</sup>HMD: head-mounted display.

<sup>c</sup>VR: virtual reality.

Second, most participants found VR enjoyable and fun [59,68] and quite easy to use [52]; some were asked to complete a short tutorial [27]. Even older adults were able to manipulate handheld controllers [57], but 1 study reported that the HMD is sometimes heavy for their neck to lift (1 participant dropped out because of this reason [52]). It is worth noting that some of these studies [20,59] involved the targeted population in co-designing the intervention in previous pilot studies, hence not only explicitly ensuring usability [57] but also enhancing users' satisfaction with the intervention. Co-designing an intervention with the targeted population and conducting a first pilot study on a small sample (eg, 12/33) can improve the level of satisfaction and usability of the intervention prototype, albeit ultimate user satisfaction can only be assessed following full-scale deployment of the intervention.

### Relative Efficacy of VR Interventions

Interventions (39% [20/51] of the studies included in the review) using VR focused on several targets such as enhancing well-being by simulating a walk in nature (while remaining seated [49,54] or walking on a treadmill [50]) or skill learning and practice on various health topics [40,42]. Some studies were interested in delivering preventive content [40,41,71], other studies used VR's ability to create standardized conditions to test theoretical frameworks (eg, nudge and time pressure on healthy food choice [26,40]), while still others used VR to embody a specific character in order to impact health outcomes [5,33,56].

The key element of most studies included in this group is that they often compared the use of VR with other modalities to deliver an intervention; for example, delivering preventive information in VR versus a 2D screen (eg, [41,54]) or without the use of specific technology (eg, live role-playing with an instructor [64], reading a pamphlet, [61]). Some studies also compared different depths of immersion [50,60,62].

When comparing the relative efficacy of VR with other modalities, mixed results were found. For example, even though participants exercising using VR experienced an attentional shift from exercising, meaning that individuals were usually distracted and entertained by the VR setting, leading them to actually enjoy physical exercise, it was not always sufficient to obtain greater physical involvement when compared to nonimmersive physical activities [25,58,60,62]. However, some studies found no difference in outcomes between the use of VR and 2D screens [54,71], and other studies even found that a virtual walk remained less efficient than a real walk in nature for mood enhancement [49]. Some studies, using VR only, also

found no impact of VR prevention interventions on target outcomes (eg, no change in physical self-perception when using VR to prevent eating disorders [39], no increased knowledge on alcohol [40]). Still, we note that VR was a great tool to induce changes in knowledge and intentions to adopt a behavior (eg, vaccination intention [61], smoking e-cigarettes [44]) and for skill practice [42].

A few recent studies [44,54] investigated the use of VR outside of the laboratory, recruiting participants who own VR devices at home. Portable VR devices have become more affordable, resulting in individuals being able to use them potentially anywhere and be autonomously engaged with VR-based interventions. Furthermore, both studies resulted in an improvement in the target outcomes (reduction of psychological distress [54], increase in vaccination [44]).

Overall, VR is impactful; it can create precise and standardized experimental situations (eg, embodying an obese or weight-gaining avatar [5,33]), and it is especially practical for skill practice and sometimes for physical activity. VR-based interventions have shown a higher degree of attendance in intervention sessions (ie, adherence) than the same intervention done without the use of VR [64]. However, when VR is only used to deliver information without leveraging its specific characteristics, such as immersivity and active use of the device (ie, interacting with the VE via a game [61]), it has often been found to have similar efficacy as more traditional ways to deliver information (eg, 2D screens).

### VR to Address Fundamental Health Research Questions: A Tool to Recreate Ecological Settings in the Lab

VR can recreate real-life situations in laboratories and has been used across different domains, such as gambling [36], tobacco cravings [28,37], and food cravings [34,70], as well as for mimicking specific situations inducing certain psychological states, such as mortality salience (eg, [29]). In all studies, exposure to specific cues (eg, food items, cemetery, individuals smoking) or situations (eg, being in a pub, gambling on a slot machine) elicited both physiological (eg, increased heart rate, arousal) and psychological (eg, self-reported craving) changes, whether individuals were actively (ie, interacting with the VE) or passively (ie, watching visual content) using the VR device, suggesting that the highly immersive characteristics of VR are effective at eliciting an emotional response.

However, only 1 study compared eliciting cravings using VR versus other types of devices [34], indicating VR is not better suited to trigger a craving response than 2D pictures. It might

be possible that this null effect was due to the passive use of VR in this specific study, as interacting with a cue in VR has been found to enhance cravings [28].

### ***VR as an Assessment Tool in Health-Related Interventions***

A total of 5 studies used VR as an assessment tool in the field of nutrition by recreating a virtual buffet displaying food [27,30-32,65], where participants' task was to collect a plate of food. Participants found the VR food buffet easy to use, independently of whether they already used a VR device in the past [27]. In this context, VR allows researchers to study precisely how many items and types of food were selected and in which quantity, enabling them to calculate the total calories contained in each plate more easily. It also helped to display to participants a standardized food buffet with diverse food items without constraints from a real food buffet (eg, expiration dates, flexibility in food types, reduced costs).

### **Study Limitations**

#### ***The Necessity to Adapt the Use of VR to Experimental Needs***

The use of VR, whether for applied or fundamental research, has shown some limitations, mainly related to the study methodology and VR technology itself (eg, cybersickness, notably in [50]). First, a majority of included studies suffered from either small sample sizes (eg, 10 participants in [65], 6 in [57]) or nonrepresentative samples (eg, students in [29], healthy and active young individuals in [58]), limiting the validity and generalizability of results. Second, the quality of the experimental designs was sometimes limited (eg, semiexperimental design with pre-post comparisons) because of a lack of a proper control condition or not conducting a rigorous randomized controlled trial [20,46]. Short-term follow-up or the lack of a follow-up altogether was also mentioned as a limiting factor in numerous studies [41,42].

#### ***Lack of Systematic Assessment of VR's Main Characteristics: Presence, Immersion, and Cybersickness***

VR's effects, especially persuasive effects, seem to come from its ability to enhance presence, which is the feeling of being there during a VR experience. Hence, participants act similarly to real life in the VE because they are fully immersed in their interaction with it. The level of presence experienced by users can impact targeted variables in the intervention; participants who felt more present in the VE showed stronger positive effects on persuasion-related outcomes (eg, attitudes toward vaccination and intention to get vaccinated [61]; higher presence resulted in more reported cravings for tobacco in [37]). However, presence is rarely measured as a moderator or covariate across studies despite its potential impact on outcomes. The same applies to immersion, which was not measured across studies, despite studies often comparing different intervention modalities of varying degrees of immersion (eg, VR versus 2D screen). VR is not the only technology able to generate presence; narrative, videos, or nonimmersive VR can too [14]. Not measuring immersion or presence across different modalities limits the understanding of VR's role in driving effects on the target outcomes.

Finally, cybersickness was rarely measured across studies despite its potential negative effect on user experience and, in turn, target outcomes. Some studies, notably the ones focusing on physical activity, measured cybersickness and found that it can completely erase the positive effects of using VR (eg, walking on a treadmill while wearing a VR device led to cybersickness, which diminished the positive effects of being exposed to nature compared to the other condition, [50]). Participants who felt symptoms of cybersickness believed that it impacted their experience [59], sometimes to the point they had to drop out of the experiment [62].

## ***Discussion***

### **Principal Findings**

This scoping review identified 51 studies published over the past 14 years that explored the use of VR in health promotion and prevention psychology. Our findings revealed three primary applications of VR: (1) as a tool to deliver interventions, either in feasibility testing or actual implementation; (2) as a means to address fundamental research questions; and (3) as an assessment tool for health-related outcomes. Although VR shows significant promise in creating immersive and engaging interventions, our review highlights the variability in effectiveness and common challenges such as small sample sizes, short follow-up periods, and limited methodological standardization.

VR technology use for health promotion and prevention research is relatively recent, with studies in this review indicating its potential as a promising tool to deliver and assess interventions. For instance, VR was effective in simulating realistic scenarios to engage participants in skills-based learning and decision-making tasks, such as risk-reduction behaviors [42,61]. VR allows researchers to create safe, ecological, and standardized VEs in which it is possible to deliver and evaluate health promotion and preventive interventions [42]; recreate situations or environments that can elicit strong emotional, physiological, behavioral, or psychological responses (eg, mortality salience [29]); and assess outcomes (eg, cravings, food choices) with a multimeasure approach included in VR technologies (eg, psychological, physiological, and behavioral measures). This scoping review identified 51 studies concerning the use of VR technology in the field of health promotion and prevention psychology published within the past 14 years. We mapped (1) the goals and research questions addressed through the use of VR in this field, (2) its effects in the identified areas, and (3) its main challenges or limitations. We identified three main applications of VR in this field: (1) as a tool to deliver an intervention, either (1a) pilot or feasibility testing VR materials or procedures or (1b) using VR to deliver an actual intervention (eg, skills learning, comparing VR vs other intervention modalities) to test its relative efficacy; (2) as a tool to address fundamental research questions; and (3) as an assessment tool.

### **Comparison to Prior Work**

Due to the relative novelty of VR in this field, only 51 eligible studies were published in the past 14 years. Research so far has mostly focused on feasibility or pilot studies, aimed at testing the ability of VR to be integrated into interventions [69], with

a minority of studies focusing on answering fundamental research questions through the use of VR [28]. Most studies employed semiexperimental designs without a control or comparison group and often had a short or no follow-up, limiting the validity and generalizability of results. Studies also included relatively small samples and were often nonrepresentative of the general population (eg, students). However, as the use of VR in the field of health promotion and prevention is still in its infancy, it appears natural to see a stronger focus on pilot or feasibility studies in the published literature.

### Strength and Limitations of the Scoping Review

When considering whether VR is effective in health prevention, it should first be noted that the effectiveness of VR interventions was variable. For instance, while some studies indicated that VR could enhance user engagement and motivation [59], others found no significant differences in outcomes compared to traditional methods [71]. This highlights the need for further research to clarify the conditions under which VR is most effective. This scoping review showed that sometimes VR use is not systematically more effective in achieving target outcomes than its nonimmersive equivalents [41,54,71]; we supposed that to be more effective, VR should be used for its specific immersive characteristics, such as gamification or embodiment, which directly involve the user. For example, skills practice in VR was more effective than role-playing in real life to learn about risk behaviors and ways to avoid them (eg, buying condoms for safer sex) due to VR scenarios' ability to recreate a situation that is realistic, induce emotional changes in the user as the scenario goes on, and finally, make the user have a real first-person experience [42]. Similar results appeared in [61], in which VR was used to represent a vaccination intervention to stop flu spread (ie, participants used handheld controllers to actively send immune cells to prevent flu transmission), whereas in other conditions, participants were just passively watching (a video on a 2D screen or a pamphlet).

It is important to consider the limitations of this review when interpreting the findings. First, as the use of VR in health promotion and prevention psychology is a relatively recent phenomenon, our literature search focused on the last 14 years (2010 - 2024). This resulted in the inclusion of 51 eligible articles, which may have excluded earlier or less accessible studies. However, the majority of included studies (63%) were published between 2020 and 2024, reflecting the increasing affordability and accessibility of VR technology for research in recent years. Therefore, the likelihood of missing pivotal studies is low. Second, the search strategy did not include gray literature, which may have reduced the total number of eligible articles and introduced publication bias by excluding studies with nonsignificant or null results (the file drawer effect). To address this gap, future reviews should consider including gray literature to provide a more comprehensive overview of the field. Third, some studies lacked sufficient reporting of critical aspects such as sample characteristics (eg, size and demographics) and details of VR implementation (eg, exposure duration, type of VR technology used). This limited our ability to draw broad conclusions about the efficacy and applicability of VR in this area. Addressing these reporting gaps in future research will improve the comparability and quality of evidence

in this rapidly evolving area of study. Fourth, although our literature search was updated during the initial revision, which was completed just a few weeks prior to this submission, we recognize that VR research is advancing rapidly. It is therefore possible that new studies may emerge shortly after the conclusion of our search period, which may influence the results of future reviews. To address this, future updates could consider conducting more frequent searches or establishing a continuous review process to ensure that all emerging data are included in real time. However, we are confident that this review accurately reflects the state of the literature as of our latest search.

### Perspectives and Future Research Directions

#### *Standardization of Designs and Replication*

Although the results of our scoping review suggest that VR has potential as a tool for health promotion, the field is still in its infancy. Many studies in this area are limited by small sample sizes, short follow-up periods, and inadequate experimental control. Replication is essential to strengthen the reliability and validity of these findings [72,73]. Replication of these studies in diverse populations and settings will help confirm the generalizability of the findings and identify any boundary conditions, such as differences in user demographics, technology exposure, or the specific health behaviors targeted [74,75]. In addition, replication can shed light on the mechanisms underlying the effectiveness of VR interventions, which may vary depending on the context and population studied. Therefore, further replication is essential not only to solidify current evidence, but also to ensure that VR interventions are applicable and effective across a wide range of health promotion and primary prevention efforts. Replicating existing results to increase the amount and quality of empirical evidence supporting the use and benefit of VR in this field is needed. For example, in this scoping review, we saw that individuals showed an increased knowledge regarding health-related topics [20,69] or changed their behavioral intentions [44,61] when exposed to a VR intervention. However, not all studies provided evidence to fully support these claims [47,63], in addition to the lack of any perspective on how long these effects last or if they are applicable to less specific populations. Therefore, a focus on study replication can strengthen the advancement of research in this field and at the same time prevent a replication crisis, as observed in other fields of behavioral sciences and medicine [76]. There is also a critical need for future research to employ longitudinal study designs. Long-term follow-up is particularly important in preventive psychology, where sustained behavior change and long-term health outcomes are key indicators of success.

#### *VR vs Nonimmersive Apparatus*

The effectiveness of VR compared to nonimmersive interventions, such as 2D presentations, remains controversial. Evidence from the studies included in this review showed mixed results. Although some studies reported that VR interventions increased engagement and enjoyment, others found no significant differences in outcomes compared to nonimmersive methods [59,71]. The immersive features of VR, such as gamification and embodiment, appear to be particularly effective in scenarios that require active user involvement. For example,

participants who practiced risk-avoidance skills in VR showed better retention than those who used real-life role-playing [42]. Similarly, the use of VR in interactive scenarios, such as vaccination education, showed higher levels of engagement than passive modalities such as 2D videos or pamphlets [61]. However, studies have also shown that VR does not always outperform traditional methods in terms of physical activity or knowledge acquisition. This variability highlights the need for future research to clarify the specific contexts in which the immersive qualities of VR are most effective. Systematic assessment of key mechanisms such as presence and immersion could help determine whether VR's effectiveness is primarily due to its immersive nature or to other factors such as interactivity or novelty.

Assessing presence and immersion is crucial for understanding the mechanisms underlying VR and its effects [14]. Evaluating the feeling of presence helps determine the extent to which participants are psychologically immersed in VEs and allows for the identification and correction of potential errors in the VE that could influence presence and, consequently, the effectiveness of VR-based interventions or content. Additionally, addressing such errors can prevent cybersickness and ensure the smooth execution of experiments [50]. Measuring presence and immersion provides valuable insights into individuals' capacity to engage with VR compared to nonimmersive interventions and helps identify how these factors correlate with target outcomes.

