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Extended Reality Use in Paediatric Intensive Care: A Scoping Review

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Abstract

Background: Extended reality (XR) technology such as virtual and augmented reality is increasingly being utilised in paediatric medicine due to its role in medical education and reported positive impacts on outcomes including pain, anxiety, and sleep. To the author's knowledge, no previous reviews investigating the use of XR in paediatric intensive care have been undertaken. **Objectives:** To scope the use of XR in paediatric intensive care, and assess its barriers to adoption, including safety considerations, cleaning and infection control. **Eligibility criteria:** All articles of any methodological design discussing the use of XR within paediatric intensive and critical care were included. **Sources of evidence:** Four databases (EMBASE, CINAHL, PsychInfo, PubMed) and Google Scholar were searched without any limitations on publication year. **Charting methods:** Data was extracted into Microsoft Excel by two authors independently (AG & SF) and cross-checked for completeness. **Results:** One hundred and eighty-eight articles were originally identified. Following the application of eligibility criteria 16 articles utilising XR in clinical interventions (n = 7) and medical education (n = 9) were included. Articles utilised VR and AR for highly variable purposes within both medical education (eg disaster preparedness, intubation) and clinical interventions (eg decrease pain, nausea, anxiety and improve Glasgow Coma Scale). **Conclusions:** While research into the use of XR in paediatric intensive care is still in its infancy it has increased dramatically over the past 5 years within two key areas. Firstly, in healthcare education, to assist in the acquisition of PICU-specific knowledge and practice of skills such as intubation of difficult airways. Secondly, studies have evaluated and demonstrated that with appropriate use, VR appears to be a safe and feasible intervention to decrease pain and anxiety in PICU patients.

Keywords

virtual reality, augmented reality, paediatrics, intensive care, education

Introduction

Paediatric intensive care units (PICU) present a myriad of complex and frequently dynamic challenges for patients, their families and healthcare providers. Overuse of analgesia and sedation in a PICU settings is associated with a high risk of developing PICU-acquired complications and poorer outcomes including delirium, prolonged length of stay, longer ventilation times, neuromuscular atrophy and weakness, post-traumatic stress disorder and increased levels of drug tolerance, dependence, and withdrawal syndrome.[1–3]

The goal of pain management in PICU settings is to improve patient comfort and reduce associated physiological stress responses while managing risks such as respiratory depression, addiction, haemodynamic instability, delirium, and end organ injury.[2,4,5] Children admitted to PICUs experience on average >10 painful and/or distressing procedures per day.[1,6–8] This number significantly increases for children who are mechanically ventilated.[1] In addition to pain and psychological distress the deleterious and often unavoidable effects of patient-ventilator dyssynchrony, patient care interactions and environmental factors in the PICU environment places critically ill children at high risk of sleep deprivation.[9–11] Poor sleep quality and quantity characterised by increased sleep fragmentation and decreased quantities of slow wave sleep are commonly associated with PICU-acquired complications.[3,11,12]

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Rationale

Guidelines currently recommend the adoption of strategies with emphasis on non-pharmacological options in all PICU patients.[3] In the absence of a commonly accepted definition, this review refers to Extended Reality (XR) as the collective term for Virtual Reality (VR), Augmented Reality (AR), and Mixed Reality (MR). XR interventions offer potential non-pharmacological solutions to challenges such as pain,[13,14] sleep disturbances[15] and anxiety.[14] However, without a systematic assessment of the evidence, the widespread uptake of XR in PICUs is unlikely to occur.[16]

A scoping review was undertaken to allow for a broad investigation into the use of XR within PICUs guided by the following research question:

1. How has XR been utilised within paediatric intensive care units (PICUs)?

The following sub-questions are utilised to provide direction and further analysis of identified articles:

2. Purpose of using XR in PICUs
3. What types of PICUs have XR technology been utilised?
4. What are the characteristics of participants?
5. What types of XR hardware and software have been utilised?
6. What cleaning/infection control policies/procedures are utilised for XR in PICUs?
7. What outcome measures are being used to explore/investigate the use of XR in PICU?
8. What are the experiences of participants (patients, caregivers, and healthcare providers)?
9. Have adverse effects been reported in the treatment of patients in PICUs?

Methodology

Protocol and Registration

A priori protocol was developed in line with recommendations by the Joanna Briggs Institute (JBI) and the Prisma extension for scoping reviews reporting guidance (PRISMA ScR).[17,18] The protocol was registered prospectively prior to the initiation of screening with Open Science Framework and updated on the 05/10/2022 (DOI:10.17605/OSF.IO/HVCAE).

Eligibility Criteria

A pre-determined eligibility criteria was developed informed by the population (any population), concept (utilising XR technology) and context (within a paediatric ICU) framework.[18] Pre-determined definitions for the terms paediatric, intensive care facility, VR and AR, outlined within the protocol, guided eligibility criteria development and exclusion processes. To ensure a broad scope of the literature was undertaken no research methodology was excluded. Due to feasibility only articles published in English were included.

Search Strategy

A search strategy was developed with the assistance of a medical research librarian in line with the following three-step methodological approach outlined by the JBI: a) a preliminary literature search was undertaken in PubMed and Google Scholar, b) additional search terms were identified and search strategies translated with the assistance of a validated search engine translation software (Polyglot),[19] c) execution of final search strategies (Appendix 1).

Information Sources

Four databases (PubMed, EMBASE, PyshInfo and CINAHL) were searched on the 16/09/2022. Google Scholar was searched, and the first 100 articles were exported on the 11/10/2022. Results from database searches were exported into Endnote X9.[20]

Selection of Sources of Evidence

Duplicate results were removed within systematic review accelerators validated deduplication software utilising the cautious algorithm prior to being manually reviewed.[21] Articles were screened by two authors (AG & SF) by title and abstract within Systematic Review Accelerators Screenatron.[21] Full-text screening was undertaken within Covidence with discrepancies identified and resolved by a third author (SG) within Covidence.[22]

Data Charting Process

A draft extraction table was developed within Microsoft Excel prior to data extraction to align with the scoping reviews research questions. Final extraction of data was undertaken by two authors (AG & SF), before manually being compiled and discrepancies resolved.

Data Items

The extracted data items are available within the data extraction template (Appendix 2). Only information described within the manuscript and supplementary documents were data extracted. Information not provided was recorded as "not described".

Critical Appraisal

Critical appraisal of the quality of the included articles was undertaken by two authors (AG & SG) utilising the mixed methods assessment tool (MMAT)[23] and guidance provided by Hong et al, 2018.[24] Discrepancies were resolved by a third author (OB). Data relating to the quality of intervention reporting was undertaken utilising the TIDieR checklist.[25]

Synthesis of Results

Data pertaining to the frequency of countries, year of publications, setting, barriers, facilitators, safety considerations and cleaning and infection protocols were tabulated within Microsoft Excel, in alignment with the research questions.

Results

Selection of Sources of Evidence

Database searching led to the retrieval of 188 articles of which 33 were automatically removed as duplicates. Title and abstract screening of the remaining 155 articles led to the exclusion of 102 articles. Full-text screening of the remaining 53 articles was undertaken with substantial agreement between authors (Cohen's Kappa = .66). Following the exclusion of a final 37 articles, 16 articles were included within our scoping review. A summary of the retrieval and screening process with reasons for exclusion has been displayed within a PRISMA flow diagram (Figure 1).

Critical Appraisal Within Sources of Evidence

The methodological quality of included articles was found to be of variable quality (Table 1).

