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# Investigating the effects of augmented reality-based interventions on pediatric patient outcomes in the clinical setting: A systematic review

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A R T I C L E I N F O

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A B S T R A C T

*Background and aim:* Augmented reality (AR)-based interventions are increasingly being used in pediatric healthcare settings as non-pharmacological tools to reduce distress and improve patient outcomes. This review aimed to synthesize current evidence on the effectiveness, feasibility, and usability of AR interventions in improving physical, emotional, and psychological outcomes among pediatric patients.
*Methods:* A comprehensive literature search was conducted across six databases—PubMed, Cochrane Library, MEDLINE, Scopus, Web of Science, and CINAHL—for studies published up to December 12, 2024. Eligible studies included those evaluating AR-based interventions with outcomes related to physical, emotional, or psychological health. Two reviewers independently conducted data extraction and assessed methodological quality using the Joanna Briggs Institute critical appraisal tools. The review followed the PRISMA 2020 guidelines and was registered in PROSPERO (ID: CRD42025638915).
*Results:* The review included 14 studies involving 1057 children across diverse clinical settings such as surgery, oncology, dentistry, rehabilitation, and anesthesia induction. AR interventions were associated with reduced procedural pain and anxiety, improved cooperation and emotional comfort, increased knowledge acquisition, and enhanced satisfaction with care.
*Conclusion:* AR-based interventions show significant promise in improving pediatric patient experiences and outcomes across a variety of healthcare domains. However, current evidence is limited by small sample sizes, methodological variability, and short-term evaluations.
*Implication to practice:* AR-based interventions can enhance pediatric care by reducing pain and anxiety, improving cooperation, and increasing patient satisfaction. Their integration into clinical routines may support more positive healthcare experiences for children.


## Introduction

Hospitalization or emergency department visits can be profoundly distressing experiences for children, often involving not only physical discomfort but also significant psychological stress (Claridge et al., 2023). Separation from family members, exposure to unfamiliar surroundings, and undergoing painful or invasive medical procedures frequently lead to intense emotional reactions, including fear, anxiety, helplessness, and loneliness (Claridge et al., 2023; Correale et al., 2022). These negative emotions may interfere with a child's sense of security and disrupt their connection to their social environment, ultimately compromising treatment adherence and overall well-being (Or et al., 2025). Among the most frequently observed psychological and behavioral responses in hospitalized children are heightened anxiety, excessive crying, irritability, anger, and even aggression—each of which can adversely affect both immediate and long-term health outcomes (Goldsworthy et al., 2023; Günay, 2017; Yaldız & Şener, 2024). In response to these challenges, nonpharmacological interventions have gained growing recognition as essential components of holistic pediatric care (Pérez-Pozuelo et al., 2025). Evidence-based strategies such as distraction techniques, therapeutic play, and guided imagery are now widely implemented to mitigate procedural anxiety and enhance

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children's coping abilities during medical encounters (Moran & Wilson, 2024).

In recent years, immersive technologies like virtual reality (VR) and augmented reality (AR) have created new opportunities for distraction-based approaches in pediatric healthcare. These technologies help engage children's senses and support emotional control during medical procedures (Coşkun & Çiğdem, 2025; Ferraz-Torres et al., 2023; Hess et al., 2025). Immersive technology generally refers to digital systems that make users feel more involved by providing strong sensory experiences. While some researchers focus on how much or how high-quality the sensory input is (Slater, 2009), others highlight the way these technologies make the line between the real and virtual world less clear, creating a feeling of immersion (Lee et al., 2012). VR creates a completely virtual environment, while AR adds digital elements—like images, videos, or sounds—on top of the real world in real time (Tang et al., 2020). This allows users to stay aware of their surroundings while interacting with digital content. VR has been widely used around the world to reduce children's stress during medical procedures such as blood draws and port access (Gerçeker et al., 2021; Hundert et al., 2021; Menekli et al., 2022; Semerci et al., 2021). More recently, AR has become a promising alternative because it is easier to use in busy hospital settings and helps children stay engaged while still seeing what is around them (Arjomandi Rad et al., 2022; Mott et al., 2008; O'Connor et al., 2023a). AR has also been shown to capture children's attention, improve their experience in the hospital, and help them take part in their care. For example, Mott et al. (2008) found that AR reduced pain during burn dressing changes, especially when the procedures were longer. Similarly, Chamberland et al. (2024) reported that AR helped lower children's anxiety before surgery and was well accepted by patients. These findings suggest that AR can be a useful non-drug method to reduce distress during medical procedures.