### ***Set Up for Success***

Conducting feasibility or pilot studies to test the VR procedure and VEs is recommended. As shown in the scoping review, evaluating the enjoyability, usability, and safety of the procedure can be very helpful. Finally, co-designing the VR-based intervention with participants from the targeted population can

enhance the relevance, validity, and user experience with the intervention itself. Cocreating a procedure with participants could induce a bias in their judgment, making them judge the intervention more positively than it actually is. Pilot testing with different groups of participants is recommended to validate the final design.

### ***Make It Simple and Clear for Participants***

VR studies are attractive to participants (eg, higher attendance for intervention sessions than the non-VR condition in [19,42,77]), but they can be complex to follow all the way through (ie, risk of cognitive overload, fatigue [78]). When designing studies using VR, keeping them as simple and short as possible will minimize participant burden and fatigue. It is also highly possible that most participants have never experienced VR before, so making sure they understand how to move and interact with the environment at first is necessary. If possible, we recommend doing a short tutorial on how to use the controllers or putting the participant in a tutorial VE before the experimental procedure. The participants can then fully concentrate on what is happening in the VR rather than think about how to interact with the VE.

### **Conclusion**

This scoping review provides an overview of VR's emerging role in health promotion and prevention psychology, highlighting its potential to create immersive and engaging interventions. Although VR has shown promise in delivering health interventions and answering fundamental research questions, its effectiveness remains variable, and many studies are limited by methodological constraints. Future research should prioritize replication, longitudinal designs, and standardized methodologies to strengthen the evidence base and realize the full potential of VR in this field.

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### **Data Availability**

This scoping review is based on a synthesis of publicly available research articles. The datasets analyzed during this study are derived from published sources that are referenced within the manuscript. No new datasets were generated.

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### **Authors' Contributions**

SB contributed to the conceptualization, formal analysis, methodology, and writing of the original draft of the manuscript. OZ was involved in the conceptualization, formal analysis, methodology, writing of the original draft, and reviewing and editing the manuscript, while also providing supervision throughout the project. MB participated in the conceptualization, methodology, and writing of the original draft, and offered supervision during the research process.

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### Multimedia Appendix 1

Summary of Studies Using Virtual Reality for Health-Related Behavioral Interventions.

[[DOCX File, 37 KB](#) - [xr\\_v2i1e49923\\_app1.docx](#) ]

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### Checklist 1

PRISMA-ScR checklist.

[[PDF File, 326 KB - xr\\_v2i1e49923\\_app2.pdf](#)]

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## Abbreviations

**HMD:** head-mounted display

**PRISMA-ScR:** Preferred Reporting Items for Systematic Reviews and Meta-analyses extension for Scoping Reviews

**VE:** virtual environment

**VR:** virtual reality

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# Applications of Augmented Reality for Prehospital Emergency Care: Systematic Review of Randomized Controlled Trials

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## Abstract

**Background:** Delivering high-quality prehospital emergency care remains challenging, especially in resource-limited settings where real-time clinical decision support is limited. Augmented reality (AR) has emerged as a promising health care technology, offering potential solutions to enhance decision-making, care processes, and emergency medical service (EMS) training.

**Objective:** This systematic review assesses the effectiveness of AR in improving clinical decision-making, care delivery, and educational outcomes for EMS providers.

**Methods:** We searched databases including PubMed, Cochrane CENTRAL, Web of Science, Institute of Electrical and Electronics Engineers (IEEE), Embase, PsycInfo, and Association for Computing Machinery (ACM). Studies were selected based on their focus on AR in prehospital care. A total of 14 randomized controlled trials were selected from an initial screening of 2081 manuscripts. Included studies focused on AR use by EMS personnel, examining clinical and educational impacts. Data such as study demographics, intervention type, outcomes, and methodologies were extracted using a standardized form. Primary outcomes assessed included clinical task accuracy, response times, and training efficacy. A narrative synthesis was conducted, and bias was evaluated using Cochrane's risk of bias tool. Improvements in AR-assisted interventions and their limitations were analyzed.

**Results:** AR significantly improved clinical decision-making accuracy and EMS training outcomes, reducing response times in simulations and real-world applications. However, small sample sizes and challenges in integrating AR into workflows limit the generalizability of the findings.

**Conclusions:** AR holds promise for transforming prehospital care by enhancing real-time decision-making and EMS training. Future research should address technological integration and scalability to fully realize AR's potential in EMS.

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## KEYWORDS

prehospital emergency care; emergency medical services; randomized controlled trials; clinical decision support; training; augmented reality; emergency; care; systematic review; BLS; procedures; traumatic injury; survival; prehospital; emergency care; AR; decision-making; educational; education; EMS; database; technology; critical care; basic life support

## Introduction

### Overview

The prehospital setting represents a critical area of emergency medical care. Emergency medical services (EMSs) providers,

such as emergency medical technicians, firefighters, and paramedics care for diverse patient populations in variable in highly acute settings; they are often the first to respond to life-threatening scenarios such as traumatic injury or cardiac arrest. Innovations in prehospital care have led to improvement in patient outcomes over the past several decades, including a

reduction in early deaths following traumatic injuries and improved survival from out-of-hospital cardiac arrest following early initiation of basic life support (BLS) procedures [1-5]. However, there remain significant challenges to providing high-quality prehospital emergency care, especially in resource-limited settings. Prehospital emergency care literature reports that top research priorities include augmenting the education and training of EMS personnel as well as improving the management of patients with life-threatening conditions such as asthma exacerbation, traumatic brain injury, and cardiac ischemia [6,7]. Further, improving the availability and response quality of medical control physicians for EMS systems has been cited as an additional area of interest [8].

With the need for improvements in both real-time decision support in prehospital care and the education and training of prehospital care providers, researchers have posited the utility of integrating AR into the prehospital setting. AR technologies are tools to superimpose digitally generated 3D and 2D visual information into a user's environment in real time for display and guidance. Unlike virtual reality, in which a user is completely immersed in a virtual environment that occludes their physical environment, users of AR technologies can interact with both their physical environment and digitally generated images [9].

AR already has significant implications within health care, with AR-based clinical and training modalities beginning to emerge within several medical fields [10-13]. The most well-documented examples come from surgical specialties, which have for years used AR-based equipment as clinical decision support (CDS) and training tools to practice intricate procedures; additionally, many subdisciplines including bariatric surgery, oral-maxillofacial surgery, and neurosurgery use AR-based minimally-invasive robotic procedures [14-19]. Experts have suggested that AR-based CDS tools may prove useful to a variety of prehospital applications, such as providing real-time decision support for patient resuscitation or enhancing BLS education.

To date, there have been few systematic examinations of AR in emergency medicine (EM), with even fewer specifically investigating prehospital emergency medical care. This manuscript thus presents a systematic review of randomized control trials (RCTs) investigating applications of AR in prehospital emergency medical care. Our primary objective is to evaluate the efficacy and effectiveness of AR applications in improving patient outcomes, care processes, and learning outcomes in the prehospital emergency care setting. Our secondary objectives are to identify challenges and limitations for the implementation of AR-based CDS and training tools in prehospital EM and to explore future directions for AR applications in these domains.

## Methods

### Literature Search

A systematic review of the available literature was performed to investigate the effect of AR on prehospital emergency medical care. Eligibility criteria for inclusion in the systematic review

included peer-reviewed manuscripts published between 1970 and 2024 (June 10) in English-language journals. A search was conducted of online academic databases including PubMed, CENTRAL, Web of Science, Institute of Electrical and Electronics Engineers (IEEE), Embase, PsycInfo, CINAHL Complete, and Association for Computing Machinery (ACM). Detailed search strategy across databases for identifying studies on AR in prehospital emergency care can be found in [Multimedia Appendix 1](#).

### Full-Text Review

A search of these 8 academic databases yielded 2081 manuscripts for review. Two independent reviewers first screened titles and abstracts to remove duplicates (n=726) as well as manuscripts that were not related to EM (n=1228). A full-text review of 127 studies was conducted by 8 independent researchers to assess their eligibility. Studies were included in full-text screening if a reviewer consensus of 2 reviewers deemed the study eligible. Each study during full-text screening was reviewed by 2 of the 8 reviewers independently and consensus was determined by a third reviewer. Data extraction was conducted independently by 2 reviewers using Covidence software (Veritas Health Innovation), which facilitated the management and review of manuscripts. Each reviewer independently extracted data, including study characteristics, participant demographics, intervention details, and outcome measures. Any discrepancies in the extracted data were resolved through discussion, with a third reviewer stepping in to make the final decision when necessary. No automation tools were used in the data extraction process. The full data extraction form can be seen in [Multimedia Appendix 2](#).

### Criteria for Inclusion

Criteria for inclusion into the final systematic review included full RCT or crossover RCT design; study setting in an EM; and use of wearable, handheld, or projection-based AR in intervention. Studies were included if they investigated the impact of AR on health care professionals or health care students, including emergency responders, paramedics, emergency medical technicians, medics, EM physicians, residents, or fellows, physician assistants, medical and health care students, surgeons, nurses, firefighters, law enforcement officers, or other relevant population (eg, lifeguards, other university students and lay first-responders, or unspecified medical specialties). Studies were also excluded if they were only a description of the technology without learning, performance, or other intervention outcomes.

### Key Data Extracted

Primary outcomes of interest included patient outcomes or clinical performance outcomes such as task completion time, accuracy, number of attempts, and errors. Secondary outcomes included user experience or human factors outcomes such as technology acceptance, workload, stress, and cyber- or simulator-sickness. Key data for analysis was extracted from each of the included manuscripts by 2 independent reviewers using a standardized data extraction form. All data were collected and recorded using Microsoft Excel software. Data collected included study characteristics, participant

demographics, AR information, outcome measures, results, and limitations.

In addition to primary outcome measures such as task completion time, procedure accuracy, and protocol compliance, we collected data on several other key variables. These included study characteristics (publication year, country of study, design type, sample size), participant characteristics (professional roles such as first responders, paramedics, medical students; study population size; and whether the setting was civilian or military). Intervention characteristics were also documented, focusing on the type of AR platform used (eg, HoloLens, Vuzix, and Google Glasses) and the intervention context (real-time clinical support or educational training). Secondary outcome measures like user experience, technology acceptance, workload, and the occurrence of simulator sickness were also analyzed. No assumptions were made about missing or unclear data, and any such data were marked as “not reported.”

### Consensus

Consensus between reviewers was tracked via Microsoft Excel spreadsheet and calculated using Cohen  $\kappa$ , with an average of

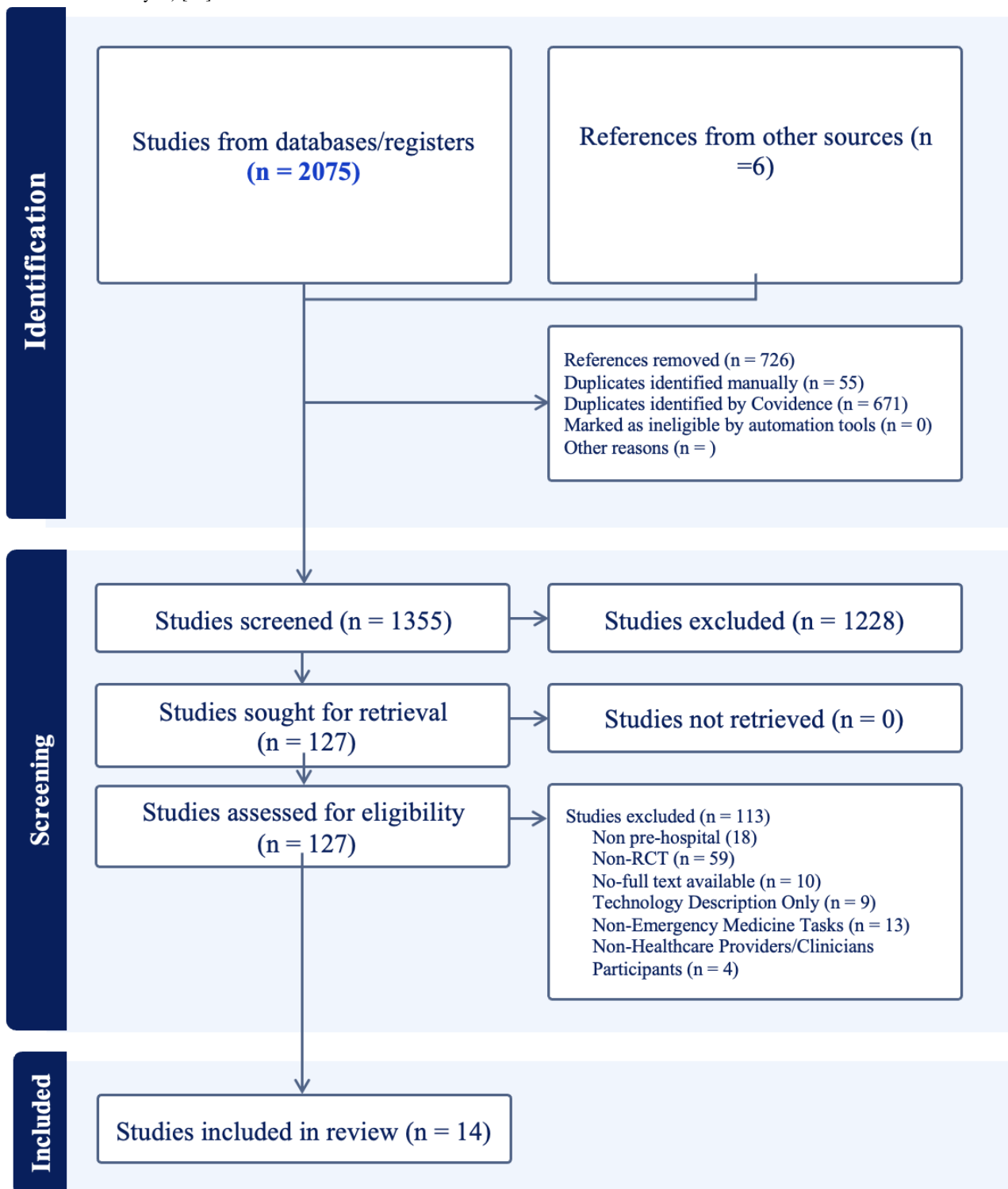
0.71 (95% CI 0.635 - 0.785). The quality and potential bias of the included studies were evaluated on a manuscript level by independent reviewers using Cochrane’s risk of bias tool [20], which can be seen in [Multimedia Appendix 3](#), and reviewed by group consensus. The literature review and evaluation process are detailed in [Figure 1](#). All data were summarized collectively and reported as an aggregate as well as in subgroups including “education and training” and “clinical decision making”. Qualitative and descriptive data were synthesized narratively. The review protocol can be accessed in the [Multimedia Appendix 2](#).

## Results

### Characteristics of Included Studies

[Figure 1](#) presents the review procedure and the resulting number of relevant papers based on PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analysis) [21]. The characteristics of the 14 studies included in this systematic review are summarized in [Table 1](#).

**Figure 1.** Systematic literature review procedure and the resulting number of relevant papers using PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analysis) [21]. RCT: randomized controlled trial.



**Table .** Summary of studies evaluating augmented reality (AR) interventions in prehospital care, including study populations, AR platforms used, primary outcomes, and main findings across various emergency medical scenarios.