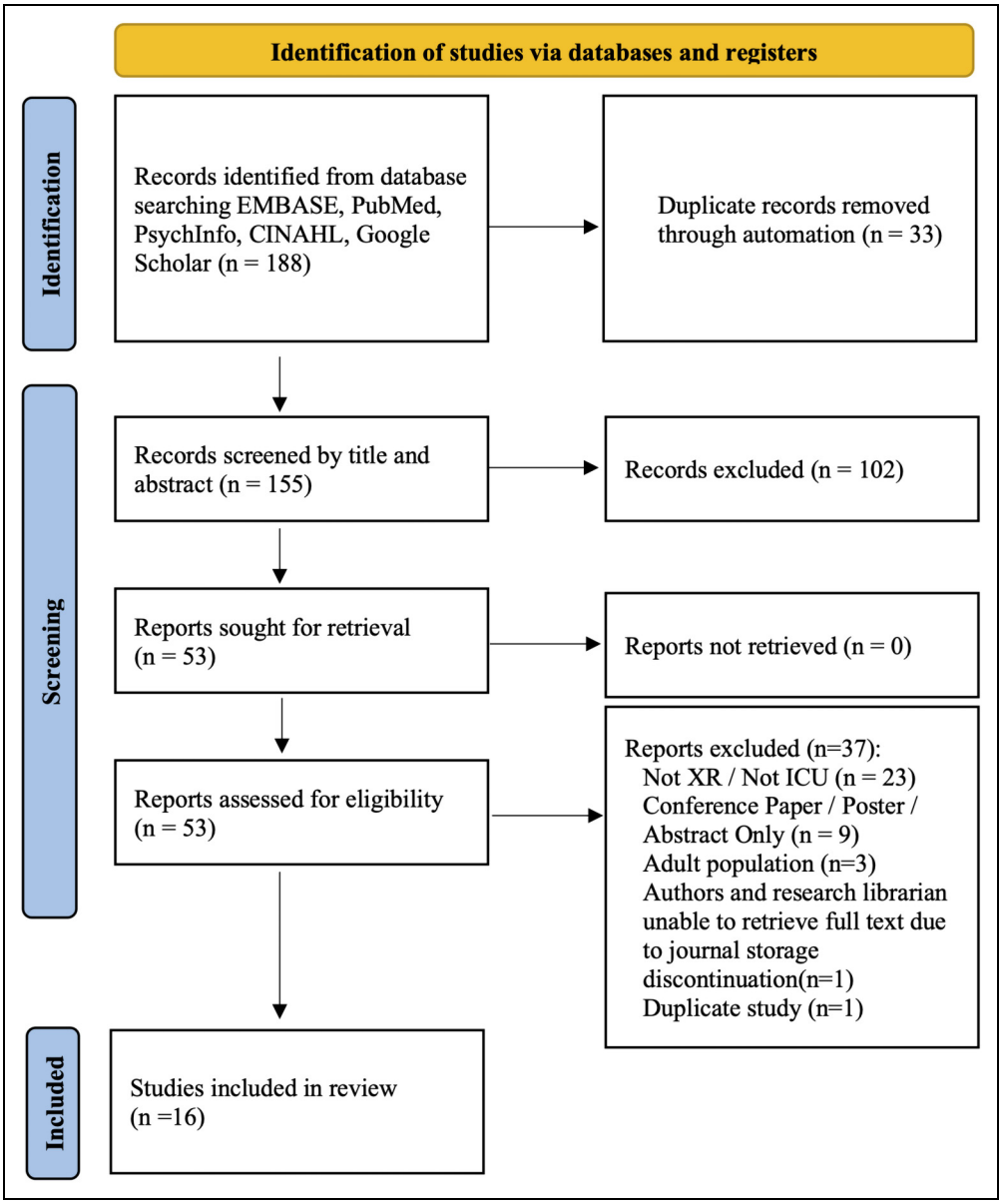

Figure 1. PRISMA flow diagram.

Table 1. Mixed Methods Assessment Tool (MMAT) Critical Appraisal Decision.

	Screening Questions		Qualitative					Quantitative RCTs					Quantitative Non-randomised				Quantitative Descriptive				Mixed Methods			
Study Reference	S1	S2	1.1	1.2	1.3	1.4	1.5	2.1	2.2	2.3	2.4	2.5	3.1	3.2	3.3	3.4	3.5	4.1	4.2	4.3	4.4	4.5	5.1	5.2	5.3	5.4	5.5
Agasthya, Penfil and Slamon. (2020)[26]	Y	Y																N	N	CT	N	CT					
Badke et al. (2019)[27]	Y	Y											Y	N	N	CT	CT	Y	Y	N	CT	N	N	N	N	N	N
Badke et al. (2022)[28]	Y	Y											Y	Y	Y	N	Y	Y	Y	N	Y	Y	N	Y	Y	Y	N
Dias et al. (2021)[36]	Y	Y																Y	CT	Y	Y	Y					
Farra et al. (2019)[37]	Y	Y	§	§	§	§	§						CT	Y	N	CT	CT					§	§	§	§	§	§
Hoffman et al. (2019)[40]	Y	Y											Y	Y	Y	N	Y										
Kucher et al. (2020)[30]	Y	Y	Y	CT	N	N	N											CT	CT	CT	N	N	N	N	N	N	N
Liang et al. (2022)[29]	Y	Y						Y	Y	Y	CT	Y															
Natomi.et al. (2021)[41]	N	N											Y	CT	Y	Y	Y										
Ralston et al. (2021)[31]	Y	Y											Y	Y	Y	N	CT										
Yang and Oh. (2022)[33]	Y	Y																									
Yu et al. (2021)[34]	Y	Y											Y	Y	Y	Y	Y										

Key: Y: Yes; CT: Can't tell; N: No; §: Not assessed as authors chose to only report the quantitative arm of the mixed methods study in this manuscript.

Synthesis of Results

The majority of included publications were published since 2019 (Figure 2). Extended reality was utilised for the purposes of medical education and clinical interventions (Figure 3). Only three countries, The United States, China, and South Korea were represented. Articles were primarily of a quantitative (n = 7) or mixed methods (n = 6) design, with a case study, protocol and a cost analysis representing the remainder. No systematic reviews or meta-analysis met our eligibility criteria.

Types of Intensive Care Facilities

Three paediatric clinical settings; intensive care,[26–30] neonatal intensive care and cardiac intensive care unit[31,32] were described. Three articles utilised XR within a nursing college setting for the purposes of medical education.[33–35] Neonatal intensive care was the most common setting for utilising XR for medical education.[36–39] Comparatively, paediatric intensive care was underrepresented with only one article identified relating to medical education.[26] Conversely, PICUs represented the majority of intervention articles.[27–29,40]

Uses of XR in Medical Education

Nine articles were identified which utilised XR within medical education (Figure 3). The participant population was highly heterogenous including paediatric cardiac intensive care physicians,[31] paediatric medical residents,[26] neonatal intensive care nurses,[35,36] and pre-registration nursing students[33,34] (Table 2). No articles looked at the use of XR for patient and family education. Articles which used XR for the purposes of medical education pertained to four clinical skills: intubation,[26,31,33,36] recognising and responding to a deteriorating patient,[31] neonatal ICU evacuation procedures[37] and high-risk neonatal infection control[34,35] (Table 3). Healthcare providers reported that XR was easy to set up and required little space while improving learner satisfaction.[26,31] However, haptic feedback within simulations of medical procedures was reported to be hard to reproduce accurately.[26] Farra et al, detailed the simulation design process,[38] implementation[37] and provided a cost analysis[39] of their simulation. No medical education articles utilised XR to assess performance or knowledge acquisition instead relying predominantly on surveys and expert examiners who evaluated performance (Table 3). Numerous benefits to the use of XR were noted (Table 4), primarily relating to learning outcome achievement and satisfaction, as well as areas of feasibility relating to cost and ease of delivery.

Uses of XR in Medical Interventions

Seven articles were identified which utilised XR for medical interventions (Figure 3.). Virtual reality was the only XR modality used as a medical intervention in PICU patients. Patient populations were inclusive of a wide range of primary conditions including respiratory, cardiac, and neurological