Distraction techniques work by diverting the child's attention away from painful procedures and redirecting it toward an engaging task, thereby alleviating pain, anxiety, and fear (DeMore & Cohen, 2005). Given the growing interest of children in smartphones, tablets, and computer-based games, technology-driven interventions have increasingly gained prominence in pediatric healthcare settings (Kerimoglu Yildiz et al., 2022). In particular, the customizable, gamified, and remotely accessible features of AR position it as a sustainable and scalable tool, especially for children with limited access to conventional psychosocial support services (Dey et al., 2023). This systematic review aims to investigate the psychological and physiological effects of AR-based interventions on pediatric patients by synthesizing the existing evidence on their therapeutic effects on anxiety, pain, and behavioral responses, and to provide guidance for future research.

## Method

### *Study purpose*

This systematic review aims to investigate the effects of AR-based interventions on pediatric patient outcomes in clinical settings. This review aims to provide insights into how AR technology influences physical, emotional, and psychological outcomes among pediatric patients by synthesizing current evidence.

### *Study design*

The study design described by Booth et al. (2022) in Systematic Approaches to a Successful Literature Review follows a seven-step process of planning: defining the scope, searching, assessing, synthesizing, analyzing, and writing to identify gaps in the literature, and providing evidence for future research directions (Booth et al., 2022). Each step adheres to a specific methodology, outlined in Fig. 1. At the same time, the study also follows the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines to ensure methodological rigor and transparency (Page et al., 2021). Additionally, the protocol for this systematic review was registered in the International Prospective Register of Systematic Reviews (PROSPERO) under the registration number CRD42025638915.

### *Step 1 planning*

The planning phase is the initial step to carry out a systematic literature review, as shown in Fig. 1. For this systematic literature review, six databases were searched: PubMed, Web of Science, Cochrane, MEDLINE, CINAHL, and Scopus. These databases were chosen based on their relevance to the research topic and comprehensive coverage of healthcare and clinical studies. The reference management software utilized was EndNote (version 21.5) and Covidence, chosen for their advanced features, including robust organization tools, seamless collaboration capabilities, and integration with systematic review processes. These tools facilitated efficient reference management and ensured accurate citation throughout the review process.

### *Step 2 defining the scope*

Defining the scope is essential to properly formulate answerable research questions. This process was actualized through an iterative approach involving (i) initial brainstorming, (ii) a comprehensive literature search, and (iii) the application of the PICOS (Population, Intervention, Comparison, Outcome, and Study Design) framework. As a result of the brainstorming and literature search, relevant review articles and key studies on AR in healthcare were identified. The PICOS framework was then applied to define the key concepts for this review (Table 1).

Based on these considerations, the following research questions were formulated to guide the review:

Q1: How do augmented reality-based interventions affect physical outcomes in pediatric patients in clinical settings?

Q2: How do augmented reality-based interventions impact emotional and psychological well-being in pediatric patients in clinical settings?

Q3: What are the characteristics of augmented reality-based interventions used for pediatric patient care?

### *Step 3 searching*

The searching phase involved systematically browsing the databases identified during the planning stage (Step 1) using a predefined search strategy. The search strings were developed based on the research questions and key concepts outlined in Section 0, ensuring the inclusion of relevant studies. The following search strings were employed: #1: "Augment* reality"[Title/Abstract] OR "Augmented Reality"[Mesh]; #2: ("pediatric"[Title/Abstract] OR pediatr*[Title/Abstract] OR "child"[Title/Abstract] OR children [Title/Abstract] OR peadiatrics[Title/Abstract]) OR ("Pediatrics"[Mesh] OR "Child"[Mesh]).

Boolean operators, such as "AND" were used to refine the search and link the key concepts of augmented reality and pediatric healthcare. These strings were applied separately across the six databases: PubMed, Web of Science, Cochrane, MEDLINE, CINAHL, and Scopus. The search was conducted with the support of a librarian for studies published up to December 12, 2024.