First author, publication year	Study population and sample size	AR intervention; platform	Primary outcome measures	Main findings
Rebol et al, 2023 [22]	First responders (n=25)	Real-time assistance for CPR <sup>a</sup> performance; HoloLens	CPR performance metrics (compression depth and rate)	No significant performance difference between mixed reality and control group
Koutitas et al, 2019 [23]	EMS <sup>b</sup> cadets (n=30)	Training module for the operation of Ambus systems; HoloLens	Time to task completion and error rate	Significant reduction in task completion time and error rate in AR group
Gruenerbl et al, 2018 [24]	Nursing students (n=50)	CPR training module; Google glasses	CPR performance metrics (compression depth and rate) before and after training	Significant improvement in posttraining performance in AR group
Doswell et al, 2020 [25]	First responders (n=10)	BLS <sup>c</sup> procedures training module; HoloLens	Time to correct procedure performance	No significant difference in performance time between AR and control group
Collington et al, 2018 [26]	Firefighters (n=10)	BLS procedures training module; Moverio glasses	Performance in simulated trauma scenarios	Significant improvement in self-reported hands-on skills proficiency in AR group
Barcala-Furelos et al, 2023 [27]	Lifeguards (n=38)	Real-time assistance for simulated infant delivery; Vuzix	Performance time and compliance with protocol	Significantly improved protocol adherence in AR group
Follman et al, 2019 [28]	Paramedics (n=31)	Real-time assistance in MCI <sup>d</sup> triage; ReconJet	Screening time and assessment accuracy	Significant improvement in triage accuracy in AR group
Du et al, 2022 [29]	Medical students (n=20)	Tactical Combat Casualty Care (TCCC) training module; HTC VivePro	Posttest knowledge acquisition	No significant improvement in posttest scores between AR and control groups
Aranda-García et al, 2024 [30]	Health sciences and nursing students (n=60)	CPR and AED <sup>e</sup> training module; Vuzix	Time to task completion, adherence to BLS protocol, CPR performance	Significantly improved CPR quality and protocol adherence in AR group
Follman et al, 2021 [31]	Non-EM <sup>f</sup> health care professionals (n=40)	Real-time assistance in MCI triage; ReconJet	Time to triage; triage accuracy	Significantly decreased triage time in non-AR; no difference in accuracy
Hou et al, 2022 [32]	Health care university students (n=27)	CPR training module; HoloLens	CPR performance metrics (compression rate and depth)	No significant performance difference between AR and control groups
Apiratwarakul et al, 2022 [33]	Emergency physicians, nurses, and EMTs <sup>g</sup> (n=68)	Real-time assistance in MCI casualty detection; HMT-1	Time to completion; accuracy of casualty count in simulated MCI	Significantly decreased time to task completion in AR group, no significant difference in accuracy
Azimi et al, 2018 [34]	EM providers (n=20)	Training in advanced life support procedures; HoloLens	Task performance, task time	No significant difference between AR and control groups
Glick et al, 2021 [35]	Medical students (n=13)	Remote guidance in performing chest thoracotomy; HoloLens	Procedure quality rated by independent observer	Significantly improved procedure quality rating in AR group

<sup>a</sup>CPR: cardiopulmonary resuscitation.

<sup>b</sup>EMS: emergency medical service.

<sup>c</sup>BLS: basic life support.

<sup>d</sup>MCI: mass casualty incident.

<sup>e</sup>AED: automated external defibrillator.

<sup>f</sup>EM: emergency medicine.

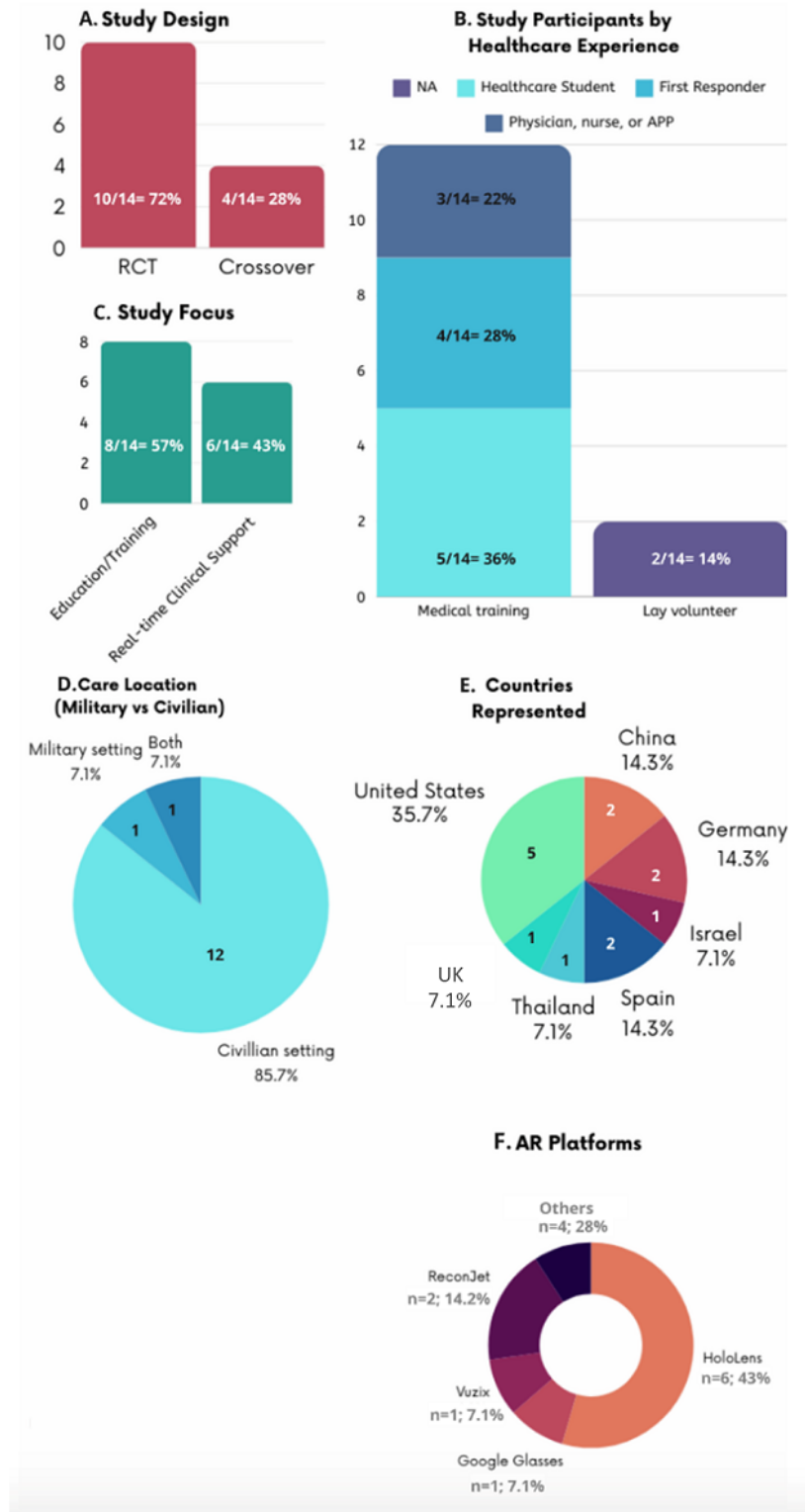
<sup>g</sup>EMT: emergency medical technician.

### Type of Study Design

Figure 2 highlighted the summary-level study characteristics of the 14 studies. Figure 2A and C shows the distribution of studies by study design (Crossover RCT and Full RCT) and their focus areas: real-time decision support, training or

education, or both. Full RCTs are the most frequent, with 4 studies focused on training or education and 3 on real-time decision support. Additionally, one study addressed both focus areas. Crossover RCTs primarily focus on training or education (4 studies), with one study focused on real-time decision support.

Figure 2. Summary characteristics of 14 included studies.



## Settings and Regions

The 14 studies included a total of 420 participants and were conducted in 7 different countries. A total of 10 (71%) studies were full RCTs while 4 (29%) studies used a crossover design. Overall, 12 (86%) studies were conducted in civilian settings while 1 (7%) study was conducted in a military setting and 1 (7%) study used both military and civilian settings (Figure 2E). Eight (57%) studies used AR for use in task training and education, while the remaining 6 (43%) used AR to provide real-time decision support for clinical scenarios. All 14 (100%) studies used medical simulation rather than real clinical encounters to test their AR interventions.

## Measured Outcomes

While specific outcome measures varied, all studies aimed to compare the efficacy of their AR intervention relative to the current standard of practice. Outcomes examined included time to initiation or completion of desired procedure or intervention

(n=5) percentage of correctly informed procedures, procedure quality, or error rate (n=8), and knowledge acquisition (n=1). Overall; 57% (n=8) found statistically significant improvements in their desired outcomes using AR modalities, while 36% (n=5) indicated no significant difference, and 7% (n=1) demonstrated worse performance following AR interventions.

## Type of AR Platforms

All studies used wearable head-mounted displays to deliver their AR intervention (Figure 2F). The most used AR platform across studies was HoloLens goggles (6/14; 43%); other AR platforms used included Vuzix (n=1), Google glasses (n=1), ReconJet (n=2), Epson Moverio (n=1), HTC Vive Pro (n=1), and HMT-1 (n=1). A description of the AR platforms used in the 14 studies is presented in Table 2.

A variety of apps and software platforms were used across the 14 studies; selected novel interventions are highlighted in Table 3.

**Table .** Comparison of augmented reality/virtual reality (AR/VR) devices used in prehospital simulations, showing manufacturer, model, release date, price, and key features.

Device	Manufacturer; models and release date; and retail price	Capabilities
<b>HoloLens</b>	Microsoft; V2 (2019); US \$3500	Eye-tracking, audio and speech command, spatial mapping, MR <sup>a</sup> capture, Windows connectivity
<b>Google Glasses</b>	Google X; Explorer (2019) NOTE: no longer manufactured; US \$999-US \$1848	Voice command, internet browsing, camera, calendar, android iOS
<b>Moverio</b>	Epson; BT 35-e (2018); US \$200-US \$800	Voice recognition, high definition (HD) display, drone connectivity, remote service, and support
<b>Vuzix</b>	Vuzix; M400 (2020); US \$1799	Voice recognition, eye-tracking, spatial mapping, iOS and Android compatibility, waterproof
<b>RealWear</b>	RealWear; HMT-1 (2018); US \$797-US \$1500	Voice-activated display, noise cancellation, voice-activated, outdoor-compatible display, water and shock resistant, android and Bluetooth compatible, 20-degree field of view
<b>ReconJet</b>	Intel; Smart Glasses (2015); US \$699	3-axis sensor, biometric tracking data (heart rate, sleep, etc), GPS, accelerometer, microphones, android iOS compatible, Bluetooth and wifi connectivity
<b>HTC VivePro</b>	HTC; VivePro 2.0 (2021); US \$699-US \$1999	5k resolution, submillimeter tracking capabilities, balanced ergonomic, 120-degree horizontal field of view

<sup>a</sup>MR: mixed reality.



**Table .** Selected augmented reality (AR) apps and software platforms in 14 prehospital included studies.

App	Description	Platform (location)	Manuscript
PRIOR	Android app for technical support in MCI <sup>a</sup> triage	Tech2Go GMBH Mobile System (Hamburg, Germany)	Follman et al, 2019 [28]
AUDIME	Android app for technical support in MCI triage in the disaster setting	Tech2Go GMBH Mobile System (Hamburg, Germany)	Follman et al, 2021 [31]
AMBUS	App for learning layout of Ambulance Bus Systems	Unity Game Systems (San Francisco, CA)	Koutitas et al, 2019 [23]
Tensor Flow	Artificial intelligence android app for assistance with casualty detection	Google (Mountain View, CA)	Apiratwarakul et al, 2022 [33]
Juxtapia CAMMRAD PREPARE	App for training in BLS <sup>b</sup> procedures	Juxtapia AR systems (Baltimore, MD)	Collington, 2018 [26]

<sup>a</sup>MCI: mass casualty incident.

<sup>b</sup>BLS: basic life support.

## Applications

### AR as CDS Tools

A total of 6 studies examined AR-based real-time decision support in the prehospital setting. Rebol et al [22] investigated AR-based real-time feedback for adult cardiopulmonary resuscitation (CPR). They found no significant difference in CPR quality in non-health care university students receiving real-time mixed reality-based feedback on performance as compared with students receiving feedback via standard video conference. Barcala-Furelos et al [27] investigated an AR-based intervention aimed at guiding lifeguards assisting in imminent childbirth situations. They found significantly higher adherence to out-of-hospital birth protocols in the AR-intervention group than in the control group ( $P < .05$  for all protocol variables). Follmann et al [28] found that real-time AR-based guidance in mass casualty incident (MCI) triage led to a significant improvement in triage accuracy over the control group, which performed triage without AR assistance ( $P = .04$ ). A similar result was found by Follman et al [31], which examined the effect of AR support on MCI triage time and accuracy; they found that triage time was significantly reduced in the control group ( $P < .001$ ) but found no difference in triage accuracy between groups. Apiratwarakul et al [33] employed an AR intervention for assistance in casualty identification; results demonstrated a decreased time to completion of casualty count in the AR group ( $P < .05$ ) but no significant difference in accuracy. Glick et al [35] investigated real-time AR-based guidance for medical students in performing a chest thoracotomy and found that expert rating of procedure quality was significantly improved in the AR group ( $P = .004$ ).

### AR as Training Tools

A total of 7 studies examined the utility of AR for education and training in the prehospital setting. Two studies (Doswell et al [25] and Collington et al [26]) investigated AR-augmented training for BLS procedures such as Narcan administration and tourniquet application. Doswell et al [25] found no significant difference in procedure time and accuracy between the AR training group and control group; Collington et al [26] showed an increase in self-reported skills proficiency in the AR training

group (mean 2.2, SD 1.03) but no significant difference in clinical proficiency. One study [34] examined the efficacy of an AR-based training module on performing advanced life support procedures, including needle chest decompression, direct intravenous placement, and cricothyroidotomy, but found no significant difference in procedure performance between the AR and standard training groups. One study [23] demonstrated that an AR-based training module for familiarization with an AmBus system led to a 10% reduction in time to task completion (involving finding objects on the AmBus) and 34% reduction in errors than the group receiving standard audiovisual-based training. Two studies (Du et al [29] and Follman et al [31]) examined AR-based training for tactical combat casualty care (TCCC) and MCI triage. Du et al [29], which examined TCCC knowledge gain based on pre and posttraining tests, found no significant performance difference between the AR-based training group and the control group.

A total of 3 studies (Gruenerbl et al [24], Aranda-García et al [30], and Hou et al [32]) specifically examined the performance of adult CPR following AR-based training modules. Two of the 3 studies (Gruenerbl et al [24]; Aranda-García et al [30]) found significant improvement in aspects of CPR performance following AR intervention. They demonstrated a significantly improved percentage of time spent performing chest compressions at the correct depth and rate among nursing students receiving AR-based instruction as compared with standard teaching ( $P < .001$ ,  $F = 14.85$ ). Aranda-García et al [30] demonstrated significant improvement in the percentage of chest compressions performed with adequate chest recoil ( $P = .008$ ) among health sciences and nursing students receiving AR-based instruction as compared with control; however, they did not find a significant difference in other metrics. Hou found no significant difference in CPR performance (chest compression rate and depth) receiving AR-based training as compared with instructor-led training.