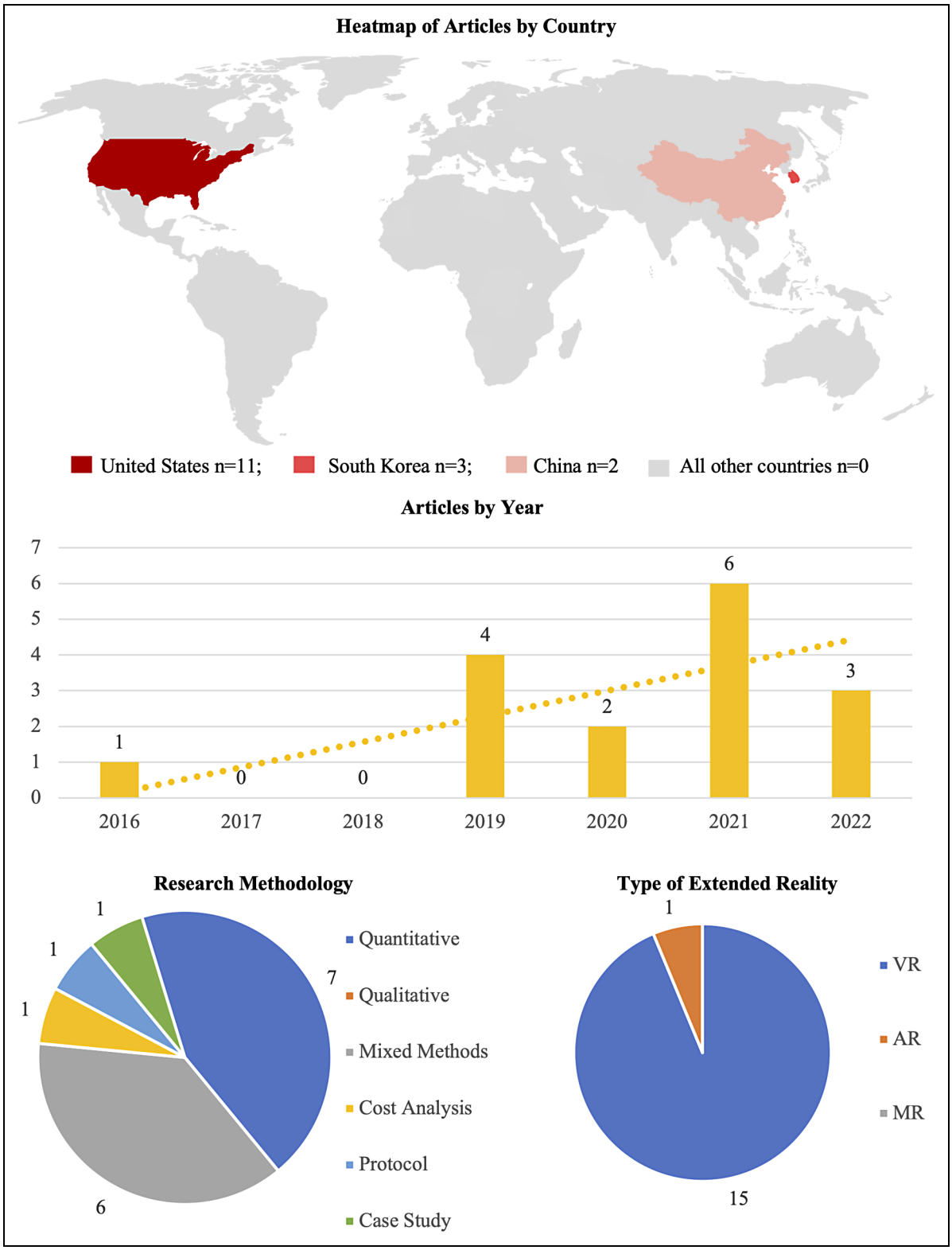

Figure 2. Articles by country, research methodology and type or extended reality.

disorders, burns, sepsis, and individuals admitted post-surgery. Patient populations included children between the ages of 3 and 18 who were either intubated or non-intubated and had varying levels of consciousness.

Virtual reality was most commonly used to improve psychological outcomes and decrease pain and discomfort. Hemphill et al, 2021, utilised the experience Beat Saber during physiotherapy to improve engagement in undertaking active proximal

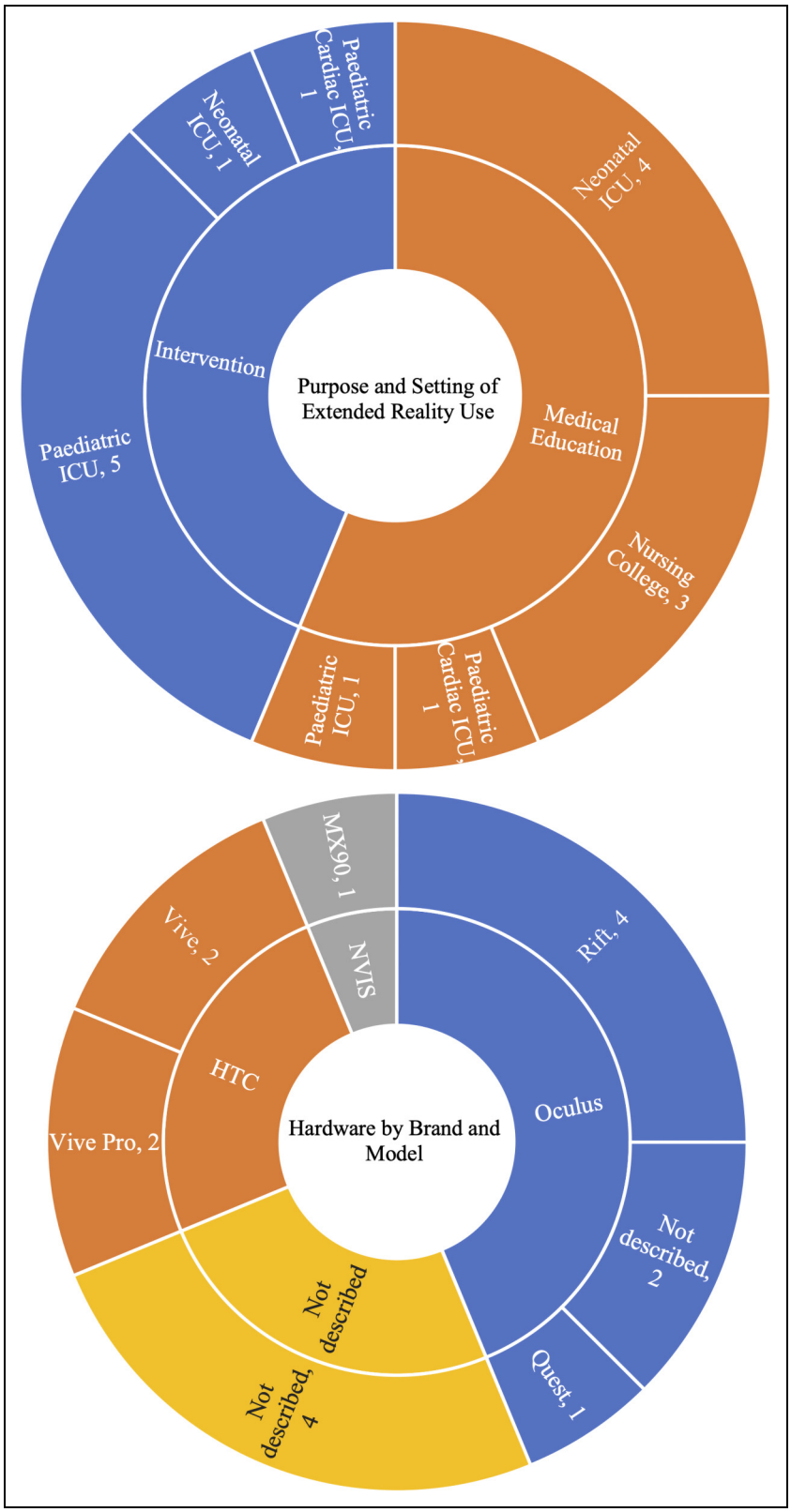

Figure 3. Purpose and setting of extended reality use and hardware by brand and model.

trunk strengthening exercises leading to improvements in independent sitting balance and reduced barriers to discharge.[32] Liang et al, (2022) utilised customised videos with accompanying audio from families to try to improve the level of consciousness in patients with low Glasgow Coma Scale scores.[29] A potential lack of engagement resulting from low

Table 2. Characteristics of Articles Pertaining to the Aims, Methodology, Type of Care Facility and Participant Characteristics.

Author (Year) Country	Aim(s) / Objective(s) / Research question(s)	Methodology	Type of Critical Care Facility	Use of Extended Reality	Participant characteristics M: Male F: Female
Agasthya, Penfil and Slamon. (2020)[26] United States	**Hypothesis 1:** Inexperienced pediatric trainees would have comparable performance with experienced senior fellows and emergency medicine residents after undergoing a brief immersive VR tutorial.	Quantitative (Non-RCT)	Pediatric ICU	Medical Education	VR Intervention (n = 5): **M/F:** Not described **Age:** Not described **Population:** Pediatric medical residents
Dias et al, (2021)[36] United States	**Objective 1:** Convert standard disposable direct laryngoscope into a video laryngoscope **Objective 2:** Investigate if augmented reality assisted video laryngoscopy improved novice intubation proficiency on manikins compared to indirect video laryngoscopy and direct laryngoscopy.	Quantitative (RCT)	Neonatal ICU	Medical Education	Intensive care nurses (n = 45): **M/F:** Not described **Age:** Not described **Population:** Neonatal intensive care nurses with minimal simulated intubation experience. Direct laryngoscopy (n = 15), Indirect video laryngoscopy (n = 15), Augmented reality laryngoscopy (n = 15)
Farra et al, (2016)[38] United States	**Purpose:** Describe the methods for developing a VR neonatal intensive care evacuation simulation by an interdisciplinary team using a storyboard.	Mixed Methods (Convergent Design)	Neonatal ICU	Medical Education	Simulation reviewers (n = 26) **M/F:** Not described **Age:** Not described **Population:** Not well described
Farra et al, (2019)[37] United States	**Aim 1:** Evaluate the impact of a program of VR Simulation on health care providers' reactions (comfort, confidence) and knowledge after participating in VRS. **Aim 2:** Evaluate the impact of a program of VR Simulation on health care providers' behaviours during a hands-on simulation exercise	Quantitative (RCT)	Neonatal ICU	Medical Education	N/A (Simulation design)
Farra et al, (2019)[39] United States	**Purpose:** Provide a cost analysis of one live disaster exercise compared to development and implementation of VR exercises.	Cost Analysis	Neonatal ICU	Medical Education	N/A (Cost analysis): Cost comparison of 2 disaster preparedness training methods conducted for cost analysis: 1 live disaster exercise compared to development and implementation of the VR exercise in NICU
Ralston et al, (2021)[31] United States	**Purpose 1:** Describe initial experience in developing two pilot VR scenarios and to demonstrate its feasibility in specialised clinical environments.	Quantitative (Non-RCT)	Cardiac ICU (Pediatric)	Medical Education	VR Simulation Group (n = 6): **M/F:** Not described **Age:** Not described **Population:** Attending pediatric cardiac intensive care unit physicians
Yang and Oh. (2022)[33] South Korea	**Hypothesis 1-6:** Students receiving VR simulation training will demonstrate greater improvements in knowledge, problem solving, clinical reasoning, self-confidence, learning motivation and decreased anxiety compared to online learning.	Quantitative (Non-RCT)	Nursing College	Medical Education	VR Group (n = 29): **M/F:** 2/27 **Age:** Not described **Population:** Pre-registration nursing students Non-VR Simulation Group (n = 28) **M/F:** 4/24 **Age:** Not described **Population:** Pre-registration nursing students Control Group (n = 26)

(continued)

Table 2. (continued).