### *Step 4 assessing*

The assessing phase aims to refine the list of documents retrieved during the searching phase by applying inclusion and exclusion criteria to identify studies most relevant to answering the research questions. Titles and abstracts were screened independently by two reviewers to assess eligibility according to the inclusion criteria. The inclusion and exclusion criteria used in this step were designed to ensure the selection of high-quality, focused studies.

*The inclusion criteria* for the study were as follows: studies conducted in clinical settings, studies involving pediatric patients, studies measuring health outcomes (e.g., physical, emotional, or psychological), studies

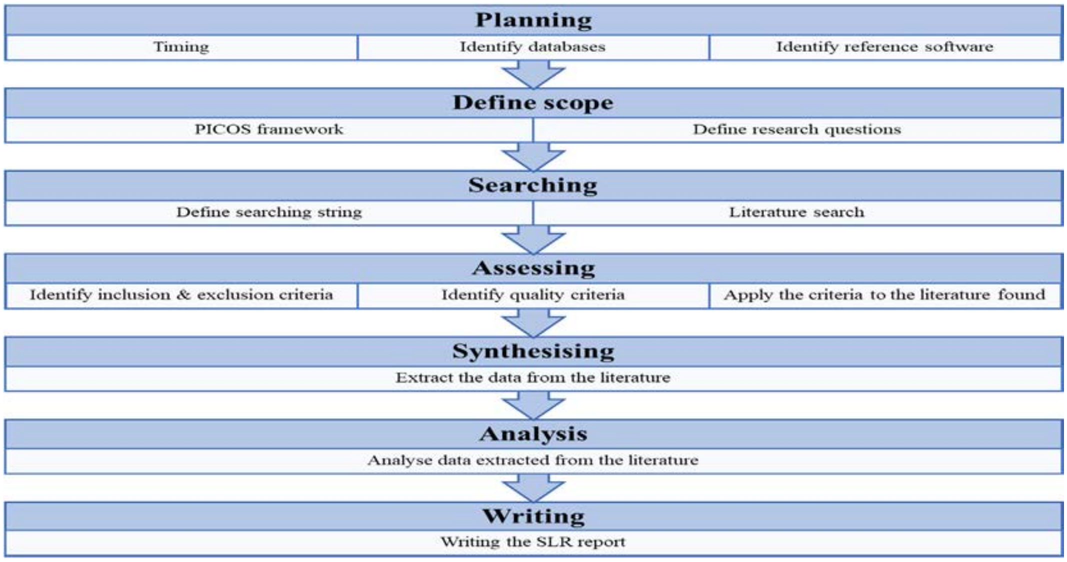


**Fig. 1.** Systematic Literature Review Steps.

available in full text and published in English, and studies published up to December 12, 2024.

*The exclusion criteria* were studies conducted in school settings, studies involving children with neurological disorders or those focused on clinical diagnosis, studies prioritizing educational outcomes instead of health outcomes, and protocol studies, gray literature, systematic reviews, meta-analyses, conference papers, and abstracts.

These criteria were applied to the documents found in the six databases listed in Step 1. Initial screening was conducted using the search tools provided by each database to exclude studies that did not meet the inclusion criteria. Titles and abstracts of the remaining studies were reviewed to refine the list of documents further. Full-text articles were reviewed independently by two reviewers for the introduction, methods, and results sections to confirm their relevance and compliance with the criteria. Any discrepancies between the reviewers were resolved through discussion and consensus to ensure the reliability of the selection process. After applying these criteria, a total of 14 studies were selected for further analysis, as shown in Fig. 2.

*Quality Assessment*: To assess the quality of the included studies, the Joanna Briggs Institute Meta-Analysis of Statistics Assessment and Review Instruments (JBI-MAStARI) was employed for randomized controlled trials (RCTs), quasi-experimental study (Barker et al., 2024). The JBI critical appraisal checklist for RCTs consisted of 13 questions, and the quasi-experimental studies checklist comprised nine questions. Each question was answered as 'Yes,' 'No,' 'Unclear,' or 'Not Applicable,' and 1 point was assigned for each applicable item. RCTs could receive a maximum score of 13, and quasi-experimental studies could receive a maximum score of nine. Two independent reviewers conducted the quality assessment and assigned a risk of bias grade to each study, with disagreements resolved through discussion or consultation with a third reviewer. The quality assessment results and risk of bias grading are detailed in File S1 and File S2.