### Risk of Bias Analysis

Risk of bias of studies was assessed via Cochrane's risk of bias tool, which examined parameters including sampling technique, adequacy of randomization, reliability of outcome measures, and statistical power (Multimedia Appendix 3). Overall, the

quality of the included studies was judged to be high. Each of the 14 studies was examined on a manuscript level with consensus reached between 8 independent reviewers. All 14 studies were determined to have a randomized design, with 10 comprising full RCTs and 4 having a crossover design. Most studies were found to have adequate randomization methodology, similar baseline participant characteristics, reliable outcome measures, and a participant dropout rate below 20%. Two of the 14 studies were recorded as lacking sufficient sample size to achieve 80% power with one recorded as “unable to be determined.”

## Discussion

### Principal Findings

This systematic review sought to examine the application of AR to emergency medical care in the prehospital setting, with the primary objective of evaluating the efficacy or effectiveness of AR apps in improving patient outcomes, care processes, and learning outcomes. Of the 14 studies analyzed in this systematic review, the majority demonstrated a significant improvement in desired outcomes with the integration of AR into their workflow, suggesting that AR may have a valuable role to play in enhancing the quality of prehospital care.

### AR as CDS Tools

Studies investigating the utility of AR in providing real-time CDS demonstrated a significant improvement in at least 1 outcome. AR interventions are especially effective in providing real-time decision support for MCI scenarios, enhancing both the accuracy and efficiency of triage procedures and casualty counts. AR-based remote guidance improved procedure quality for fully-trained medical students performing simulated chest thoracotomy procedures, as well as for laypeople responding to simulated childbirth. These results suggest that AR may have an important role to play in improving medical control for EMS, as AR-based feedback and guidance could greatly enhance decision-making for prehospital care providers as compared with traditional audio feedback [36-38]. Results of these studies also suggest that AR may serve a vital purpose in tactical emergency medicine scenarios, including military and law enforcement operations that could benefit from remote guidance in high-acuity scenarios [35,39]. Future research could investigate AR integration into tactical emergency medicine scenarios, such as SWAT team activations.

It is also important to note the potential integration of AR with other emerging technologies, such as artificial intelligence algorithms, which could further enhance decision support by providing predictive analytics and personalized recommendations [13,40,41]. Combining AR with wearable biometric sensors could offer real-time monitoring of vital signs, providing a context-aware decision support system that enhances situational awareness and operational efficiency [10].

### AR as Training Tools

With regards to education and training, 2 of the 4 studies examining the benefit of AR in augmenting CPR training demonstrated significant improvement in CPR quality following AR intervention. These findings suggest that it may be feasible to integrate AR into CPR training. The study by Koutitas et al [23], which examined an AR-based training module for familiarization with AmBus systems also demonstrated improved task completion and enhanced comfort and familiarity with the vehicle in the AR intervention group, suggesting that AR may prove a useful adjunct to EMS companies in training new hires. Notably, some studies, that examined AR intervention in prehospital education and training modules for skills including, CPR, BLS, advanced life support procedures, and TCCC, showed no difference in performance with AR intervention. It is possible that some of these tasks, which involve a significant number of hands-on skills, were more difficult to adapt from in-person instruction to AR-based training. Future research could more thoroughly explore discrepancies in AR-based training modules among various prehospital clinical skills [42]. Furthermore, the scalability of AR training modules offers a significant advantage for widespread training initiatives, allowing consistent and repeatable training experiences across different geographical locations. This scalability is particularly beneficial for remote and underserved areas where access to high-quality training resources is limited.

### Challenges of AR Technology

Overall satisfaction with AR platforms was high across the 14 studies; manuscripts that solicited user feedback found that most participants reported positive perceptions of the technology. Several common concerns emerged from this user feedback. These common concerns are summarized in Table 4.

Of greatest concern was user comfort as well as occasional unpleasant side effects associated with the use of AR. Several manuscripts indicated that wearable interventions, particularly those including headsets, were not compatible with participants who wore prescription eyeglasses. Additionally, some reported participants experiencing side effects after AR use, including dizziness, headache, and nausea. This constellation of adverse effects is collectively known as “cybersickness [43],” and has been demonstrated to impact AR, mixed reality, and virtual reality users, particularly those who are susceptible to motion sickness [44]. Future research into AR should factor cybersickness risk into study design and look to mitigate side effects. Other common concerns included the costs associated with both the purchase and maintenance of AR platforms [45], as well as inconsistent user interface and frequent technological glitches [46]. Addressing these concerns requires a multi-faceted approach [47,48]. Collaborations with manufacturers, health care providers, and end users will be crucial in creating AR systems that are not only effective but also user-friendly and economically viable [9,12]. Additionally, ongoing education and support for users can help mitigate some of the initial discomfort and resistance to new technology [49].

**Table .** Summary of common concerns related to augmented reality (AR) use in prehospital care, including user comfort, user interface issues, information technology (IT) challenges, and cost.

Concern	Source
User comfort	<ul style="list-style-type: none"> <li>Headgear uncomfortable or disruptive to workflow, causes unpleasant side effects (Rebol et al, 2023 [22]; Doswell et al, 2020 [25]; Follman et al, 2019 [28]; Du et al, 2022 [29]; Follman et al, 2021 [31]; Hou et al, 2022 [32])</li> <li>AR implicated: HoloLens, Google Glass, Moverio</li> </ul>
User interface	<ul style="list-style-type: none"> <li>User interface confusing or difficult to use or requires steep learning curve (Follman et al, 2021 [31]; Glick et al, 2021 [35])</li> <li>AR implicated: HoloLens, ReconJet</li> </ul>
IT issues	<ul style="list-style-type: none"> <li>Poor battery life, screen glitching, application freezing (Rebol et al, 2023 [22]; Barcala-Furelos et al, 2023 [27]; Aranda-García et al, 2024 [30]; Follman et al, 2021 [31])</li> <li>AR implicated: HoloLens, ReconJet, Vuzix</li> </ul>
Cost	<ul style="list-style-type: none"> <li>High cost of materials, setup, and maintenance (Du et al, 2022 [29])</li> <li>AR implicated: HTC VivePro</li> </ul>

## Limitations and Future Directions

This systematic review had several limitations. First, many of the included studies were of small sample size. Most studies included under 50 participants, with several included 10 or fewer, which may result in some included studies being underpowered. It is not unusual for studies investigating expensive technologies in potentially cumbersome settings to by necessity include small numbers; however, future research can prioritize adequate sample sizes to ensure robust statistical analyses. Second, our review compared studies with variable outcomes and statistical methodology and thus was not able to examine data in aggregate. A potential next step would be to conduct a meta-analysis of AR interventions in specific emergency prehospital applications, such as CPR training or MCI triage. Third, this review only included studies of AR apps in the prehospital care of adults. Future research will include inquiries into applications of AR for use with pediatric

populations. Finally, a main limitation of our search approach was the potential for missed manuscripts due to not features like MeSH headers in PubMed. However, the use of broad search terms across multiple databases helped mitigate this limitation.

## Conclusion

This systematic review shows the promising role of AR technology in enhancing the efficacy of prehospital emergency care. The analyzed studies, involving a total of 14 RCTs demonstrate that AR may enhance clinical decision-making and training modalities within prehospital settings. These improvements are crucial in high-stakes environments where rapid and accurate response is essential. Challenges related to technology integration, cost, and user acceptance remain. Addressing these barriers and conducting further research will be vital for realizing the full potential of AR in prehospital care delivery.

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## Data Availability

This study is a systematic review, and all data analyzed are derived from previously published studies. Complete references and sources for all data used are provided within the paper, ensuring full transparency and accessibility.

## Conflicts of Interest

AE serves as an advisor for MedVR Education and Apoqlar. Their products are not discussed in this paper.

## Multimedia Appendix 1

Detailed search strategy across databases for identifying studies on augmented reality in prehospital emergency care.

[[DOCX File, 21 KB](#) - [xr\\_v2i1e66222\\_app1.docx](#) ]

## Multimedia Appendix 2

Systematic review form used for extraction relevant information from included papers.

[\[DOCX File, 23 KB - xr\\_v2i1e66222\\_app2.docx \]](#)

## Multimedia Appendix 3

Bias evaluation tool questions.

[\[DOCX File, 17 KB - xr\\_v2i1e66222\\_app3.docx \]](#)

## Checklist 1

PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analysis) checklist.

[\[DOCX File, 32 KB - xr\\_v2i1e66222\\_app4.docx \]](#)

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## Abbreviations

**ACM:** Association for Computing Machinery

**AR:** augmented reality

**BLS:** basic life support

**CDS:** clinical decision support

**CPR:** cardiopulmonary resuscitation

**EM:** emergency medicine

**EMT:** emergency medical technician

**IEEE:** Institute of Electrical and Electronics Engineers

**MCI:** mass casualty incident

**PRISMA:** Preferred Reporting Items for Systematic Reviews and Meta-Analysis

**RCT:** randomized controlled trial

**TCCC:** tactical combat casualty care

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# Understanding the Views of Health Care Professionals on the Usability and Utility of Virtual Reality Multidisciplinary Team Meetings: Usability and Utility Study

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## Abstract

**Background:** Multidisciplinary team (MDT) meetings are one of the facilitators that enhance knowledge sharing among health care professionals. However, organizing a face-to-face MDT meeting to discuss patient treatment plans can be time-consuming. Virtual reality software is widely used in health care nowadays to save time and protect lives. Therefore, the use of virtual reality multidisciplinary team (VRMDT) meeting software may help enhance knowledge sharing between health care professionals and make meetings more efficient.

**Objective:** The objectives of this study were to introduce VRMDT software for enhancing knowledge sharing and to evaluate the feasibility and usability of the VRMDT for use by professionals in health care institutions.

**Methods:** We invited participants from The University of Manchester Faculty for Biology, Medicine, and Health who had a health care background. As this was the first stage of software development, individuals who did not usually attend MDT meetings were also invited via email to participate in this study. Participants evaluated VRMDT using a Meta Quest 3 headset, and software developed using the Unity platform. The software contained an onboarding tutorial that taught the participants how to select items, load and rotate 3D Digital Imaging and Communications in Medicine files, talk to a generative artificial intelligence-supported avatar, and make notes. After the evaluation (approximately 15 min), participants received an electronic survey using the Qualtrics survey tool (Qualtrics International Inc) to score the usability and feasibility of the software by responding to the 10-item system usability scale, and 12-point heuristic evaluation questions with Nielsen severity rating.

**Results:** A total of 12 participants, including 4 health informatics, 3 with a nursing background, 2 medical doctors, 1 radiologist, and 2 biostatisticians, participated in the study. The most common age bracket of participants was 20 - 30 years (6/12, 50%). Most of the respondents had no experience with virtual reality, either in educational or entertainment settings. The VRMDT received a mean usability score of 72.7 (range between 68 and 80.3), earning an overall “good” rating grade. The mean score of single items in the heuristic evaluation questionnaires was less than 1 out of 4 (the overall mean was 0.6), which indicates that only minor problems were encountered when using this software. Overall, the participant’s feedback was good with highlighted issues including a poor internet connection and the quality of the generative artificial intelligence response.

**Conclusions:** VRMDT software (developed by Sentira<sup>XR</sup>) was developed with several functions aimed at helping health care professionals to discuss medical conditions efficiently. Participants found that the VRMDT is a powerful, and useful tool for enhancing knowledge sharing among professionals who are involved in MDT meetings due to its functionality and multiuser interactive environments. Additionally, there may be the possibility of using it to train junior professionals to interpret medical reports.

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**KEYWORDS**

knowledge sharing; multidisciplinary team meetings; artificial intelligence; heuristic evaluation; usability; virtual reality; VR; simulation; virtual environments; digital environments

## Introduction

### Overview

The United Kingdom's health care sector is facing significant pressures from increased patient demands and workforce supply issues. A need for efficiently connected health care employees is important for sharing knowledge and it is an integral part of knowledge management. During COVID-19, communication across sectors moved towards web-based communication methods [1-3], such as videoconferencing (eg, Microsoft Teams and Zoom), which helped to protect the lives of patients and staff [3-5]. To maintain knowledge-sharing practices among professionals, there are several professional digital communities [6,7]. The purpose of these professional digital communities is to get professionals with common expertise to share their knowledge without considering geographical barriers [6]. Virtual multidisciplinary team (MDT) meetings have been shown to have a visible role in maintaining communication among cancer care professionals to discuss, follow up, and set clear treatment plans [8]. Additionally, it has been shown to improve cancer patients' outcomes [9-13]. Traditional face-to-face methods of MDT have drawbacks that limit attendance including lack of time and funding [8]. Introducing new technology for communication has benefits, although there are also drawbacks such as reliance on bandwidth, increased conversation time, and loss of gesture communication that can be difficult compared with traditional methods, thereby directly affecting good decision-making [14,15].

The use of videoconferencing has surged as a communication method during and post-COVID, although it has limitations including the inability for natural F-2-F interaction due to the participants only seeing a video image. Additionally, smooth and stable internet network is required to ensure that video conferencing runs smoothly. Moreover, the inability to show 3D images compared with the virtual reality (VR) tools may be a distinct disadvantage [16]. As a result, the existence of a powerful web-based tool that simulates a real environment may have benefits. VR and augmented reality are increasingly being used in the medical field both for training and as a procedural aid [17]. VR is defined as "a three-dimensional computer-generated simulated environment, which attempts to replicate real world or imaginary environments and interactions, thereby supporting work, education, recreation, and health" [3,18]. In addition, the user can interact with avatars using generative artificial intelligence (AI) supported natural language processing (NLP) which further enhances the realism of the experience. It requires head-mounted displays, and either hand controllers or hand tracking in order to perform practical procedures [19]. The sense of presence is one of the key characteristics of VR that makes it different from other communication mediums [14]. The use of VR applications in the health care market has grown massively in recent years. In 2022, the VR health care market reached over US \$2.3 billion worldwide, with 171 million VR users [20].

VR in health care has several benefits, such as facilitating training, education, and the development of technical skills. Additionally, VR is being used for a variety of purposes, including surgery and treatment, training, and patient therapy and rehabilitation [21]. Kyaw et al [22], illustrated that using VR applications improves professionals' skills, and knowledge compared with face-to-face communication and web-based digital education. In particular, it has the ability to negate the need for face-to-face contact, while maintaining the illusion of being with colleagues in the real world [23].

There are several factors that affect knowledge sharing in the medical imaging department at cancer centers, which are similar to those in most health care sectors [24]. MDTs are considered important departmental facilitators that enhance knowledge sharing among health care professionals [24]. MDT is considered a pillar of the best practices in cancer centers and plays an important role in cancer Treatment [25]. The United Kingdom's National Health Service definition of MDT is "a group of professionals from one or more clinical disciplines who together make decisions regarding the recommended treatment of individual patients" [26]. MDT in cancer centers is defined as the collaboration of several health care professionals in different fields engaged in the treatment of cancer with the overall objective of enhancing the rate of interpreting treatments of cancer patients, and patient care [13,26]. Cancer centers began to use a multidisciplinary approach in the mid-1980s, and by the 1990s, the MDT meeting was introduced as an instrument for providing coordinated, collaborative care, which allow a broader range of opinions on treatment plans [13,27]. In addition, it provides training for junior health care professionals. However, there are several barriers that contribute to not attending those meetings as per policy recommendations. These include time constraints, lack of departmental arrangements, geographical barriers among health care professionals, and shortage of staff [13].

In health care institutions, implementing new interventions such as VR among health care professionals may overcome current barriers and enhance knowledge-sharing practices to increase patients' outcomes and minimize medical mistakes. However, there are several challenges to implementing VR as a communication tool, including providing evidence that these technologies can save time, increase productivity, and reduce carbon footprint, without adding significant hardware costs and training time [28-30]. The aim of this research is to introduce new technology and perform a usability study of VR in MDT to investigate the feasibility and usability of using VR in cancer health care meetings.