Author (Year) Country	Aim(s) / Objective(s) / Research question(s)	Methodology	Type of Critical Care Facility	Use of Extended Reality	Participant characteristics M: Male F: Female
					M/F: 8/18 **Age:** Not described **Population:** Pre-registration nursing students
Yu and Mann. (2021)[35] South Korea	**Aim 1:** Develop an immersive VR simulation program addressing high-risk neonatal infection control in the NICU for nursing students and new graduate nurses.	Protocol Development	Nursing College	Medical Education	Expert panel (n = 7): **M/F:** Not described **Age:** Not described **Population:** 5 nurses with greater than 10 years' experience within NICU and 2 doctoral students majoring in pediatric nursing with simulation education experience.
Yu et al, (2021)[34] South Korea	**Hypothesis 1-3:** Nursing students which experience VR simulation will have a higher level of knowledge, self-efficacy, and learner satisfaction regarding high-risk neonatal infection control.	Mixed Methods (Non-RCT)	Nursing College	Medical Education	Control group (n = 25): **M/F:** 2/23 **Age:** 22.36 ± 1.22 **Population:** Nursing student VR Intervention group (n = 25): **M/F:** 2/23 **Age:** 22.44 ± .87 **Population:** Nursing student
Badke et al, (2019)[27] United States	**Objective 1:** Measure participant and patient satisfaction **Objective 2:** Assess feasibility of VR in a PICU population	Mixed Methods (Convergent Design)	Pediatric ICU	Intervention	VR Intervention (n = 32): **M/F:** 18/14 **Age:** Median 9 years old, interquartile range 7–13.3 **Ethnicity:** 47% identified as Hispanic/Latino **Population:** Pediatric intensive care patients
Badke et al, (2022)[28] United States	**Objective 1:** Explore if children enjoyed the VR experience. **Objective 2:** Assess any adverse effects of the experience. **Objective 3:** Assess physiological responses by measuring heart rate variability.	Mixed Methods (Convergent Design)	Pediatric ICU	Intervention	VR intervention (n = 115): **M/F:** 56/59 **Age:** Median: 10, range 3–17 years old **Population (Primary ICU Diagnosis):** Respiratory disease 33.9%, post-surgical 22.6%, neurologic disease 11.3%, shock/sepsis 15.7%, other 6.5%
Hemphill et al, (2021)[32] United States	**Objective 1:** Demonstrate the successful application of VR to improve physiotherapy in the pediatric cardiovascular intensive care unit.	Case study	Cardiac ICU (Pediatric)	Intervention	VR intervention (n = 1) **M/F:** 0/1 **Age:** 16 years old **Case description:** Complex medical history including developmental delay, hypoplastic left heart syndrome, heart transplantation x2, diastolic heart failure, recent respiratory failure, pleural injury, phrenic nerve injury.
Hoffman et al, (2019)[40] United States	**Hypothesis 1:** Compared to standard of care (standard pain medications + No VR), during adjunctive Yes VR, children will report significant reductions in worst pain ratings.	Quantitative (Within Subjects Randomised Trial)	Pediatric ICU	Intervention	VR Intervention (n = 48): **M/F:** 34/14 **Age:** Mean 12, range 6–17years

(continued)

Table 2. (continued).

Author (Year) Country	Aim(s) / Objective(s) / Research question(s)	Methodology	Type of Critical Care Facility	Use of Extended Reality	Participant characteristics M: Male F: Female
	Hypothesis 2: During VR, children will report significant reductions in pain unpleasantness, and will spend less time thinking about pain during burn wound debridement in the ICU hydrotank. **Hypothesis 3:** VR will increase how much fun patients have during wound care, and that patient will be more satisfied with their pain management during VR.				**Population:** Burns covering on average 40% of total body surface area.
Kucher et al, (2020)[30] United States	**Aim:** Demonstrate 3-D nature-based therapy leads to reductions in pain, nausea and anxiety in children and adolescents undergoing total pancreatectomy islet auto-transplant	Mixed Methods (Convergent Design)	Pediatric ICU	Intervention	VR nature-based therapeutics (n = 6): **M/F:** Not described **Age:** Range 8–18 **Population:** Pediatric total pancreatectomy islet auto-transplant patients in the immediate post-operative period
Liang et al, (2022)[29] China	**Objective:** Determine if VR based sensory stimulation can improve the level of consciousness in pediatric disorders of consciousness compared with general rehabilitation.	Quantitative (Randomised Control Trial)	Pediatric ICU	Intervention	VR + standard rehabilitation (n = 15): **M/F:** 8/7 **Age:** Median 6.1, interquartile range 3.6–11.1 **Population:** Traffic accident injury (40%), Fall injury (26.7%), Viral encephalitis (33.3%) Standard rehabilitation (n = 15): **M/F:** 11/4 **Age:** Median 4.8, interquartile range 3.8–9.1 **Population:** Traffic accident injury (46.6%), Fall injury (26.7%), Viral encephalitis (26.7%)
Natomi et al, (2021)[41] Japan	**Aim:** Develop a system that can reproduce the sensation of holding an infant.	Mixed Methods (Sequential Explanatory Design)	Neonatal ICU	Intervention	Individuals with experience of holding an infant (n = 18 quantitative analysis n = 4 qualitative analysis): **M/F:** Not described **Age:** Not described **Population:** Not described

Key: VR, Virtual reality; PICU, Pediatric intensive care unit; NICU, Neonatal intensive care unit; RCT, Randomised control trial; ICU, Intensive care unit.

Table 3. Characteristics of Articles Pertaining to Hardware, Software, Protocols, Outcome Measures and key Findings.

Author (Year) Country	AR / VR / MR	Hardware B: Brand M: Model CA: Commercial Availability	Software B: Brand S: Software CA: Commercial Availability	Protocol (intervention) Details F: Frequency T: Time I: Intervention	Outcome Measures/Evaluation Tools	Key Findings
Agasthya, Penfil and Slamon. (2020)[26] United States	VR	**B:** Meta **M:** Rift S **CA:** Not described	**B:** Acadicus* **S:** Not described **CA:** Not described	VR intubation simulation: **F:** Single session **T:** 19 min **I:** An interactive avatar discussed steps in detail in a room created to replicate a pediatric intensive care unit. Participants able to interact and utilise equipment in VR to simulate intubation.	• 24 Item timed checklist developed by authors who have completed critical care fellowship training	VR pediatric intubation simulations were effective in teaching pediatric residents the steps involved in pediatric airway intubation.
Dias et al, (2021)[36] United States	AR	**B:** Not described **M:** Not described **CA:** Not described	**B:** Not described **S:** Not appliable, direct video feed **CA:** Not described	Augmented reality Video Laryngoscopy: **F:** Single session (5 attempts) **T:** Not described **I:** Intubation of a Basic Infant CRiSis manikin **C:** Indirect video laryngoscope and direct laryngoscope	• Successful intubation • Failure due to prolonged intubation • Failure to intubate within 60 s • Failure due to oesophageal intubation • Time to intubate • Time to visually identify airway • Time between airway identification and intubation (successful attempts only)	Intubation success was significantly improved by indirect and direct video laryngoscopy as measured by number of successful attempts and time to intubate.
Farra et al, (2016)[38] United States	VR	**B:** Meta **M:** Rift **CA:** Not Described	**B:** Not described **S:** Not described **CA:** Not described	Simulation storyboard design process based on the objective, scene, actions, challenges, and redirect (formative feedback facilitation) processes.	• Survey consisting of 2 open ended questions and 12 questions requiring responses on a Likert scale	A storyboard format including objectives, scenes, actions, challenges, redirection, and debriefing opportunities allowed the interprofessional team to build a VR simulation reflective of best practices.
Farra et al (2019)[37] United States	VR	**B:** Meta **M:** Not described **CA:** Not Described	**B:** Not described **S:** Not described **CA:** Not described	VR and web-based evacuation simulation: **F:** 4 sessions **T:** Approximately 10 min **I:** Evacuation simulation. VR and web-based interventions clinical updates. Participants told to utilise web-based application if experienced motion sickness.	• Emergency preparedness information questionnaire • Live evacuation exercises utilising mannequins • Multiple choice quiz • VARK learning style assessment	One participant experienced motion sickness with either the VR headset or web-based application. The VR groups performance in live exercise was statistically ($P < .0001$) and clinically (effect size 1.71) better than web-based interventions.
Farra et al, (2019)[39] United States	VR	**B:** Meta **M:** Not described **CA:** Not Described	**B:** Not described **S:** Not described **CA:** Not described	Cost Analysis	Costs included in analysis: • Planning • Development • External Review	VR is initially more expensive compared to live exercise drills ($327.78 and $229.79 per participant respectively). When development costs are extrapolated to repeated training

(continued)

Table 3. (continued).