*Step 5 synthesizing and analyzing*

To address the research questions, the included studies were systematically analyzed and synthesized. Data extraction was carried out independently by two authors using Microsoft Excel® to ensure consistency and accuracy. The extracted data were then reviewed by the entire research team, and any discrepancies were resolved through consensus. This process focused on the 14 articles identified through the systematic literature review, ensuring that only these selected articles directly influenced the results presented in Section 3 (Fig. 2). While the included studies formed the primary basis of the analysis, other relevant studies were occasionally referenced to provide additional context and enhance the reader's understanding of the topic. Table 2 categorizes the studies into columns based on key characteristics of AR-based interventions. These columns include the author, year, country; study design; study sample; setting and condition (if applicable); intervention; outcome; assessment tools; and conclusion. This organization highlights critical details such as the study population, clinical context, the specific intervention utilized, measured outcomes (e.g., pain reduction, anxiety relief, or procedural success rates), and the tools used for assessment. The structured format provides a comprehensive overview of the studies in the review, facilitating the synthesis and analysis of findings.

## Results

### *Study identification and study selection*

The database search yielded 1761 studies. First, after eliminating duplicates ($n = 887$), we screened the remaining 873 studies for titles and abstracts. Following this, 48 studies were selected for full-text review based on the inclusion criteria. Upon further evaluation, 34 studies were excluded due to various reasons such as wrong study design

**Table 1**
PICOS Frameweork.

| Acronym | Definition | Inclusion Criteria | Exclusion Criteria |
|---|---|---|---|
| P | Population | Pediatric patients | Newborn and adult patients |
| I | Intervention | Augmented reality | Other intervention |
| C | Comparative Controls | Standard care | None |
| O | Outcomes | Physical, emotional, and psychological outcomes | Educational outcomes |
| S | Study Design | RCT, quasi-experimental study, | Systematic review, meta-analysis, congress paper, gray literature, abstract |