### Objectives

In this study, we developed a virtual reality multidisciplinary team (VRMDT) for enhancing communication with professionals, which was evaluated in terms of its usability by professionals from a variety of backgrounds.



The aim of this study was to investigate the usability of newly developed VRMDT software that helps gather health professionals in a 3D immersive environment to aid communication and set a clear treatment plan for the cancer patient. The objectives of this study were:

- To introduce VRMDT software to health care professionals.
- Evaluate the usability, feasibility, and efficacy of VRMDT by applying the System Usability Scale (SUS), and identifying the problems with the user interface by using a heuristic evaluation questionnaire.
- Identify the strengths and weaknesses of using VRMDT.
- Determine if this technology has the potential to increase the number of MDT meetings in cancer centers locally and internationally.
- Increase awareness of using VR technology among health care professionals in cancer centers.

## Methods

### An Overview of VRMDT Software

The software was designed by our University of Manchester research team and developed using the Unity platform by Sentira<sup>XR</sup> [31], which is a University of Manchester spinout that uses VR and generative AI NLP to create authentic training simulations for health care professionals and other disciplines. The designs of the VRMDT comprise:

- An onboarding section for those not familiar with VR.
- Options to select a health care uniform of varying color and add the name to be displayed above the head of each user's avatar.
- 3D VR meeting room with round table.
- Ability to display a 3D Digital Imaging and Communications in Medicine (DICOM) scan image in the middle of the virtual table to allow 3D visualization. Additionally, there is a screen in front of each user to view the DICOM images in a traditional 2D mode.
- A whiteboard for writing notes and drawing images.
- A laser pointer beside each user for pointing to specific locations on the 3D DICOM images.
- An interactive avatar that uses generative AI NLP to provide answers to questions from users in the room related to the patient's scans, condition, and patient history.
- A master control panel where patient DICOM images can be selected.

The VRMDT (Figure 1) is designed to allow health care professionals to treatment plan anywhere and at any time. To run the VRMDT simulation, a reasonable Wi-Fi connection ( $\geq 10$  Mbps), head-mounted display, and controllers are required.

Before entering the MDT room, the user had the option to undertake an onboarding scenario that introduced them to basic functionality such as picking up objects, talking to the avatar, selecting DICOM files, and making notes on a whiteboard. The user can then begin the simulation first by typing in their username (displayed over the head of their avatar) and selecting their outfit's color (Figure 2). In the VRMDT software, there is a round table fitting 10 users with a control screen that contains the setting options, selecting the patient DICOM files, and the option to move the control panel to another user. Another screen available to all 10 users displays the traditional 2D DICOM images for cancer patients (Figure 3B). Additionally, the meeting room contains a whiteboard to allow the user to make notes or draw diagrams (Figure 4B). In the middle of the meeting table, the 3D DICOM (Figure 4A) images appear with the facilities to rotate the images on the x-axis to help show any tumors or lesions. A laser pointer is available to each participant to help highlight a region on the 3D image (Figure 3A). DICOM images were retrieved from The Cancer Imaging Archive which are accessible for the public to download and use without ethical approval. The time zones for both the United Kingdom and Kuwait are displayed on the wall of the meeting room.

Generative AI NLP used the InWorld platform [32]. Voice cloning (voice of MA cloned) uses Eleven Labs software which is supported by InWorld [32,33]. Patient information and avatar background details were entered into InWorld and quality assurance was conducted to ensure that the responses from the generative AI NLP had an accuracy of 95% or greater. The generative AI NLP-supported avatar was placed in the meeting room (Figure 5) and allowed the user to ask questions regarding the medical condition of the patients. The Photon platform was used to allow users to speak with each other as they would with any teleconference software [34]. The purpose of the AI-supported avatar was to provide the MDT with specific details on each of the patients, such as name, age, status of the medical condition, medications, chemotherapy/radiotherapy received, response to treatments/medications, bloodwork, and patient concerns. Providing patient information via an avatar, removed the need for reading extensive text notes which is not ideal in a VR environment due to reduced visual resolution and an increased risk of cybersickness. It also allowed for one or more of the MDT to be absent and still provide the information.

For the implantation, the software required a direct connection with the Picture and Archiving and Communication System to visualize patient images. Additionally, the VRMDT contains instructions voiced over to guide the user throughout testing the software.

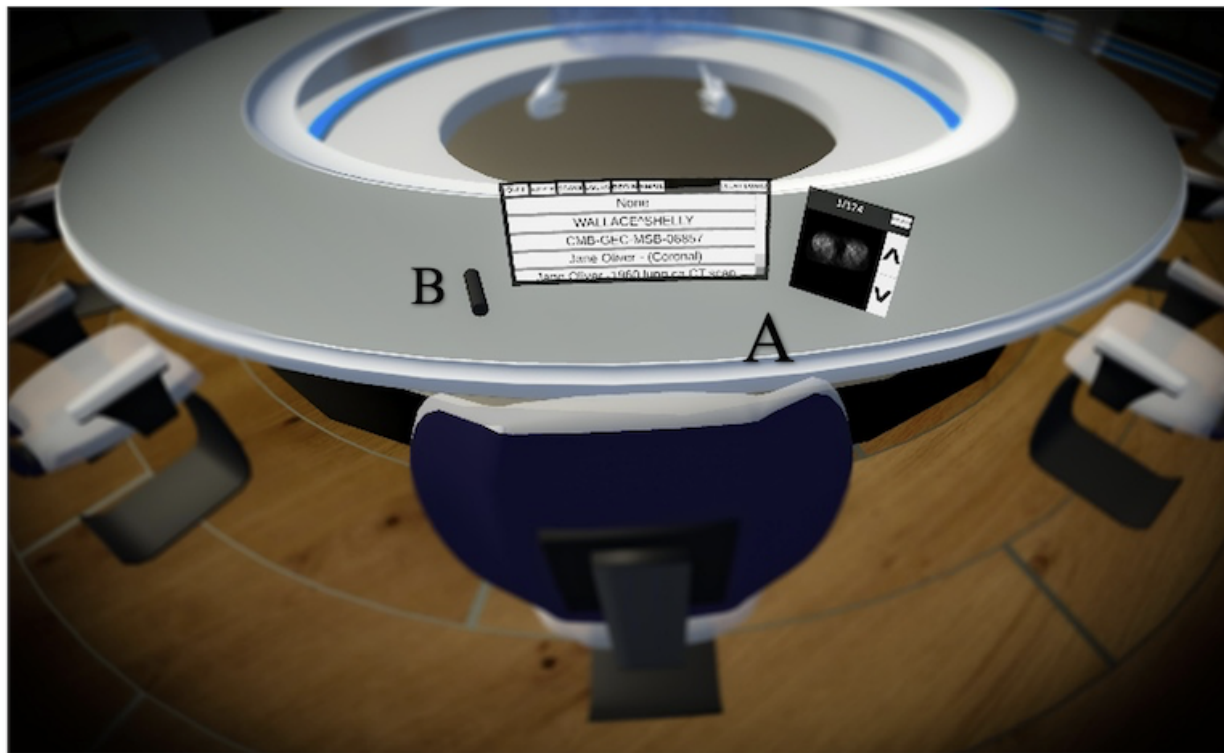
Figure 1. The environment of the virtual reality multidisciplinary team software.



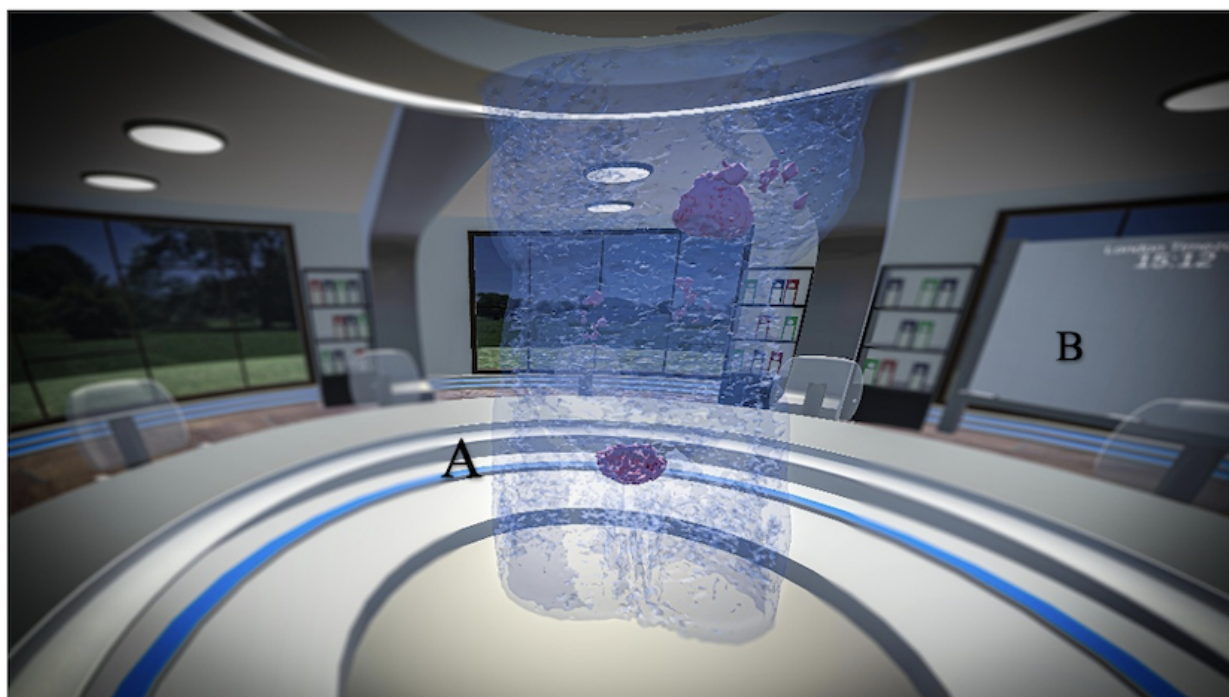
Figure 2. “On boarding” interface page for selection of the outfits, and the info that will appear on the user (such as name).



**Figure 3.** (A) Two screens: a controlled screen and a screen to display the traditional 2D scan images. (B) Laser pointer.



**Figure 4.** (A) The 3D Digital Imaging and Communications in Medicine (DICOM) images and (B) a whiteboard.



**Figure 5.** Interactive avatar.



### **Participants**

To be eligible for participation in this study, the participant had to have a health care background, with those recruited being postgraduate students and staff at The University of Manchester.

As this was the first stage of software development, participants who were not routinely involved in MDTs were also invited to evaluate the software.

Participants were recruited via email with the inclusion criteria as provided in [Textbox 1](#).

**Textbox 1.** Inclusion and exclusion criteria.

## Inclusion criteria

- Postgraduate students and staff at the University of Manchester.
- 21 years or older.
- Any gender.
- Health care professional background (including but not limited to doctors, nurses, and radiologists).
- Health care professionals who are involved in multidisciplinary teams.
- Willing to provide informed consent.
- English speakers.
- No pre-existing conditions that may cause discomfort or distress in a virtual reality (VR) environment.

## Exclusion criteria

- People who do not read, speak or understand English, because the software is in English only.
- People who are unwilling to wear a VR headset.
- People who had a pre-existing condition that may cause discomfort or distress in a VR environment

**Instruments**

Validated usability and utility questionnaires were used to assess the simulation's efficacy, efficiency, and user pleasure [35]. Two methods were used to assess the usability evaluation: 10-item SUS, and 12-item heuristic evaluation questionnaires [36,37]. Upon completion of the trial, the SUS and heuristic questionnaire links were emailed to the participant to complete in their own time in [Multimedia Appendix 1](#). The survey was built using the Qualtrics survey tool [38]. Participants were asked to assess the software based on 10-point scales [36] and answer statements using a 5-point Likert [36,39-46]. The SUS was selected as it is suitable method when applied to a small sample size (N less than 14) [39]. Questions 1, 3, 5, 7, and 9 are positive, whereas questions 2, 4, 6, 8, and 10 are negative. The 10 connected questions provide a full review of a product. The SUS yields a score between 0 and 100 [47]. A higher SUS score is associated with greater product usability.

To evaluate the user interface, and identify problems with the software, heuristic evaluation was used [37]. There are several heuristic evaluation questionnaires used to assess human-computer interaction [37,48,49]. In this study, we used the heuristic evaluation questionnaire based on Sutcliffe and Gault's heuristic evaluation of VR apps [37]. It consists of 12 heuristic items, including natural engagement, compatibility with the user's tasks and domain, natural expression of action, close coordination of actions and representation, realistic feedback, faithful viewpoints, navigation and orientation support, clear entry and exit points, consistent departures, support for learning, clear turn-taking, and sense of presence.

Our survey was an open survey (no password required) based on several previous VR usability studies but modified slightly

to align with our simulation [36,37]. The survey was checked by 10 individuals with a health care background to ensure it was easy to understand. In addition to the SUS questions and heuristic evaluations, we also collected information on demographics.

**Procedure**

At the beginning of the evaluation, participants were given a brief introduction to the project and shown how to use the VR headset and controllers. For those new to VR, an onboarding section was available. The overall evaluation ran for approximately 10 to 15 minutes. If there was more than 1 participant present at the same time, we allowed them to trail the software together so that they could see and interact with each other through the VRMDT. For those who evaluated solo, one of the development team would join them in the simulation so they could experience multiuser functionality. The participants were emailed the survey to complete within a 2 week time frame with a reminder sent after this period. Evaluations were conducted between February and March 2024). All sessions are located at The University of Manchester in a dedicated VR lab.

**Data Interpretation**

The results are interpreted as a grade for the SUS and a mean for the heuristic evaluation. To provide the grade of the SUS, there are 4 ratings for SUS interoperation: excellent (score greater than 80), good (69 - 80.3), okay (score equal to 68), poor (51-68), and awful (less than 51) [36]. For the heuristic evaluation, each item was rated for severity using Nielsen scale (no problem=0, cosmetic problem=1, minor problem=2, major problem=3, and catastrophe=4), as shown in [Table 1](#) [47]. Only completed questionnaires were included in the final results.

**Table .** Nielson severity rating [48].

Rating	Definition
Don't Agree	I do not agree that this is a usability problem at all (there are no problems with usability)
Cosmetic problem	Needs not to be fixed unless extra time is available on the project (if there is time, aesthetic issue that only has to be fixed).
Minor problem	Fixing this should be given low priority (a low priority for a minor usability problem).
Major problem	Important fix required that should be given high priority (major usability problems, must be fixed right away)
Catastrophic	Imperative to fix this before product can be released.

## Data Analysis

The final data were analyzed by entraining it into an Excel spreadsheet where the SUS score was calculated and the rate of the severity of each heuristic item based on the Nielsen severity scale for each item. The SUS questionnaire consisted of 10 questions. The score of SUS was calculated by adding the odd questions minus 5 and 25 minus the even number then multiplied by 2.5 [36]. On the other hand, the rate of heuristic severity was calculated by adding the number of statements and accepting the first statement which is no problem because it has zero value [37].

## Ethical Considerations

The main purpose of this study is an anonymized evaluation of the VRMDT software in terms of its usability and utility. Therefore, the University of Manchester web-based ethics tool

and the School of Health Sciences ethics representative confirmed that ethical approval was not required for this study. Consent was obtained from all participants that required them to sign a consent form. Anonymized responses were securely saved using the Qualtrics database.