Author (Year) Country	AR / VR / MR	Hardware B: Brand M: Model CA: Commercial Availability	Software B: Brand S: Software CA: Commercial Availability	Protocol (intervention) Details F: Frequency T: Time I: Intervention	Outcome Measures/Evaluation Tools	Key Findings
					• Implementation and participation • Other costs (eg, specific software licences)	over 3 years VR becomes less expensive ($115.43 per participant) while live exercise price remains fixed.
Ralston et al, (2021)[31] United States	VR	**B:** Meta **M:** Quest **CA:** Not described	**B:** SimX **S:** Custom medical simulation program **CA:** Not described	Critical care VR Simulation experience: **F:** Single experience **T:** Not described **I:** Scenario 1 – participants required to correctly recognise and treat junctional ectopic tachycardia and low cardiac output syndrome. Scenario 2 – follow correct infection control procedures while intubating a patient with suspected COVID-19.	• Survey (0-5 Likert scale) • Participant comments on simulation experience	**VR medical education findings:** • VR enhanced simulation experience • Participants felt VR environment felt realistic
Yang and Oh. (2022)[33] South Korea	VR	**B:** Meta **M:** Rift **CA:** Not described	**B:** Not described **S:** Not described **CA:** Not described	VR neonatal resuscitation program: **F:** Single session **T:** 50 min **I:** VR resuscitation program. Content developed according to Neonatal Resuscitation 2020 American Heart Association Guidelines.	**ICU Related Outcomes:** • Neonatal resuscitation nursing knowledge measurement tool. • Problem solving ability of adults. • Nurses clinical reasoning scale (Korean version) • Self Confidence • State-trait anxiety inventory • Medical Education **Medical education outcomes:** • Learning motivation test paper (modified)	**VR medical education findings:** • Improved neonatal resuscitation knowledge, problem-solving ability, self-confidence, learning motivation of the nursing students. • Anxiety lower in simulation group compared to VR
Yu and Mann. (2021)[35] South Korea	VR	**B:** HTC Vive **M:** Vive Pro **CA:** Not Described	**B:** SAMWOO immersion Co., Ltd **S:** Not described **CA:** Not described	N/A Software development and validation.	• Item content validity index	Item content validity index for each step for each procedure >/=.80. Development of three scenarios relating to Basic care upon initial admission, feeding management, skin care and environmental management.
Yu et al, (2021)[34] South Korea	VR	**B:** HTC Vive **M:** Vive Pro **CA:** Not Described	**B:** SAMWOO immersion Co., Ltd **S:** Not described	High-risk neonatal infection control simulation: **F:** 1 day training **T:** 10 min orientation to VR, 40 min medical education VR intervention	**Medical education outcomes:** • High-risk neonatal infection control competency scale performance Likert scale	The VR group showed significantly greater improvements in high-risk neonatal infection control performance self-efficacy and learner satisfaction

(continued)

Table 3. (continued).

Author (Year) Country	AR / VR / MR	Hardware B: Brand M: Model CA: Commercial Availability	Software B: Brand S: Software CA: Commercial Availability	Protocol (intervention) Details F: Frequency T: Time I: Intervention	Outcome Measures/Evaluation Tools	Key Findings
			CA: Not described	**I:** VR intervention on basic care, feeding management, skin care and environmental management.		The virtual reality simulation program can expand the nursing students' practice experience in safe virtual spaces and enhance their performance self-efficacy and learning satisfaction.
Badke et al, (2019)[27] United States	VR	**B:** Not described **M:** Not described **CA:** Not described	**B:** Not described **S:** Not described **CA:** Yes, details not described	VR Intervention: **F:** Single session **T:** Median 6 min **I:** Age-appropriate experiences ranging from serene nature landscapes to snowboarding and roller coasters.	• Open ended comments • Parent survey (0-4 Likert scale) • Patient survey (0-4 Likert scale)	VR is easily administered and enjoyable tool that subjectively calms pediatric intensive care unit patients. All patients enjoyed using VR, and 84% reported preference to VR for a longer duration. All parents agreed that their child enjoyed using virtual reality and enjoyed watching their child use virtual reality. Eighty-two percent of parents reported that virtual reality calmed their child.
Badke et al, (2022)[28] United States	VR	**B:** Not described **M:** Not described **CA:** Not Described	**B:** Not described **S:** Not described **CA:** Yes, details not described	VR nature, animal, and adventure experiences: **F:** Not adequately described. **T:** As long as the patient liked **I:** Experience selected by patient.	• Patient survey, expressions, comments, utterances, smiles, laughs • Parent survey • Engagement score • Heart rate variability	72% of participants made positive comments while using VR. 78% of participants felt that VR was calming. 92% of parents reported that VR calmed their child. High levels of patient and parent satisfaction. 79% of participants were highly engaged with VR.
Hemphill et al, (2021)[32] United States	VR	**B:** HTC **M:** HTC VIVE (customised) **CA:** Not described	**B:** Not described **S:** Beat Saber **CA:** Yes	VR Intervention: **F:** 3 sessions **T:** 10–30 min **I:** Played Beat Saber while standing and sitting down.	Repeated outcome measures not described	Virtual reality can be used safely for carefully selected and monitored children in critical care. VR was successfully used to improve engagement in this case study.
Hoffman et al, (2019)[40] United States	VR	**B:** NVIS **M:** MX90 **CA:** Not described	**B:** Not described **S:** SnowWorld **CA:** Not described	VR SnowWorld: **F:** Repeated days during burn wound debridement **T:** 12 min **I:** VR SnowWorld experience, patient	• Graphic rating scale • Worst pain (0-10) • Pain unpleasantness (0-10) • Time spent thinking about pain (0-10)	Worst pain improved by a mean difference of 3.42 (p=<0.001)/ Pain unpleasantness improved by a mean difference of 2.93 (p=<0.001). Time spent thinking about pain

(continued)

Table 3. (continued).

Author (Year) Country	AR / VR / MR	Hardware B: Brand M: Model CA: Commercial Availability	Software B: Brand S: Software CA: Commercial Availability	Protocol (intervention) Details F: Frequency T: Time I: Intervention	Outcome Measures/Evaluation Tools	Key Findings
				interacted with game through use of computer mouse.	• Satisfaction with pain management	improved by a mean difference of 2.81 ($p = 0.001$). Satisfaction with pain management improved by a mean difference of 2.83 ($p = <0.001$)
Kucher et al, (2020)[30] United States	VR	**B:** Meta **M:** Rift with Samsung Galaxy 7 phone **CA:** Yes	**B:** Not described **S:** Not described **CA:** Yes	Nature based VR program: **F:** Not described **T:** Mean average 25.6 min, range 9–90 min **I:** Nature based programs with no commercials, no words, no music accompanying the program and multiple time ranges to choose from.	• Entry interviews • Wong Baker Faces Scale (FACES) • Baxter Retching Faces Scale (BARF) • Novel (unvalidated) Nature-Based Anxiety Scale • Post experience interviews and surveys	• 4 out of 6 patients used the device • Patients who utilised the device • Found the device 'enjoyable' and 'helpful • Indicated they 'would' or 'might use' it again and 'would recommend it to others'
Liang et al, (2022)[29] China	VR	**B:** HTC **M:** Vive **CA:** Not described	**B:** Not described **S:** Not described **CA:** Not described	Personalised VR Videos: **F:** Daily for 2 weeks **T:** 30 min **I:** Customised videos developed of family with accompanying auditory stimulation (15 min). Panoramic videos that provide visual, auditory, and vestibular input (15 min). Patients with continuous eye closure provided 1 min pain stimulus prior to intervention.	• Glasgow Coma Scale (GCS) • Coma recovery scale-revised (CRS-R) • Amplitude integrated electroencephalogram (aEEG) • Glasgow outcome scale extended pediatric revised (GOS-E Peds)	VR + Rehab improved • Mean GCS by 1 ($p = 0.045$) following treatment • Mean CRS-R by 9 ($p = 0.003$) • Improved functional deficits according to Glasgow outcome scale extended pediatric revised at 3 months ($p = 0.073$)
Natomi et al, (2021)[41] China	VR	**B:** Not described **M:** Not described **CA:** Not described	**B:** Not described **S:** Not described **CA:** Not described	Design process only.	• Survey (1-6 Likert scale) • Open feedback of four individuals with experience on holding baby regarding potential improvements	Proposed design of a method of simulation the sensation of hugging an infant utilising virtual reality with haptic feedback. Future research will investigate if model are able to provide parents the feeling of hugging their child.