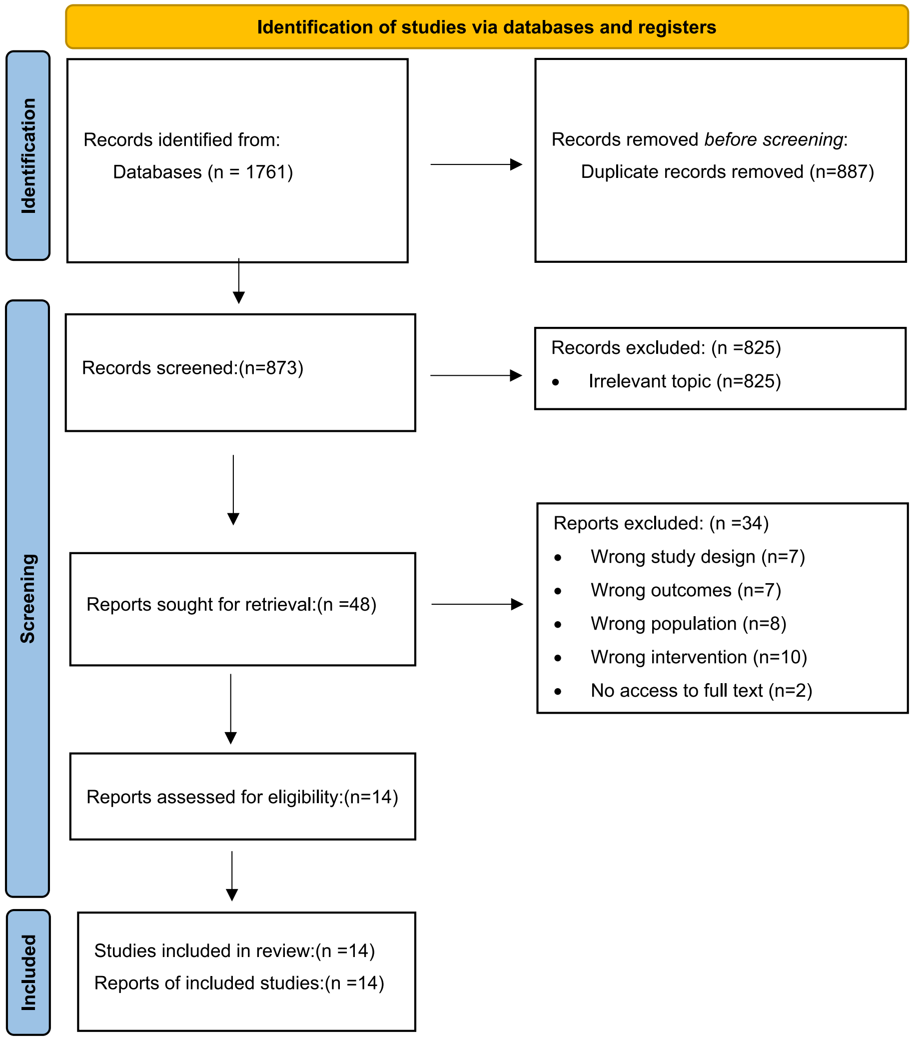


**Fig. 2.** PRISMA flow diagram.

($n = 7$), wrong outcomes (n = 7), wrong population (n = 8), wrong intervention ($n = 10$), and lack of access to full text ($n = 2$). Finally, 14 studies met the eligibility criteria and were included in the systematic review (Fig. 2).

*Study characteristics*

A total of 14 studies published between 2008 and 2024 were included in the review. The studies involved a combined sample of 1057 pediatric patients across various medical conditions, with sample sizes ranging from 15 to 511 participants. Among these studies, three were conducted in the USA (Cata et al., 2022; Connelly et al., 2023; Yun et al., 2024) and three in Australia (Mott et al., 2008); O'Connor et al., 2023a; O'Connor et al., 2023b). The remaining studies were conducted in Spain (Calle-Bustos et al., 2017), Peru (Alarcón-Yaquetto et al., 2021), Indonesia (Megasari et al., 2024), Canada (Chamberland et al., 2024), Korea (Youn et al., 2022), Iran (Khamees et al., 2024), India (Deshmukh et al., 2024), Turkey (Yucel et al., 2023), and United Kingdom (Bray et al., 2024).

In terms of study design, four studies were randomized controlled trials (RCTs) (Chamberland et al., 2024; Khamees et al., 2024; Mott et al., 2008; Yucel et al., 2023), and two employed quasi-experimental designs (Calle-Bustos et al., 2017; Megasari et al., 2024). One study was a randomized cross-over trial (Alarcón-Yaquetto et al., 2021), and another used a prospective matched case-control design (Yun et al., 2024). The remaining studies included a prospective observational study (Youn et al., 2022), a feasibility RCT (Cata et al., 2022), a mixed-methods study (Connelly et al., 2023), a development and usability study (O'Connor et al., 2023a), a qualitative study (O'Connor et al., 2023b), a pilot trial (Deshmukh et al., 2024), and an exploratory cohort study (Bray et al., 2024).

*Intervention characteristics*

All included studies investigated the effects of AR-based interventions on pediatric patient outcomes in clinical settings, each using a different approach. Mott et al. (2008) used an animated 3D character called 'Hospital Harry' to engage children during burn dressing changes. Cata et al. (2022) implemented a digital AR-based treasure hunt game to support postoperative pain management in pediatric cancer patients. Yun et al. (2024) investigated the use of Dream Glass, an AR headset, to improve mask acceptance during anesthesia induction. Mask acceptance referred to a child's level of cooperation and emotional response when an anesthesia mask is applied before induction of anesthesia. Megasari et al. (2024) used 3D modeling AR technology combined with cold vibration to reduce anxiety during intravenous procedures. Furthermore, AR books were used by Alarcón-Yaquetto et al. (2021) to increase engagement and reduce emotional stress among hospitalized children. Four studies focused on AR-enabled smartphone or tablet applications to deliver educational or preparatory content (Bray et al.,