## Results

### Participants

A total of 12 participants from a variety of health care fields were recruited (8/12, 67% female; 4/12, 33% male) with half of the participants being between 20 and 30 years of age (6/12, 50%). Most of the volunteers had a doctorate degree (8/12, 67%), with 4 having experience in health informatics. Most of the participants had no experience using VR before the evaluation. The demographic characteristics of the respondents are shown in [Table 2](#).

**Table .** Demographics characteristics of the respondents (N=12).

Characteristics	Values, n (%)
Sex	
Female	8 (67)
Male	4 (33)
Age group (years)	
20-30	6 (50)
30-40	5 (42)
50-60	1 (8)
Highest education level	
Master degree	8 (67)
Doctorate degree	4 (33)
Background	
Nursing	3 (25)
Radiologist	1 (8)
Health Informatics	4 (33)
Medicine	2 (17)
Biostatistics	2 (17)

### Usability (SUS Questionnaires)

A total of 67% (n=8) of participants gave SUS scores greater than or equal to 68. Four (33%) of the participants scored “Poor” with the VRMDT, with the SUS score rate less than 62. The total mean score was 72.7, resulting in an overall “Good” rating. The SUS scores for the respondents are shown in [Table 3](#).

[Multimedia Appendix 2](#) presents the interpretation of the SUS. Based on the SUS items, the participants indicated that the

software was easy to learn how to use, with a mean score of 4.1. The highest score was given to the item “I found the various functions in this software were well integrated (eg, whiteboard, and DICOM images)” with a mean score of 4.25. In contrast, the lowest score was given to the item “I thought there was too much inconsistency in this software” with a mean score of 1.5 where low scores are an indicator of better consistency.

**Table .** System Usability Scale (SUS) scores for respondents. Average=72.7 (Good).

Respondents	Results			
	X0 <sup>a</sup>	Y0 <sup>b</sup>	SUS	Grade <sup>c</sup>
1	19	15	85	A
2	17	17	85	A
3	17	12	72.5	B
4	12	19	77.5	B
5	16	9	62.5	D
6	7	14	52.5	D
7	16	19	87.5	A
8	14	14	70	B
9	14	9	57.5	D
10	11	10	52.5	D
11	18	16	85	A
12	18	16	85	A

<sup>a</sup>The total odd SUS questions–5.

<sup>b</sup>25–the total even SUS questions.

<sup>c</sup>Sum of X0 and Y0 × 2.5 (A=Excellent, B=Good, C=Okay, D=Poor, and F=Awful).

### Heuristic Evaluation

The participants rated the severity of each heuristic item based on Nielsen severity scale. The results of these ratings are shown in [Table 4](#). The value of the first severity scale “no problem” is zero, so it was not counted. We estimated the number and severity of reported problems for each item. For example, we received 3 statements that indicated the minor problems for the

first item “natural engagement,” 1 for the major problem, and 2 for the cosmetic problem. The total score was calculated by adding each heuristic item. All the items had a usability score of less than 12, with a mean score of less than 2. This indicated well-functioning software.

The summary rate is shown in [Table 5](#). One of the respondents reported 32 problems and 3 indicated no problems at all based on 12 heuristic items.

**Table .** Heuristics evaluation for each item with Nielsen severity rating.

	Number of items of the heuristics	Nielsen severity rating					Total	Mean
		No problem (0)	Cosmetic problem (1)	Minor problem (2)	Major problem (3)	Catastrophe (4)		
1. Natural engagement	9	0	2	1	0	3	0.7	
2. Compatibility with the user's task	6	2	2	2	0	6	1.5	
3. Natural expression of action	6	2	3	0	1	6	1.5	
4. Close coordination	8	2	0	1	1	4	1	
5. Realistic feedback	87	2	1	2	0	5	1.2	
6. Faithful viewpoint	10	0	2	0	0	2	0.5	
7. Navigation and orientation support	10	1	0	1	0	2	0.5	
8. Clear entry and exit point	9	1	1	1	0	3	0.7	
9. Consistent departures	8	3	1	0	0	4	1	
10. Support for learning	7	0	4	1	0	5	1.2	
11. Clear turn	11	0	0	1	0	1	0.2	
12. Sense of presence	8	1	2	1	0	4	1	



**Table .** Heuristics evaluation with Nielson severity rating for each respondent (resp).

Number of items of the heuristics	Respondents scores												Total
	Resp.1	Resp.2	Resp.3	Resp.4	Resp.5	Resp.6	Resp.7	Resp.8	Resp.9	Resp.10	Resp.11	Resp.12	
1. Natural engagement	0	0	0	2	3	0	0	2	0	0	0	0	0.5
2. Compatibility with the user's task	0	2	0	0	2	3	0	3	0	1	1	0	1
3. Natural expression of action	0	1	0	0	4	2	0	2	0	2	1	0	0.7
4. Close coordination	1	0	0	0	4	0	1	3	0	0	0	0	0.4
5. Realistic feedback	0	0	0	2	3	0	1	3	0	0	1	0	0.8
6. Faithful viewpoint	2	0	0	0	0	0	0	2	0	0	0	0	0.3
7. Navigation and orientation support	0	0	0	1	0	0	0	3	0	0	0	0	0.3
8. Clear entry and exit point.	0	0	0	2	0	0	1	3	0	0	0	0	0.5
9. Consistent departures	0	1	0	1	0	0	0	2	0	1	0	0	0.4
10. Support for learning	2	0	0	2	0	0	0	3	0	2	2	0	1
11. Clear turn	0	0	0	0	0	0	0	3	0	0	0	0	0.2
12. Sense of presence	0	0	0	2	0	2	0	3	0	0	1	0	0.7
Total	5	4	0	12	8	7	3	32	0	6	6	0	0.6

## Discussion

### Principal Findings

The findings of this study provide valuable insight into the current usability and future improvements of VRMDT software.

Previous research into VR meeting rooms indicates that they may be an efficient tool for improving communication during the planning of patient treatments [50]. Kirchgessner et al [51] illustrated that VR meeting rooms are more motivational than traditional technologies such as Zoom. Our work supported this

with participant comments mentioning that presenting DICOM images in both 2D and 3D formats made the VR meeting more efficient than standard videoconferences with, respondent (D) mentioning “Being able to view images in 3D is the best thing about the VR software.”

Our results found that the VRMDT software had adequate usability, with a mean SUS of 72.7, which is classed as “Good” as an overall interoperation. Most of the participants indicated that the simulation does not require intensive training to use it, suggesting that the inbuilt onboarding software is sufficient for training purposes, the respondent (C) said that “Browsing menus was simple and they were easy to use. Viewing DICOM images was intuitive.” This is important for any health care institution as it will reduce the impact on existing training budgets and trainer time. Additionally, most of the respondents indicated that the software contains several useful functions, such as 2D and 3D DICOM views, a whiteboard, and an avatar that responds naturally to questions. These results suggest our software has clear advantages compared with conventional teleconferences. Another positive feedback was that the immersive 3D meeting room environment helped users feel as though they were in a real-world meeting. It is worth mentioning that a low score (mean=1.5) was given to the item “I thought there was too much inconsistency in this software,” which indicated that the software was more relevant to its aim and objectives, and it performed well. The heuristic evaluation method indicated that the VRMDT has a good user interface with a low number of reported issues.

### User Experience

Participant feedback highlighted a few areas for improvement. Respondent (A) illustrated that “The reason why I indicated there were some problems was due to the internet connection not being stable, which sometimes led to lagging and the AI avatar being slow to respond,” and another respondent (B) said that “Software has potential but requires good Wi-Fi connection.” Therefore, one of the major issues indicated by most of the users was the poor internet connection, which effected the sense of presence and interaction with some functionality. Additionally, the internet connection effected the interaction with the avatar which resulted in delayed responses to questions. This was an issue with the evaluation room which received a poor internet signal and was not an issue with the software. The other issue was related to the avatar. The respondents mentioned that the AI needed to be further developed to respond to more specific clinical questions other than age, general treatment, and health conditions. Additionally, it should be designed to respond to any questions with different accent words, the respondent (C) said that “It also struggled with my accent for certain words.”

On the other hand, most of the respondents indicated that VRMDT was a powerful tool for sharing knowledge digitally compared with the other mediums because it contains several functions that make the environment immersive and very close to reality. Respondent (A) said that “it felt very futuristic, and I feel it will play an important role in future trans-geographical meetings.” Therefore, this software would be a good alternative tool in the future when face-to-face communication is not

possible. Additionally, it was suggested that VRMDT may be an alternative tool for training and assessing the knowledge of junior professionals instead of in-person training. In the future, I would like to update the software by adding several functions that help in upgrading the current software. For instance, the meeting room will be secure under each hospital’s policies. In addition, those who have permission to enter this room can join this meeting after the invitation occurs. Moreover, It will contain the digital library, which contains the files and information about the cases that you want to make decisions regarding those cases.

Overall, the simulation was identified as a powerful tool for VR clinical meetings. In particular, it contained a functionality that allowed users to view both 3D and 2D DICOM images. While this has also been developed for off-the-shelf software (eg, [52]), the other software does not cater to a larger number of users generally seen at clinical meetings and lacks additional functionality such as a whiteboard, laser pointer, and AI-assisted avatar. Indeed, the avatar as an AI assistant was generally found to be very helpful in answering questions regarding the patients’ condition and was found to elevate the usability of the VR meeting. Previous independent work has suggested that cybersickness is an issue for some users [29,30,53]. That issue was not indicated in the user’s feedback from our study. The reasons for cybersickness not being an issue may include that the simulation was developed so the user can remain seated, which reduces excessive body movement both in real life and the simulation and provides a comfortable body position. Second, the headsets were modern (Meta Quest 3’s with battery strap) and had a high frame rate (90 Hz), with a wide field of view (110°H × 96°V), which also helps reduce the risk of sickness. The Quest 3 headset is also reasonably priced (£480; US \$596) and easy to set up and use, making it a cost-scalable solution. We also found that the software was usable in the Meta Quest 2 without significant loss in performance, with this headset being a much cheaper option (£200; US \$249.45). Overall, the hardware experience was good, with users finding the headset very light on their head, and the controllers easy to use. As a first-time exposure to VR, the majority found the experience “amazing” enough that they recommended its implementation for future VR meetings.

### Limitation and Future Studies

This study has several limitations that are worth documenting, and which we will consider for future developments. First, the VRMDT software was evaluated by a small number of health care professionals. Second, most of the volunteers were researchers, and many were from the health informatics field. Third, we encountered another issue that the evaluation took place in a room that had a poor internet connection. That limited the testing of the software efficiently, particularly the avatar generative AI NLP which had lag, and multiuser functionality where verbal communication between users was slightly delayed. Finally, the generative AI seemed limited in answering questions related to the patient’s condition due to the lack of information available on the archival system.

Future research will need to consider testing using a more statistically powerful number of health care professionals

involved in MDT meetings to determine how powerful the 2D or 3D DICOM images are at identifying cancer lesions. Second, to overcome the internet issue, we need to test the network stability before performing the usability study. Thirdly, the AI generative avatar needs to be supplied with more detailed knowledge about the patients so it can more accurately answer. Additionally, a longitudinal analysis after implementation would allow researchers to assess the impact of the software on productivity. Finally, a direct comparison of our software with current digital tools such as Zoom and Microsoft Teams will help to assess its usefulness in terms of features, and productivity.

## Conclusions

In health care institutions, applying knowledge management is crucial to using resources in a good way to increase patients' outcomes, and reduce medical errors. Knowledge sharing is considered an important step for the successful implementation of knowledge management. There are several factors that affect knowledge sharing in medical imaging. These factors can be divided into 3 categories: individual, departmental, and technological factors. MDT meetings are considered a crucial

departmental factor in enhancing knowledge sharing. However, time constraints and geographical barriers can impact knowledge exchange efficiency. We have shown that creating a VRMDT meeting room may be a powerful tool to reduce those barriers.

Our VRMDT allowed the volunteers to interact with other users, and use the specialized features that allowed them to understand the patient's condition and scans in a correct and efficient way with the volunteers rating the simulation as good. Our results suggest that multiuser VR meeting rooms that use generative AI, and the ability to visualize DICOM files in both 2D and 3D have advantages over currently used meeting methods and would benefit from further development and research.

Future development and research by our group would evaluate the usability with a wider range of health care staff and an increased number of volunteers, and overcome the limitations that were outlined in this study. We also intend to explore software security for connecting to health care systems in order to access patient scans and data and develop the software across platforms to include a wider range of VR headsets as well as PCs and tablets.

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## Conflicts of Interest

None declared.

### Multimedia Appendix 1

The consent form and the questionnaire of the survey.

[[DOCX File, 28 KB](#) - [xr\\_v2i1e60651\\_app1.docx](#) ]

### Multimedia Appendix 2

The interpretation of the System Usability Scale and heuristic evaluation.

[[XLSX File, 14 KB](#) - [xr\\_v2i1e60651\\_app2.xlsx](#) ]

### Checklist 1

STROBE Checklist.

[[DOCX File, 35 KB](#) - [xr\\_v2i1e60651\\_app3.docx](#) ]

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## Abbreviations

- AI:** artificial intelligence
- DICOM:** Digital Imaging and Communications in Medicine
- MDT:** multidisciplinary team
- NLP:** natural language processing
- SUS:** System Usability Scale
- VR:** virtual reality
- VRMDT:** virtual reality multidisciplinary team

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# Augmented Reality in Enhancing Operating Room Crisis Checklist Adherence: Randomized Comparative Efficacy Study

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## Abstract

**Background:** Effective crisis management in operating rooms (ORs) is crucial for patient safety. Despite their benefits, adherence to OR crisis checklists is often limited, highlighting the need for innovative solutions.

**Objective:** The objective of this study was to evaluate the efficacy of augmented reality (AR)-enhanced checklists in improving protocol adherence, compared to traditional paper checklists and no checklist scenarios during simulated OR crises.

**Methods:** This study was a randomized comparative efficacy study comparing the utility of AR checklists, paper checklists, and no checklist scenarios using 4 validated and simulated OR crises scenarios: asystolic cardiac arrest, air embolism, unexplained hypotension/hypoxia, and malignant hyperthermia. The study took place in a simulated OR setting and had applicability to the standard procedures in ORs, critical care units, and urgent care scenarios in the emergency department. To form the 24 OR teams, 50 professionals including 24 anesthesiologists, 24 nurses, 1 surgeon, and 1 scrub nurse from two academic hospitals were included. The primary outcome measured was the failure to adhere (FTA) rate for critical actions during simulated OR crises. Adherence was determined using retrospective video analysis involving 595 key processes evaluated across 24 surgical teams. Interrater reliability was assessed using a Cohen  $\kappa$ . Secondary outcomes included checklist usability and cognitive load, as measured by the low-frequency to high-frequency (LF/HF) ratio of the heart rate variability.

**Results:** The AR checklist group showed a significantly lower FTA rate (mean 15.1%, SD 5.77%) compared to the paper checklist (mean 8.32%, SD 5.65%;  $t_{23}=-2.08$ ;  $P=.048$ ) and the no checklist groups (mean 29.81%, SD 5.59%;  $t_{23}=-6.47$ ;  $P<.001$ ). The AR checklist also resulted in a higher LF/HF ratio for anesthesiologists ( $F_{2,46}=4.88$ ;  $P=.02$ ), showing a potential increase in the level of cognitive load. Survey data indicated positive receptions for both AR and paper checklists.