Key: VR: virtual reality; FACES: wong baker faces scale; BARF: baxter retching faces scale; GCS: Glasgow Coma Scale; CRS-R: coma recovery scale-revised; aEEG: amplitude integrated electroencephalogram; GOD-E Peds: Glasgow outcome scale extended pediatric revised; * indicates information provided by corresponding author upon further request for information.

Table 4. Barriers and Facilitators Relating to Medical Education, Clinical Interventions, and Other Considerations.

Are of Extended Reality Use	Barriers	Facilitators
Medical education	• Haptic feedback hard to accurately reproduce for some tasks (eg, placing guidewire through a blood vessel)[26]	• Portable[26] • Easy to set up[26] • Requires very little space[26] • Economic advantages[26] • Allows for replicability and standardisation of learning practice[26,35] • Immersive experience facilitates skill development[35] • Reduces instructors preparation time[35] • Increases learner satisfaction[26,31] • No additional practice related materials required[35] • Allows for experience not otherwise feasible due to risk to patient safety[35]
Clinical Intervention	None identified	• High patient satisfaction[30] • Improved engagement with Physiotherapy during prolonged hospitalisation [32] • Cost effective[28] • Safe intervention[28] • Ability to be effectively cleaned[40] • Ability to utilise extended reality devices in sitting and supine[40]
Other considerations	• Commercial VR head mounted displays were utilised which lacked diversity and meaningful design strategies[27]	

No barriers to clinical interventions or other facilitating considerations were reported in the literature. As a result, these cells have been intentionally left blank.

levels of consciousness was addressed through the use of pain provocation prior to the initiation of a salient XR experience co-designed and produced with family members. Other interventions utilised VR to provide a wide range of experiences including nature-based scenes, fun experiences such as roller coasters and environments with therapeutic design elements such as SnowWorld.[27–30,40] The number and length of interventions varied from single sessions to daily for two weeks, 6 to 90 min and were tailored by selecting age-appropriate experiences and allowing patients to select the length and content within the experience.[27,28]

Types of Hardware and Software Utilised Within Paediatric Intensive Care

Three brands of head mounted displays were identified: Meta (previously known as Oculus), HTC and NVIS (Figure 2). Articles utilising a Meta device either used a Rift,[26,30,33,38] Quest[31] or failed to describe the model.[37,39] Articles utilising a HTC device either used a Vive[29,32] or Vive Pro.[34,35] Hoffman et al[40] were the only authors to use NVIS MX90. Four articles did not describe the brand or model of the headset.[27,28,36,41] Three articles detailed that software was commercially available.[27,28,32] One article used the game Beat Saber.[32] Badke et al, used a commercially available nature-based video however, lacked specific software details enabling the experience to be identified further.[27,28]

Cleaning and Infection Control Procedures

Four articles described cleaning and infection control procedures (Table 5). Cleaning protocols consisted of disposable covers,[34,35] utilising anti-bacterial wipes[29] and UV-C wands.[40] Hoffman et al, was the only article that indicated their cleaning protocol had been internally validated within the hospital.[40]

Outcome Measures to Explore/Investigate the Use of XR in PICU

Primary outcome measures were highly heterogenous (Table 3). No validated outcome measures were utilised to ascertain the level of 'presence' or cybersickness users experienced during exposure (Table 3). One paper measured nausea with the Baxter Retching Faces Scale.[30] The experiences of healthcare professionals, patients and caregivers were most often evaluated with surveys.[27,28,30,31,38,41] No studies evaluated the experience of healthcare providers experiences providing XR interventions to patients.

Experiences of Patients, Caregivers, and Healthcare Providers

High patient satisfaction was reported by Kucher et al.[30] At times, the experience of paediatric patients was difficult to assess due to impaired consciousness or cognition.[29] Clinical judgements of the patients' healthcare providers or caregivers were utilised in circumstances to therefore assess the patients' experience.[27–29] In line with existing literature,[42] XR interventions were well accepted by caregivers with 99% of parents in the article by Badke et al,[28] reporting they agreed or strongly agreed that they enjoyed watching their child during the intervention.

Safety Considerations and Adverse Effects

Healthcare providers reported that the use of VR in clinical interventions was safe (Table 5). Protocols for screening, monitoring, and ceasing VR interventions were highly inconsistent between articles or absent. Potential absolute contraindications or precautions were highlighted within the literature (Table 5). However, there was poor consensus as to what should be considered a contraindication. Virtual reality was reported to be safe and effective[28] with high patient satisfaction.[30] Clinicians monitored patients during interventions subjectively (signs of distress), objectively (heart rate) and through questions where appropriate.[28]

Reporting Quality of Interventions

The reporting of interventions was poor within a number of domains (Table 6). No articles provided enough details regarding hardware and software to replicate the intervention. No articles fully described the training and experience level of staff with utilising VR with patients.

Discussion

Summary of Evidence

To our knowledge, this is the first review to provide insights into the utilisation of XR within PICU, including a thorough exploration of the types of facilities, patient populations, the hardware and software, safety considerations, caregiver experiences, and adverse effects associated with the delivery of XR in PICU.

The paucity of research identified demonstrates that while research into XR in this clinical setting is increasing, widespread use has still not occurred. Identified articles concentrated on the use of XR for two key purposes; 1) for medical education and 2) to assist with clinical interventions to decrease pain and anxiety in a variety of paediatric intensive care settings.

Uses of XR in Medical Education

Extended reality use within medical education presents PICU staff an opportunity to learn and practice skills and procedures

Table 5. Considerations Relating to Exclusion Criteria and Safety Protocols.

		Information and Reference
Exclusion Criteria for VR Participation	Pharmacological Considerations	• Moderate or heavy sedation[27,28] • Vasoactive support[27,28]
	Medical History	• Severe motion sickness[32] • Seizure disorder[32]
	Active Medical Conditions	• Encephalopathy[27,28] • Recent neurologic injury[27,28] • Significantly impaired vision[27–29] • Significantly impaired hearing[29] • Clinical instability[27,28] • Delirium[40] • Psychosis[40] • Organic brain disorder[40] • Burns to eyes, eyelids, face[40] • Disorders of consciousness impairing ability to engage with intervention[27,28]
	Practical Considerations	• No obstructive medical equipment[27] • Patient unable to communicate verbally[40]
	Additional notes	• Mechanical ventilation is not considered contraindication[28] • Neurological injury causing impaired consciousness is not considered contraindication[29] • No exclusion criteria[30]
Safety protocols	Cleaning and infection control	• Disposable eye masks [34,35] or disposable plastic [40] for headset to prevent cross contamination • Cleaned with alcohol based [26,29] or germicidal [31,32] disposable wipes • Cleanliness of hardware monitored by hospital infection control department[40] • Equipment systematically disinfected after each use using chemical disinfectants and periodically cleaned using ultraviolet (UV) radiation via a portable UV lamp wand[40]
	Hardware considerations	• Water friendly headsets[40] (where applicable)

	Intervention considerations	• Virtual reality exposure limited to 15 min per session as per manufacturers guidance[27]
		• Advised prior to use to:
		  • Cease if experiencing symptoms of cybersickness[32,37] or discomfort[32]
		• Monitored by researcher:
		  • For signs of anxiety[27]
		  • For signs of distress[27]
		  • And asked if required a break[32]
		  • Changes in heart rate variability[28]

Table 6. TIDieR Checklist.