**Table 2**
A summary of research studies included in the review.

| Author, year, and country | Study design | Study sample | Setting and condition (if aplicable) | Intervention | Outcome | Assessment Tools | Conclusion |
|---|---|---|---|---|---|---|---|
| Mott et al., 2008, Australia | RCT | Forty-two children with an age range of 3.5–14 years | Hospital, burns dressing changes | Hospital Harry | Pain | FLACC<br>FPS-R<br>VAS | Mean pain scores were significantly lower in the AR groups compared to the control group. |
| Cata et al., 2022, USA | A feasibility RCT | Nineteen children with a confirmed diagnosis of solid malignant tumors requiring surgery, age 3–18 years | Hospital, surgery | Scavenger hunt ARISE™ | Postoperative acute pain management<br>Rate of opioid use<br>Quality of life | PedsQL™<br>Wong-Baker Faces Pain Rating Scale | Delivering an augmented reality-enabled scavenger hunt game is feasible in the postoperative setting for pediatric patients with cancer. A larger RCT will determine the efficacy of the augmented reality digital scavenger hunt game on postoperative pain intensity, opioid use, and quality of life after pediatric cancer surgery. |
| Yun et al., 2024, USA | A Prospective, Matched Case-Control Study | Fifty pediatric patients greater than 4 years | Hospital, elective procedures requiring general anesthesia | Dream Glass | Mask acceptance<br>Emergent delirium | MAS<br>Watcha Scale | AR during mask induction improved mask acceptance compared to SOC. No relationship was observed between AR and cooperation or ED. |
| Megasari et al., 2024, Indonesia | Quasi-experimental study | 60 children aged 6–14 years | Hospital, during intravenous insertion | 3D modeling<br>AR | Anxiety | Child Anxiety Meter | The application of augmented reality and cold vibration can be considered as non-pharmacological therapy to reduce anxiety. |
| Alarcón-Yaquetto et al., 2021, Peru | RC-OT | Twenty-nine hospitalized children aged 7–11 years | Hospital | Augmented reality books | Salivary cortisol levels<br>Emotional stress | Salivas were transferred to a cryogenic vial using a transfer pipette<br>A visual analog test or Weisz test | Cortisol levels decreased after the AR intervention. Nevertheless, the decrease was not greater than the one associated to reading the standard book. VAS scores increased after the AR intervention. |
| O'Connor et al., 2023a, Australia | Development and Usability Study | Sixteen participants aged 8–17 years | Hospital | AR-enabled smartphone or tablet app to deliver asthma inhaler technique education | Participants' previous experiences with asthma and asthma education<br>Data usability | System Usability Scale<br>One-on-one interviews | Participants mainly had favorable views of the AR intervention.<br>The intervention was also found to have excellent perceived usability. |
| Chamberland et al., 2024, Canada | RCT | One hundred one pediatric patients aged 5 and 17 years | Hospital, elective day surgery under general anesthesia | The animation follows the story of a character named Constellation, through Microsoft HoloLens 2 glasses | Preoperative anxiety | Yale Preoperative Anxiety | Anxiety scores were statistically significantly lower in the augmented reality group than those in the control group at the time of admission, while no difference was observed between groups at the time of induction. |
| Calle-Bustos et al., 2017, Spain | Quasi-experimental study | 70 children with diabetes aged 5–14 years | Hospital, therapeutic education for children with diabetes | AR game to support therapeutic education | Knowledge of carbohydrate choices | Pre-knowledge and post-knowledge questionnaires | The AR game effectively improved children's knowledge of carbohydrate choices and was well received in terms of usability and satisfaction. |
| O'Connor et al., 2023b, Australia | Qualitative study | Sixteen participants (six healthcare professionals, five children with asthma, and five caregivers of children with asthma) | Hospital | AR to enhance asthma inhaler technique education | Previous experiences with asthma education, the use of smartphone and tablet apps for health, and AR | Semi-structured one-on-one interviews | AR was an acceptable modality for delivering asthma education to children, caregivers, and healthcare professionals. |
| Connelly et al., 2023, USA | Mixed-methods study | Fifteen youths aged 10–17 years with migraine | Hospital | XR relaxation training with and without wearable neurofeedback (three conditions: immersive virtual reality without neurofeedback, immersive virtual reality with neurofeedback, augmented reality with neurofeedback) | Acceptability and side effect | Acceptability and side effect questionnaires | AR group received lower acceptability ratings than the immersive VR, with participants citing challenges such as reduced engagement, difficulty maintaining focus, and discomfort from holding the device during sessions. |

(continued on next page)