**Conclusions:** These results suggest that AR checklists could offer a viable method for enhancing adherence to critical care protocols. Although, further research is needed to fully assess their impact on clinical outcomes and to address any associated increase in cognitive load.

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## KEYWORDS

augmented reality; operating room; crisis checklist; checklist; guideline adherence; quality improvement; patient safety; cardiac arrest; hypotension; hyperthermia; critical care; emergency department

## Introduction

Unexpected crises in the operating room (OR), such as cardiac arrests or severe hemorrhages, create a critical situation in which surgical teams should deliver rapid and coordinated care with a time-sensitive order of actions listed in the OR crisis checklists

[1-3]. Although these high-stakes, low-frequency crises may occur infrequently for any single practitioner, their cumulative incidence across hospitals underscores a significant challenge to patient safety and surgical outcomes [4-7]. The OR teams' ability to effectively manage these life-threatening complications depends on their preparedness in managing crises [8,9], training [10], and adherence to the validated crisis checklists [11].

Presurgical checklists are used before surgery to ensure correct patient identification and procedure planning. In contrast, crisis management checklists guide surgical teams during emergencies, helping them respond quickly to life-threatening situations. While both checklists improve safety, this study focuses specifically on crisis management checklists, which aim to support decision-making during critical events in the OR.

The lack of adherence to the checklists negatively impacts surgical mortality rates and overall hospital performance [12]. Evidence suggests that adherence to established best practices during these critical moments is varied and often associated with a decay in the retention of essential skills and knowledge over time [13-16]. In many instances, the use of surgical safety checklists was associated with a reduction in morbidity and mortality, and they were integrated as a new standard of care [17,18]. The dynamic and high-pressure nature of surgical emergencies requires not only adherence to protocols but also the ability to quickly access and use complex information under cognitively demanding conditions [19-21]. However, even though adherence to these checklists is crucial, the traditional paper ones are often difficult to use effectively in such intense scenarios [22-24]. The low adoption of checklists underscores the need for innovative approaches to using checklists that fit with surgical workflows, enhancing protocol adherence without disrupting the clinical focus.

Augmented reality (AR) technology, by relaying important procedural information directly into the clinicians' vision [25-28], can enhance protocol adherence in medical settings [29-33]. Initial applications of AR in medication management and emergency trauma care have shown promise in reducing errors and guiding clinicians through complex procedures with enhanced clarity and efficiency [34-38]. This evidence positions AR as a potential technology for improving adherence to

medical protocols [39-41]. However, the effectiveness of and adherence to AR-enhanced surgical checklists during OR crises has not been thoroughly studied.

This study aims to evaluate the efficacy of AR-enhanced checklists in improving protocol adherence by surgical teams during simulated OR crises. By comparing outcomes with the traditional paper checklists and scenarios without a checklist, the research seeks to provide evidence on AR's utility to reduce the failure to adhere (FTA) rate for crucial procedural steps when managing surgical crises, ultimately improving patient outcomes in the OR. We hypothesize that the AR-enhanced checklists will significantly reduce the FTA rate for crucial procedural steps compared to traditional paper checklists and no checklist scenarios.

## Methods

### Study Design

This prospective within-subject study aimed to compare the impact of AR checklists, traditional paper checklists, and no checklist conditions on managing OR crises (Figure 1). A detailed outline of team participation and the methodological framework is included in Multimedia Appendix 1. The development and rationale behind the crisis checklists, guided by surgical safety standards, have been detailed in a previous publication [14]. Teams, including anesthesia staff, OR nurses, and a mock surgeon, faced simulated intraoperative crises with randomized scenario assignments and checklist types. Before the main investigation, a pilot study tested the scenario fidelity and the AR checklist's practicality. Paper checklists were provided in booklet form and placed near the anesthesia machine and the circulating nurse's station, mirroring their accessibility in actual ORs. A summary and the checklists are available in sections 1 - 3 of Multimedia Appendix 1.

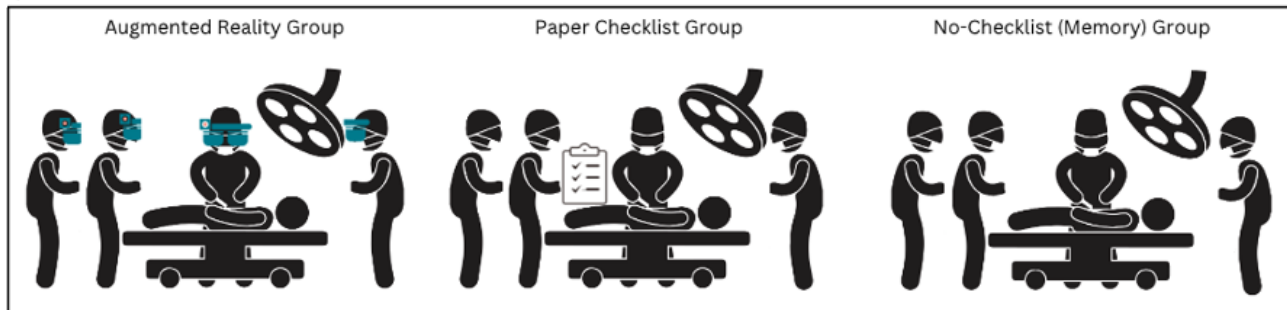


**Figure 1.** Study overview diagram. (a) Checklists presented in an augmented reality interface using Microsoft HoloLens 2. (b) Study design scenarios including an augmented reality checklist, paper checklist, and no checklist.

**a**



**b**



### Setups: The OR Checklists

We used OR crisis checklists for 4 critical scenarios: (1) asystolic cardiac arrest, (2) air embolism, (3) unexplained hypotension/hypoxia, and (4) malignant hyperthermia. These scenarios were derived from a comprehensive checklist development and testing process explained by Ziewacz et al [42] and were chosen for their clinical importance and feasibility for implementation in AR. Additionally, we followed the standardized approach used by Arriaga et al [14], which evaluated the efficacy of these checklists in improving adherence to lifesaving protocols through high-fidelity medical simulations. More details on the checklists and key processes evaluated to measure adherence to protocols can be found in section 3 of [Multimedia Appendix 1](#).

### Participants

Participants were recruited from 2 academic hospitals between October 2021, and September 2023. Each team comprised the anesthesia staff (including attending physicians and residents), OR nurses, one mock surgeon, and one scrub nurse, totaling 24 attending physicians and residents, 24 OR nurses, and one mock surgeon across 24 teams. Team formations were randomized. Each team dedicated an average of 3.5 hours within a single day to participate in a high-fidelity simulated OR environment. In the simulated OR, they encountered a series of crisis scenarios designed to test their adherence to critical and evidence-based practices. Recruitment of staff members was facilitated through sign-up sheets and random selection from those scheduled to work on designated study dates. Hospital departments arranged for staff to attend the simulation sessions instead of their regular workday. Hospital or department rules required that all anesthesia staff taking part had to have up-to-date certification

in advanced cardiac life support. Each participant only took part in one study session.

### Ethical Considerations

Ethical approval for this study was obtained from the Ministry of Health, Kuwait (IRB#: SKU-219328). Informed consent was obtained from all participants prior to their involvement in the study. Participants were informed about the study's objectives, procedures, and their rights, including the ability to withdraw at any point without any repercussions. All data collected during the study were deidentified and stored securely to ensure participant confidentiality. Data were anonymized during analysis to protect privacy, and access was restricted to authorized personnel only. No monetary or nonmonetary compensation was provided to participants for their involvement in this study. Identifiable features of participants were not captured in any images or supplementary materials.

### Primary Outcome: FTA rate

The primary outcome was the FTA rate for 47 key lifesaving processes outlined in [Multimedia Appendix 1](#). Adherence was evaluated and scored as either yes or no by 2 physician reviewers from our team (AA and RG) who observed and scored recorded simulation sessions. These sessions were recorded as synchronized videos on 2 screens for a comprehensive review. To ensure the accuracy of adherence scoring, interrater reliability was assessed. Any disagreements or uncertainties in scoring were reviewed by third reviewers (CP, HS) and were resolved. The primary variables included the checklist group and the medical crisis scenario. The primary aspect of the study was the measured FTA rates.

### Secondary Outcomes

#### Cognitive Load

We used a Polar chest strap to collect interbeat interval data from participants during scenarios with an accuracy of 1 millisecond. Previous studies have shown that a low-frequency to high-frequency (LF/HF) ratio extracted from heart rate variability is a validated proxy for cognitive load [43-45], particularly when collected using chest wraps [46]. We used NeuroKit2, a toolbox for neurophysiological signal processing [47], to extract the LF/HF ratio from data aggregated into a 1-minute time window.

**Table .** Participant's role and their years of experience.

Role	Years of experience in specialty, n (%)			
	0 - 2	2 - 8	>8	Unknown
Anesthesiologist				
Attending physician (n=14)	0 (0)	7 (50)	7 (50)	0 (0)
Anesthesia resident (n=10)	10 (100)	0 (0)	0 (0)	0 (0)
Operating room nurse (n=24)	6 (25)	12 (50)	3 (12.5)	3 (12.5)
Surgical resident (n=1)	(1) 100	0 (0)	0 (0)	0 (0)
Scrub nurse (n=1)	0 (0)	1 (100)	0 (0)	0 (0)

### Participant Satisfaction and Usability

To evaluate the ease of use and the perceived effectiveness of the AR and paper checklists, we administered a structured survey adopted from Arriaga et al [14]. The survey assessed participants' preparedness, ease of use, readability, willingness to use the checklist in real scenarios, and perceived impact on the clinical flow during emergencies. Responses were captured on a Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree), providing insights into participants' attitudes and perceptions across various aspects of checklist usage.

### Statistical Analysis

Participant characteristics were presented by descriptive statistical analysis, which reported the number and percentage of participants across different roles and years of experience. To assess the consistency in observational scoring, the agreement between two reviewers on the adherence scores was quantified using a Cohen  $\kappa$ . The Shapiro-Wilk test was used to evaluate the normality of the data distribution. ANOVA was used to compare the efficacy of interventions across 3 groups and post hoc analyses were conducted to examine the checklist's efficacy across various scenarios. Participant satisfaction and usability were analyzed using descriptive statistics and reporting means and SD. The statistical analyses were performed using SAS with all  $P$  values being 2-sided and a threshold for statistical significance set at  $P < .05$ .

## Results

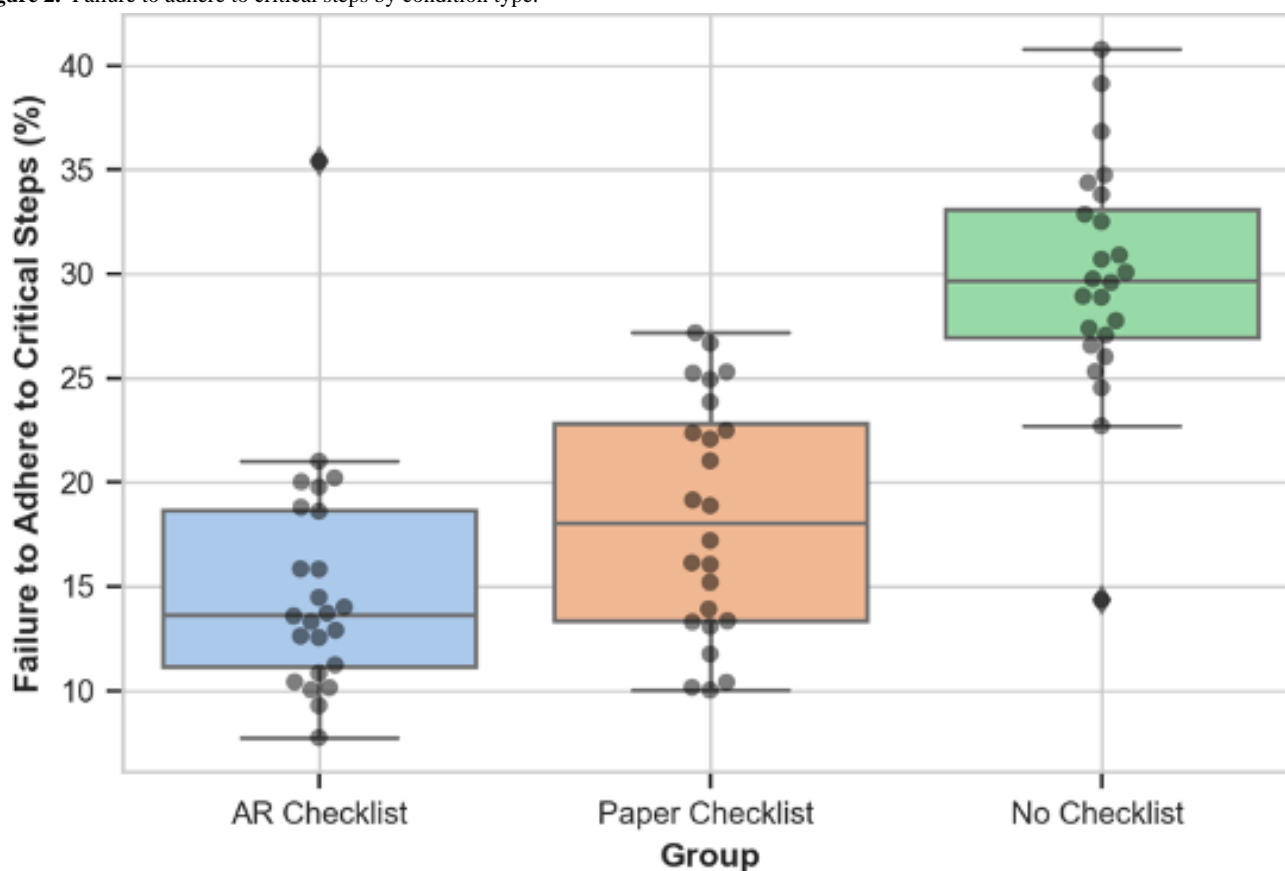
### Participants

A total of 50 participants, forming 24 teams, took part in this study, which included anesthesiologists (n=14), anesthesia residents (n=10), OR nurses (n=24), a surgical resident (n=1), and a scrub nurse (n=1). All anesthesia residents were in the early stages of their careers with 0 - 2 years of experience, and OR nurses included a more diverse range of experience, spanning from 0 - 8 years. Each team contained 1 mock surgeon and 1 surgical assistant (scrub nurse), who attended as stand-in participants to the operative field without participating in decision-making or survey completion; these stand-in staff members were not counted as participants. Participants' years of experience are summarized in [Table 1](#).

## Adherence Rating

The assessment of adherence to key processes during the simulated scenarios demonstrated high interrater reliability among independent reviewer pairs, with Cohen  $\kappa$  values of  $\geq 0.83$  across all pairs. In instances where initial disagreement or uncertainty arose among the physician reviewers, consensus was reached through expert review with video replay. Out of a total of 595 key processes, evaluated across 24 teams for 25 key processes (excluding 8 key processes from one team that did not initiate the unexplained hypotension/hypoxia followed by an unstable bradycardia scenario), only 23 instances necessitated this expert review. The process of video replay facilitated immediate full agreement among all reviewers, highlighting the effectiveness of this approach in resolving ambiguities and ensuring accurate adherence assessment.

Figure 2. Failure to adhere to critical steps by condition type.