Number of Intervention Articles Identified = 7		Variables	
		No. of Articles	% of Articles
1. Do the authors provide the name or a phrase that describes the intervention?	Yes, complete	7	100
	Yes, incomplete	0	0
	No	0	0
2. Do the authors describe any rationale, theory, or goal of the elements essential to the intervention?	Yes, complete	5	71
	Yes, incomplete	2	29
	No	0	0
3. Materials: Do the authors describe any physical or informational materials used in the intervention, including those provided to participants or used in intervention delivery or in training of providers, or provide information on where the materials can be accessed (online appendix or URL)?	Yes, complete	0	0
	Yes, incomplete	7	100
	No	0	0
4. Procedures: Do the authors describe each of the procedures, activities and/or processes used in the intervention, including any enabling or support activities?	Yes, complete	3	43
	Yes, incomplete	4	57
	No	0	0
5. For each category of intervention provider (psychologist and nursing assistant), describe their expertise, background and any specific training given?	Yes, complete	0	0
	Yes, incomplete	1	14
	No	6	86
6. Do the authors describe the modes of delivery (face-to-face or by some mechanism, such as internet or telephone) of the intervention and whether it was provided individually or in a group?	Yes, complete	5	71
	Yes, incomplete	1	14
	No	1	14
7. Do the authors describe the type(s) of location(s) where the intervention occurred, including any necessary infrastructure or relevant features?	Yes, complete	3	43
	Yes, incomplete	4	57
	No	0	0
8. Do the authors describe the number of times the intervention was delivered and over what period of time including the number of sessions, their schedule, and their duration, intensity, or dose?	Yes, complete	3	43
	Yes, incomplete	4	47
	No	0	0
9. If the intervention was planned to be personalised, titrated, or adapted, do the authors mention so and then describe what, why, when, and how?	Yes, complete	5	71
	Yes, incomplete	1	14
	No	1	14
	N/A	0	0
10. Do the authors mention if the intervention was modified during the course of the study, and if so, describe the changes (what, why, when, and how)?	Yes, complete	4	47
	Yes, incomplete	1	14
	No	2	29
	N/A	0	0
11. Planned: If intervention adherence or fidelity was assessed, do they describe how and by whom, and if any strategies were used to maintain or improve fidelity, did the authors describe them?	Yes, complete	1	14
	Yes, incomplete	1	14
	No	0	0
	N/A	5	71
12.(If above answer was yes) Actual: If intervention adherence or fidelity was assessed, did the authors describe the extent to which the intervention was delivered as planned?	Yes, complete	1	14
	Yes, incomplete	0	0
	No	1	14
	N/A	5	71

such as intubation which are otherwise challenging and expensive for PICU staff to gain sufficient experience and proficiency through traditional methods.[35] Difficulty in simulating realistic haptic feedback, however, remains a major barrier to the development of real-world proficiency.[26] Articles included in this review utilised XR equipment that has been superseded in recent years by technology able to more accurately provide realistic haptic feedback. As haptic technology becomes cheaper and more accessible the transferability of PICU specific procedural skills learnt within a XR environment to the real world may improve.

Use of XR in Medical Interventions

The diverse nature of patient ages, primary diagnosis and acuity within the PICU setting requires interventions to be able to be adapted to individual patient requirements and clinical goals.[43] Decreasing pain and psychological distress were the most common clinical goals identified. Research to date lacks the appropriate outcome measures and study designs to determine if improvements in patient pain and anxiety result in reduced requirements for sedatives and analgesics, improved sleep or reduces the rates of or severity of complications such

as delirium. Moving forward it is important clinicians and researchers develop an understanding of XRs potential mechanisms in order to maximise the effectiveness of these interventions.

Distraction, or the allocation of cognitive resources away from the painful stimulus, is commonly cited as the primary mechanism of VR-mediated pain relief.[44,45] However, modulation of stress responses with XR has the potential to influence pain perception and tolerance through the overlap of spinal and supraspinal neural substrates of stress and pain.[46–48] Further research is currently required to determine if highly engaging and distracting experiences (eg, roller coasters) or relaxation experiences are more protective against negative outcomes associated with various common PICU scenarios and procedures.

Visual cues resulting from witnessing a caregiver's emotional reaction or identifying a potential threat (eg needle) can also modify a child's experience of pain.[49,50] Extended reality may therefore assist in modifying pain by providing alternate visual input and occluding the child's vision of potentially distressing visual cues. Additionally, healthcare provider interaction with the patient may reduce sensations of presence altering clinical effectiveness. Clinicians and researchers need to improve reporting to clarify intervention procedures and assist in determining how interacting with patients while using XR or preventing patients from viewing painful stimuli (eg, needle) with the use of XR modifies procedural anxiety and/or pain.

The nature and context of the visual input are also of potential importance.[44] The experience SnowWorld[40,51–53] is an example of how XR experiences can be tailored to improve outcomes associated with clinical goals. Research in pain science relating to colours and the contextualisation of information relating to pain suggests the depiction of the blue and snowy landscape within SnowWorld[40,51–53] is of clinical significance.[54] Moreover, VR has the potential to indirectly reduce a child's experience of pain by reducing the deleterious effects of sleep deprivation on subjective ratings of pain, their pain threshold and activation within their somatosensory cortex.[55,56]

Hardware Considerations

The hardware and software utilised within the identified literature were poorly reported impacting on the potential for research to be translated into clinical practice. To enable the wider integration of XR into PICUs hardware must be designed carefully to overcome potential barriers. Devices made of easily cleanable materials that do not incorporate Velcro into the design of the headstrap and minimise unnecessary cracks and crevices will assist healthcare providers in ensuring adequate infection control in a way that allows for efficient and effective cleaning protocols. Additionally, hardware must be able to fit a wide range of age groups. Headstraps that are easily fitted and comfortable in a supine position may also provide benefits within an intensive care environment to prevent unwanted cervical movement or disruption of attachments. Due to poor reporting and a lack of use of new XR hardware, it is unclear if more recent XR hardware is appropriate for use within the PICU. Researchers and clinicians should endeavour to utilise new technology to ensure research can be translated effectively into clinical practice.

Cleaning and Infection Control Policies and Procedures

Cleaning and infection control protocols were poorly reported in some articles preventing replication of interventions. Where reported infection control practices utilised antibacterial wipes and UV-C in line with the findings of a recent survey of VR hygiene practices by Hoeg and Lange., 2022.[57] Strict adherence to infection control measures are important in preventing hospital associated infections and associated increases in morbidity, mortality and healthcare expenditure.[58] Hoffman et al, 2019[40] described the use of a UV wand. Clinicians and researchers should consider that UV-C wands may be unsafe with the FDA reporting some disinfection wands emitting 3000 times the safe limit of international standards.[59] Additionally, Roberts et al, 2022 found UVC failed to provide adequate disinfection.[60] Further research is therefore required to adequately detail if current UV-C technologies can effectively clean XR devices. This will be an important step in the development of new industry evidenced-based regulations and cleaning protocols which meet healthcare standards.

Participants Excluded from Participation in Studies

Participants were excluded from VR interventions according to four main categories: Pharmacological considerations, medical history, active medical conditions, and practical considerations.[27–29,32,40] None of the included studies in this review featured AR interventions. Contrasting viewpoints exist within the literature pertaining to the need to exclude patients with a medical history (eg, epilepsy),[32] and active medical conditions such as neurological conditions.[27–29,40] Hemphill et al, excluded individuals with a history of epilepsy[32] despite existing literature suggesting VR use is not a risk factor for individuals (including children) with a history of epilepsy or photo paroxysmal responses.[61,62] Similarly, patients with recent neurological injuries were at times excluded from trials featuring VR.[27,28] Liang et al,(2022) reported no serious complications requiring medical intervention or an escalation of care in this population.[29] The exclusion criteria identified within this review (Table 5) may assist clinicians and researchers in developing screening and exclusion protocols for use in PICU. To ensure future screening and exclusion protocols are appropriate and not overly restrictive it is recommended clinicians critically analyse the literature and utilise clinical reasoning, informed by an understanding of the psychological and neurophysiological impacts of VR.

Adverse Effects and Outcome Measures

Consistent with the wider literature adverse effects reported within included articles were rare, mild, transient in nature and related to symptoms of cybersickness (eg, nausea, dizziness) or neck discomfort.[28] Despite experiencing "mild discomfort" no

patients requested the discontinuation of their intervention in a cohort of 115 PICU patients.[28] While all the mechanisms behind cybersickness have yet to be fully elucidated, research has demonstrated that reducing conflicts between sensory (vestibular, visual tactile etc) and predictive modelling systems is important. The users' position (eg, supine, sitting or standing) may therefore contribute to any adverse effects.[63] Thoughtful design and thorough reporting of intervention protocols may assist in understanding if the adverse effects reported so far in the literature can be mitigated through the use of simple strategies such as progressive habituation, reducing positional and vestibular-ocular conflicts, and using fans. These would then need to be evaluated to ensure feasibility in a PICU setting. Validated outcome measures examining XR specific factors such as 'presence' and cybersickness need to be standardised and used for future research within PICU.[64,65] Due to a lack of formal outcomes no conclusions regarding the experiences of clinicians utilising XR with patients can be drawn at this time. Qualitative approaches may assist in future to provide insights into patients' experiences and the effect of XR interventions on clinicians' decision-making.

Experiences of Patients, Caregivers, and Healthcare Providers

Positive experiences were reported when XR was used in both medical education and clinical interventions in the PICU setting indicating further research may be warranted.[26,30,31,37] However, the identified research indicates that to date research has been limited to the experience of the child and the caregivers perception of their child's experience. No research was identified within this review that sought to evaluate if witnessing their child partake in positive XR experiences has a positive effect on caregivers experience and well-being. Additionally, in future further research should investigate how providing XR interventions affect healthcare provider workflow and decision-making.