**Table 2** (*continued*)

| Author, year, and country | Study design | Study sample | Setting and condition (if aplicable) | Intervention | Outcome | Assessment Tools | Conclusion |
|---|---|---|---|---|---|---|---|
| Khamees et al., 2024, Iran | RCT | Seventy-two children aged 8–14 years with hand burns | Hospital, rehabilitation | AR-based rehabilitation using an educational booklet with AR application to guide hand exercises | Hand function | JHFT | Significant improvement in hand function in the AR intervention group compared to the control group, with a greater reduction in the time needed to complete the Jebsen-Taylor Hand Function Test |
| Deshmukh et al., 2024, India | A Pilot Trial | Thirty-two children aged 6–8 years | Dental College & Hospital | AR-assisted toothbrushing with a sensor-based toothbrush | Oral hygiene improvement | Modified Quigley Hein Plaque Index Loe & Silness Gingival Index | The AR-assisted brushing group showed a significant improvement in oral hygiene, with a notable reduction in plaque and gingival bleeding scores compared to the conventional group. |
| Yucel et al., 2023, Turkey | RCT | 511 pediatric patients aged 6–14 years | Private dental clinic | AR exposure through an interactive AR application | Pediatric dental anxiety | Turkish version of Corah's DAS | The preoperative use of AR was effective in alleviating dental anxiety among pediatric patients, demonstrating its potential as a distraction technique in dental settings. |
| Lucy Bray et al., 2024, UK | Exploratory cohort study | Twenty-four children aged 6–14 years, 24 parents, six health professionals | Hospital, planned blood tests | Xploro app | Children's understanding and anxiety regarding blood tests | Paper data collection booklets with qualitative and quantitative questions | Xploro was found to be an acceptable and feasible intervention to prepare children for blood tests, improving their experience and understanding. |

RCT: Randomized controlled trial, FLACC: Face Legs Activity Cry Consolability, FPS-R: Faces pain scale-revised, VAS: Visual analog scale, PedsQL: Pediatric quality of life inventory, SOC: standard-of-care, ED: Emergent delirium, MAS: Mask Acceptance Scale, AR: Augmented reality, RC-OT: Randomized cross-over trial, DIVA: Difficult Intravenous Access, XR: Extended reality, JHFT: Jebsen-Taylor Hand Function Test, DAS: Dental Anxiety Scale.

2024; Calle-Bustos et al., 2017; O'Connor et al., 2023a; O'Connor et al., 2023b). Chamberland et al. (2024) presented an AR animation following the story of a character named ‘Constellation’ to alleviate preoperative anxiety. Connelly et al. (2023) examined the integration of AR with neurofeedback techniques to support relaxation training in pediatric migraine management. Khamees et al. (2024) applied AR-based rehabilitation to improve hand function in children with burns, while Deshmukh et al. (2024) evaluated an AR-assisted toothbrushing system aimed at improving oral hygiene. Finally, Yucel et al. (2023) investigated the effects of an interactive AR application designed to reduce preoperative dental anxiety in children. Further details on the content and characteristics of each intervention are provided in Supplementary File S1, 2 & 3.

### *Measurement tools used in the studies*

The included studies used a variety of patient outcomes and measurement tools for the outcomes of AR-based interventions. Pain management outcomes were assessed using the FLACC scale, FPS-R, VAS, and PedsQLTM in one study (Mott et al., 2008), while another study evaluated pain with the Wong-Baker Faces Pain Rating Scale (Cata et al., 2022). Mask acceptance was measured using the Mask Acceptance Scale and the Watcha Scale in one study (Yun et al., 2024). Anxiety was assessed across different studies using the Child Anxiety Meter (Megasari et al., 2024), the Yale Preoperative Anxiety Scale (Chamberland et al., 2024), and the Turkish version of Corah's Dental Anxiety Scale (Yucel et al., 2023). Quality of life was evaluated using PedsQLTM in the same study that assessed pain management with the Wong-Baker Faces Pain Rating Scale (Cata et al., 2022). Emotional stress was examined using the Weisz test, and salivary cortisol levels were measured through cryogenic vial collection with a transfer pipette in the same study (Alarcón-Yaquetto et al., 2021). Knowledge levels were assessed in four studies through self-designed questionnaires and semi-structured interviews (Calle-Bustos et al., 2017; Connelly et al., 2023; O'Connor et al., 2023a; O'Connor et al., 2023b). Hand function was evaluated using the Jebsen-Taylor Hand Function Test in one study (Khamees et al., 2024), while another study assessed oral hygiene improvement using the Modified Quigley Hein Plaque Index and the Loe & Silness Gingival Index (Deshmukh et al., 2024). Lastly, children's understanding and anxiety regarding blood tests were assessed in one study using paper data collection booklets with qualitative and quantitative questions (Bray et al., 2024).