## Comparing Groups for Individual Crisis Scenarios

Adherence to critical steps across various scenarios demonstrated significant differences among groups, with an ANOVA test showing distinct results for asystolic cardiac arrest ( $F_{2,46}=25.07$ ;  $P<.001$ ), air embolism ( $F_{2,46}=14.90$ ;  $P<.001$ ), malignant hyperthermia ( $F_{2,46}=12.33$ ;  $P<.001$ ), and unexplained hypotension/hypoxia ( $F_{2,46}=38.39$ ;  $P<.001$ ). Post hoc analyses indicated that, across these scenarios, the AR checklist group consistently exhibited significantly lower FTA rates compared to the no checklist group, with notable differences in asystolic cardiac arrest ( $t_{23}=-6.47$ ;  $P<.001$ ), air embolism ( $t_{23}=-4.45$ ;  $P<.001$ ),

malignant hyperthermia ( $t_{23}=-4.79$ ;  $P<.001$ ), and unexplained hypotension/hypoxia ( $t_{23}=-10.57$ ;  $P<.001$ ). Comparisons between the AR and paper checklist groups were only significant for some scenarios, with slightly lower FTA rates for critical steps using the AR checklist in asystolic cardiac arrest ( $t_{23}=-2.65$ ;  $P=.014$ ) and unexplained hypotension/hypoxia ( $t_{23}=-2.10$ ;  $P=.046$ ). The paper checklist group also demonstrated significantly improved adherence over the no checklist condition in scenarios such as an air embolism ( $t_{23}=3.72$ ;  $P<.001$ ) and unexplained hypotension/hypoxia ( $t_{23}=5.40$ ;  $P<.001$ ; Figure 3).

## Comparing Groups Across All 4 Crisis Scenarios

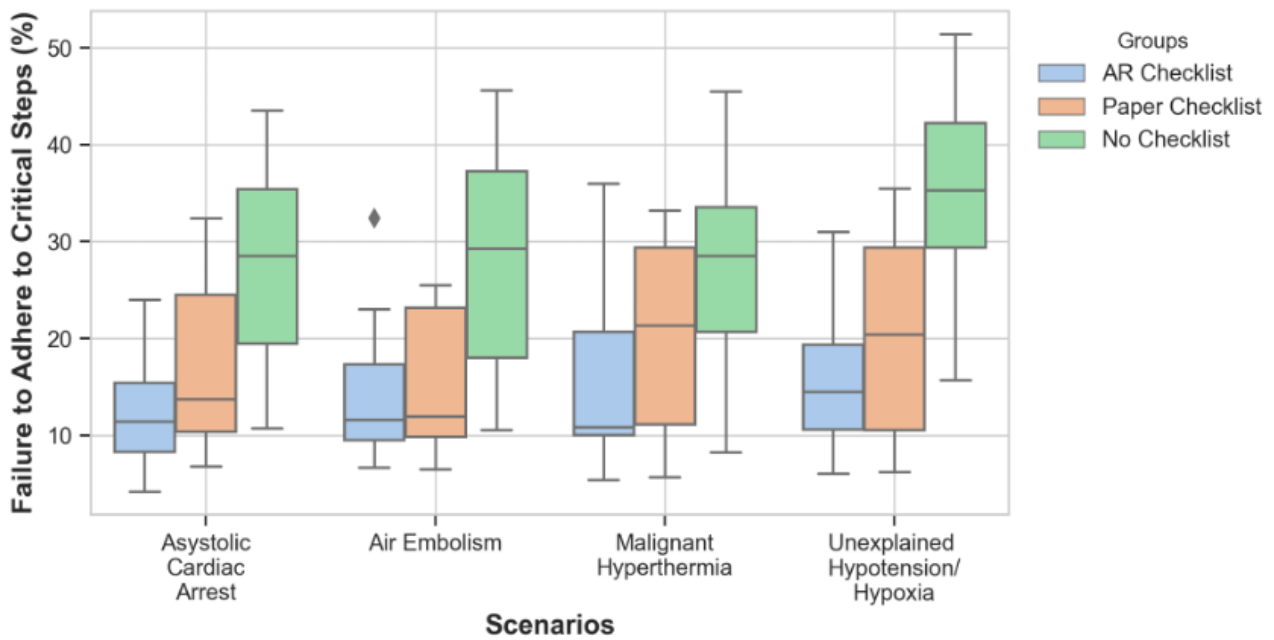
ANOVA analysis showed significant differences in the FTA rate for critical steps among the 3 checklist groups ( $F_{2,46}=48.3$ ;  $P<.001$ ). Subsequent post hoc analysis showed the AR checklist group's mean FTA rate of 15.1% (SD 5.77%, 95% CI 13.50-16.70) was significantly lower than the paper checklist group's FTA rate of 18.32% (SD 5.65, 95% CI 16.75-19.89) and the no checklist group's FTA rate of 29.81% (SD 5.59, 95% CI 28.26-31.36). The AR group's FTA rate was significantly less than the no checklist group ( $t_{23}=-10.9$ ;  $P<.001$ ) and the paper checklist group ( $t_{23}=-2.08$ ;  $P=.048$ ). Moreover, the paper checklist group also had a significantly lower FTA rate compared to the no checklist group ( $t_{23}=-6.37$ ;  $P<.001$ ; Figure 2).

While the AR checklist group demonstrated statistically significant differences in FTA rates compared to the paper

checklist group, it is important to note that this significance was observed by a narrow margin. Given the sample size, there remains the possibility that this effect could be influenced by

chance, and further studies with larger sample sizes are necessary to confirm these findings.

**Figure 3.** Failure to adhere to critical steps by scenario and group type. AR: augmented reality.

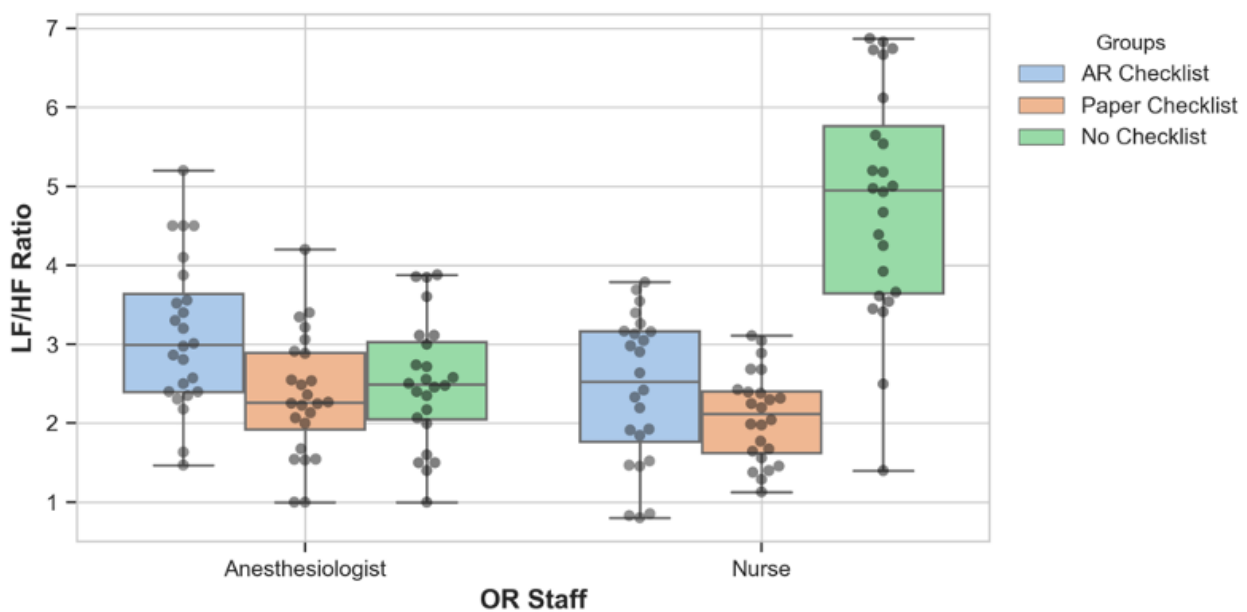


**Cognitive Workload**

For anesthesiologists, ANOVA results showed a significant effect of the checklist type on the LF/HF ratio ( $F_{2,46}=4.88$ ;  $P=.02$ ). In pairwise comparisons, the AR checklist group had a significantly higher LF/HF ratio compared to both the paper checklist and no checklist groups, suggesting a potential increase in cognitive load when using the AR checklist ( $P<.05$ ; Figure

4). There was no significant difference in LF/HF ratio when comparing the paper checklist with no checklist groups, after adjusting for multiple comparisons. For nurses, the differences were significantly different ( $F_{2,46}=43.25$ ;  $P<.001$ ). The no checklist group had a significantly higher LF/HF ratio than the other two groups ( $P<.05$ ). The AR checklist and paper checklist groups did not differ significantly.

**Figure 4.** Low-frequency to high-frequency ratio across operating room staff roles by checklist group. AR: augmented reality; LF/HF: low frequency to high frequency; OR: operating room.



## Survey

Survey responses showed that both AR and paper checklist groups viewed their respective checklists positively (Table 2). Participants in the AR checklist group rated the checklist's ability to help them feel prepared during the emergency scenario at a mean Likert score of 4.5 (SD 0.75), and the paper checklist group rated this at 4.3 (SD 0.82), indicating no significant

difference between the groups. Participants expressed a strong willingness to use the checklists in real-life situations, with the AR group scoring a 4.6 (SD 0.70) and the paper group scoring a 4.4 (SD 0.75). When considering the disruption to the clinical flow of the operative emergency, the AR checklist group reported less disruption with a mean score of 4.5 (SD 0.90) compared to the paper checklist group's score of 4.2 (SD 1.00).

**Table .** Questionnaire response data from participants on checklist usability.

Statement	AR <sup>a</sup> checklist group (n=48), mean (SD)	Paper checklist group (n=48), mean (SD)	P value
The checklist helped me feel better prepared during the emergency scenario.	4.5 (0.75)	4.3 (0.82)	.13
The checklist was easy to use.	4.4 (0.80)	4.2 (0.85)	.09
I would use this checklist if I were presented with this operative emergency in real life.	4.6 (0.70)	4.4 (0.75)	.03
The checklist did not disrupt the clinical flow of the operative emergency.	4.5 (0.90)	4.2 (1.00)	.04
If I were having an operation and experienced this intraoperative emergency, I would want the checklist to be used.	4.7 (0.55)	4.6 (0.60)	.18

<sup>a</sup>AR: augmented reality.

## Discussion

### Principal Findings

Our findings show that AR checklist groups had a superior adherence to critical steps in crises when compared to the paper checklist groups and groups who did not use any checklist. These findings highlight AR's potential to improve OR staff's adherence to predefined protocols and ultimately improve patient outcomes. This improvement suggests that sending critical and time-sensitive information to clinicians' and OR staff's field of view may help with faster and more precise decision-making in critical situations and emergencies. Considering a day-by-day improvement in technology, this will have the potential to set the ground for an extended and more effective AR checklist intervention in many other critical scenarios. This potential benefit is in line with a comparison of the AR checklist versus the traditional checklist in other health care applications [29,30]. The benefit of AR checklists, particularly in comparison with non-AR alternatives, underscores the technology's capacity to augment traditional safety measures.

It is also important to note that while the AR checklist group had a clear superiority over the no checklist group, the margin of improvement was modest when it was compared to the paper checklist group. In this comparison, the differences were not always statistically significant across different scenarios. These findings suggest that AR technology may not offer the same improvement in all clinical scenarios over the paper checklists. Considering the low sample size and extensive subgroup analysis, it is reasonable to suggest that AR's real-world application and its superiority over conventional methods

warrant further examination. We also observed variation in team performance, as highlighted in Figure 1 of [Multimedia Appendix 1](#). Some of this variation may be attributed to an order effect, where teams became more familiar with the simulation environment over time. This potential bias should be considered when interpreting the results, and future studies could include randomization or counterbalancing to mitigate this effect.

The feedback from participants indicated a high level of acceptance and perceived utility of AR checklists in crisis scenarios, pointing to the potential for AR to integrate effectively into surgical workflows. However, the nuanced performance improvements highlight the need for a tailored approach to technological integration in health care, where the specific context and user needs dictate the effectiveness of such alternatives [48-50]. The study's results align with broader trends in medical and high-risk industries, where checklists have long been recognized for their role in promoting adherence to best practices and enhancing outcomes [51-53]. Just as checklists have transformed safety protocols in aviation and nuclear power, AR checklists hold promise for surgical settings. Nonetheless, the adaptation of these tools in medicine, particularly in the high-stakes environment of the OR, requires careful consideration of design, implementation, and training to ensure they meet the unique demands of health care providers and patients.

A key consideration emerging from our research is the differential impact of AR on the cognitive load among OR staff. Anesthesiologists using the AR checklist have shown a higher LF/HF ratio, which may be associated with a higher level of cognitive load when compared to the paper and no checklist

groups. While we initially interpreted the higher LF/HF ratio in the AR checklist group as a sign of increased cognitive burden, it is also possible that this reflects heightened cognitive engagement. The AR checklist may stimulate more focused attention on the OR environment and monitoring, compared to the paper checklist, which could be perceived as more distracting. This alternative interpretation suggests that the AR condition may enhance attentional focus in a high-stakes environment, and further research is needed to clarify the relationship between LF/HF ratio and cognitive engagement.

It is an important finding that AR technology may improve adherence but simultaneously may add a cognitive burden [54,55] that adversely affects clinicians' behavior under cognitively demanding conditions. This variability in cognitive impact across different OR roles underscores the importance of designing AR applications that are tailored to the diverse needs and cognitive capacities of surgical teams. Future studies should also include qualitative methods to capture participants' experiences with AR and paper checklists. Combining this with quantitative data will provide a more complete understanding [56].

### Limitations

This study has several limitations that should be considered. First, the study was conducted in a simulation setting that may not necessarily reflect the complexity of the OR environment. Second, our sample size was relatively small with a limited statistical power that prevented us from confidently performing

subcategory analysis and extracting minor differences between groups. Larger studies with more diverse groups of clinicians and more scenario variability are needed to allow for subgroup analyses and to look for potential impacts on certain groups of clinicians or crisis scenarios. Third, the integration of AR technology into clinical practice raises questions about cost, accessibility, and the need for specialized training [57]. The development of best practices for the implementation and customization of AR checklists will be crucial to their successful adoption in surgical care. Last, we recognize that *P* values alone should not be taken as conclusive evidence of AR's superiority. The narrow statistical margin highlights the need for further validation through larger studies to confirm its efficacy.

### Conclusion

Our study showed that the use of AR-enhanced checklists significantly improved adherence to critical procedural steps during simulated OR crises compared to both traditional paper checklists and scenarios without a checklist. These findings are promising as they may contribute to the patient's safety and outcomes. However, while the benefits of AR are promising, our findings also indicate a potential increase in cognitive load among clinicians, particularly anesthesiologists. Future studies should aim to optimize AR interfaces to minimize cognitive demands and validate these results in real-world settings. Addressing the balance between improved protocol adherence and cognitive load will be crucial for integrating AR effectively in high-stakes environments like the OR.

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### Conflicts of Interest

AG is the Medical Director of Ultrasight.

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### Multimedia Appendix 1

Supplementary materials on the development and application of augmented reality checklists for crisis management in clinical settings.

[DOCX File, 106 KB - [xr\\_v2i1e60792\\_app1.docx](#) ]

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## Abbreviations

**AR:** augmented reality

**FTA:** failure to adhere

**LF/HF:** low-frequency to high-frequency

**OR:** operating room

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