Gaps and Future Recommendations

Optimal management of pain, delirium, sleep, anxiety and distress are key recommendations within critical care guidelines.[3] While VR has been utilised successfully to improve anxiety and pain in paediatric intensive care,[27,28,30,40] no studies included in this review evaluated VRs effect on delirium or sleep as a primary outcome. None of the included articles utilised XR for the purposes of improving caregiver or healthcare professional health-related outcomes. The reporting quality of interventions was poor. The development of a customised TIDieR checklist specific for the use in XR may be of use to assist in standardising reporting in the future. Further research utilising head-to-head study designs, comparing various XR protocols are required to provide further insights into effectiveness of specific design parameters.

Limitations

Despite an extensive search strategy, a limited number of articles was identified within this scoping review. South Korea and China represent two of the three countries in which XR is currently being utilised within PICU. As a result, it is likely that this review has not identified articles written in their primary languages. Rapid increases in research within this field are likely to warrant further review within the near future.

Implications for Integration of XR in PICU

Virtual reality is a rapidly emerging tool for use in patients within the PICU setting. Its use as an education role in this setting is steadily increasing and is associated with positive results. While current evidence suggests VR is safe in PICU populations conjecture remains regarding the use of VR in some populations and in determining the specific role for this tool clinically. Currently, a lack of methodological rigour and head-to-head study designs prevents the identification of optimal VR prescription protocols.

Conclusion

While researchers, educators and clinicians are increasingly seeking to harness the advantages of XR to provide education and develop new interventions in PICU the use of XR in this clinical setting is still in its infancy. To support clinicians in exploring the potential application of XR applications clinical research needs to focus on increasing the understanding of XRs mechanisms, screening, and implementation strategies. To achieve this integrated, multidisciplinary research teams that include clinicians, researchers and industry partners are required. This collaboration will ensure that current gaps in policy, evidence and clinical expertise can be overcome, and that the expertise is available for continual refinement of technology and clinical protocols to provide meaningfully outcomes for PICUs patients and their families.

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Dr Adrian Goldsworthy was involved in the conceptualisation, protocol development, data extraction, data analysis and manuscript drafting and editing.

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Appendix 1: Search Strategies

PUBMED: (infant*[Title/Abstract] OR paediatric*[Title/Abstract] OR children*[Title/Abstract] OR adolescent[Title/Abstract] OR teen*[Title/Abstract] OR "Child"[Mesh] OR "Adolescent"[Mesh]) AND (ICU[Title/Abstract] OR "intensive care unit" [Title/Abstract] OR "intensive care" [Title/Abstract] OR "PICU" [Title/Abstract] OR "NICU" [Title/Abstract] OR "Respiratory Care Units"[Mesh] OR "Coronary Care Units"[Mesh] OR "Intensive Care Units, Pediatric"[Mesh]) AND ("Virtual reality"[Title/Abstract] OR "Augmented Reality" [Title/Abstract] OR "Mixed Reality" [Title/Abstract] OR "Extended Reality" [Title/Abstract] OR "Virtual Reality"[Mesh])

EMBASE: (infant*:ti,ab OR paediatric*:ti,ab OR children*:ti,ab OR adolescent:ti,ab OR teen*:ti,ab OR 'child'/exp OR 'adolescent'/exp) AND (ICU:ti,ab OR 'intensive care unit':ti,ab OR 'intensive care':ti,ab OR PICU:ti,ab OR 'intensive care unit'/exp OR 'coronary care unit'/exp OR 'pediatric intensive care unit'/exp) AND ('Virtual reality':ti,ab OR 'Augmented Reality':ti,ab OR 'Mixed Reality':ti,ab OR 'Extended Reality':ti,ab OR 'virtual reality'/exp)

CINAHL: ((TI infant* OR AB infant*) OR (TI paediatric* OR AB paediatric*) OR (TI children*OR AB children*) OR (TI adolescent OR AB adolescent) OR (TI teen* OR AB teen*) OR (MH "Child+") OR (MM "Adolescent Medicine") OR (MM "Adolescent Health") OR (MM "Adolescent Psychiatry") OR (MM "Adolescent Psychology") OR (MM "Adolescent, Hospitalized")) AND ((TI ICU OR AB ICU) OR (TI "intensive care unit" OR AB "intensive care unit") OR (TI "intensive care" OR AB "intensive care") OR (TI PICU OR AB PICU) OR (MM "Respiratory Care Units") OR (MH "Intensive Care Units+") OR (MM "Intensive Care Units, Neonatal") OR (MM "Coronary Care Units") OR (MH "Intensive Care Units, Pediatric+")) AND ((TI "Virtual reality" OR AB "Virtual reality") OR (TI" Augmented Reality" OR AB "Augmented Reality") OR (TI "Mixed Reality" OR AB "Mixed Reality") OR (TI "Extended Reality" OR AB "Extended Reality") OR (MH "Virtual Reality+"))

PsychInfo: (infant*.ti,ab. OR paediatric*.ti,ab. OR children*.ti,ab., OR adolescent.ti,ab. OR teen*.ti,ab. OR exp Child Health/ or exp Child Psychiatry/ or exp Child Psychology OR exp Adolescent Psychiatry/ or exp Adolescent Psychology/ or exp Adolescent Health/) and ((ICU or intensive care unit or PICU).ti,ab. OR exp Neonatal Intensive Care/ or exp Intensive Care/) and (((virtual reality) or (augmented reality) or (mixed reality)).ti,ab. or exp Virtual Reality/)

Google Scholar: (infant* OR paediatric* OR child* OR adolescent* OR teen*) AND (ICU OR "intensive care unit" OR "intensive care" OR PICU OR NICU) AND ("Virtual reality" OR "Mixed Reality" OR "Augmented Reality")

Appendix 2: Data extraction form

Author(s)	Published Year
Title	
Country	
Data Extraction Table 1	
Aim(s) / hypothesis / research question(s) of study	Aim 1: Research Question 1: Hypothesis 1:
Methodology	eg, Quantitative *(randomised control trial)*
Context / Setting	eg, Inpatient, Outpatient, Research facility
Use of XR (research / intervention / education)	
Participant details / characteristics	Group 1: N = x. M/F ratio: Condition(s)/Diagnosis/Medical history:
Risk of Bias	
Data Extraction Table 2	
AR / VR / MR	
Hardware	Brand: Model: Commercial Availability:
Software	Company: Software: Commercial Availability:
Protocol	Intervention 1: Frequency: Intervention description: Type: Time:
Outcomes	Primary Outcomes: Secondary Outcomes:

Key Findings

Data Extraction TIDieR Checklist		
Brief Name	1. Do the authors provide the name or a phrase that describes the intervention?	Yes complete Yes, incomplete No
Why	2. Do the authors describe any rationale, theory or goal of the elements essential to the intervention?	Yes complete Yes, incomplete No
What	3. Materials: Do the authors describe any physical or informational materials used in the intervention, including those provided to participants or used in intervention delivery or in training of providers, or provide information on where the materials can be accessed (online appendix or URL)?	Yes complete Yes, incomplete No
	4. Procedures: Do the authors describe each of the procedures, activities and/or processes used in the intervention, including any enabling or support activities?	Yes complete Yes, incomplete No
Who Provided?	5. For each category of intervention provider (psychologist and nursing assistant), describe their expertise, background and any specific training given?	Yes complete Yes, incomplete No
How?	6. Do the authors describe the modes of delivery (face-to-face or by some mechanism, such as internet or telephone) of the intervention and whether it was provided individually or in a group?	Yes complete Yes, incomplete No
Where?	7. Do the authors describe the type(s) of location(s) where the intervention occurred, including any necessary infrastructure or relevant features?	Yes complete Yes, incomplete No
When and How Much	8. Do the authors describe the number of times the intervention was delivered and over what period of time including the number of sessions, their schedule, and their duration, intensity, or dose?	Yes complete Yes, incomplete No
Tailoring	9. If the intervention was planned to be personalised, titrated, or adapted, do the authors mention so and then describe what, why, when and how?	Yes complete Yes, incomplete No N/A
Modifications	10. Do the authors mention if the intervention was modified during the course of the study, and if so, describe the changes (what, why, when, and how)?	Yes complete Yes, incomplete No N/A
How Well	11. Planned: If intervention adherence or fidelity was assessed, do they describe how and by whom, and if any strategies were used to maintain or improve fidelity, did the authors describe them?	Yes complete Yes, incomplete No N/A
	12.(If above answer was yes) Actual: If intervention adherence or fidelity was assessed, did the authors describe the extent to which the intervention was delivered as planned?	Yes complete Yes, incomplete N/A

Safety Considerations
Excluded populations
Safety specific protocols / considerations relating to XR
Side effects / complications relating to XR
Barriers and Facilitators to Implementation of XR
Barriers to Implementation of XR
Facilitators to Implementation of XR