### *Effects of AR-based interventions on pediatric patients' outcomes*

The included studies explored the effects of AR-based interventions on a wide range of pediatric outcomes across various clinical settings. Several studies reported positive effects on pain management. For example, Mott et al. (2008) demonstrated a significant reduction in pain scores among children undergoing burn dressing changes. Similarly, Cata et al. (2022) found that an AR-based scavenger hunt was a feasible and promising tool for managing postoperative pain and reducing opioid use in pediatric cancer patients. Anxiety and emotional distress were also key outcomes assessed across the studies. Yun et al. (2024) reported improved mask acceptance during anesthesia induction with the use of an AR headset, though no significant impact was observed on cooperation or emergence delirium. Megasari et al. (2024) highlighted the effectiveness of combining AR with cold vibration therapy in reducing procedural anxiety during intravenous insertions. Chamberland et al. (2024) found that AR significantly lowered preoperative anxiety scores at the time of hospital admission, although this effect did not persist at the time of anesthesia induction. Alarcón-Yaquetto et al. (2021) observed decreased salivary cortisol levels and emotional stress after AR book use, though these reductions were comparable to those achieved with standard reading materials. AR-based tools were also evaluated for their educational value and usability.

O'Connor et al. (2023a, 2023b) concluded that mobile AR applications for asthma education were highly usable and acceptable among children, caregivers, and healthcare professionals. Similarly, Calle-Bustos et al. (2017) found that AR-based games significantly improved children's knowledge of carbohydrate choices in diabetes education, accompanied by high user satisfaction. Bray et al. (2024) reported that the AR-based Xploro app was a useful and engaging self-directed tool to help children prepare for planned blood tests, improving both understanding and overall experience. Other applications of AR focused on functional outcomes. Khamees et al. (2024) demonstrated that AR-based rehabilitation significantly improved hand function and reduced task completion time in children with hand burns. Deshmukh et al. (2024) found significant improvements in oral hygiene among children using an AR-assisted toothbrushing system, including reductions in plaque and gingival bleeding. In the dental setting, Yucel et al. (2023) showed that AR effectively alleviated preoperative anxiety, reinforcing its value as a distraction technique. In contrast, Connelly et al. (2023) reported lower acceptability of AR-based neurofeedback interventions compared to immersive VR, with participants citing reduced engagement and physical discomfort during use.

*Quality assessment/ level of methodological quality*

Among the seven RCTs, quality scores ranged from 69.23 % to 84.61 %, indicating moderate to high methodological rigor. The studies by Alarcón-Yaquetto et al. (2021) and Deshmukh et al. (2024) received the highest scores (84.61 %), demonstrating strong adherence to methodological standards (Alarcón-Yaquetto et al., 2021; Deshmukh et al., 2024). However, several RCTs exhibited limitations, particularly in blinding of participants and outcome assessors, and in allocation concealment. The other studies demonstrated a wider range of quality scores, from 44.44 % to 100 %. Megasari et al. (2024) were rated highest (100 %), reflecting a robust study design, while studies by O'Connor et al. (2023a, 2023b) and Bray et al. scored lower due to a lack of control groups and limited reporting on measurement reliability (Bray et al., 2024; Megasari et al., 2024; O'Connor et al., 2023a; O'Connor et al., 2023b).

## Discussion

This systematic review aimed to evaluate the effectiveness, feasibility, and usability of AR interventions in improving clinical and psychosocial outcomes among pediatric patients across various healthcare settings. The review synthesized evidence from diverse clinical contexts, including perioperative care, oncology, dentistry, rehabilitation, and chronic disease education. The findings suggest that AR-based interventions are generally effective in reducing pain and anxiety in children undergoing invasive or distressing procedures. Consistent with our findings, Berenguer et al. (2020) reported the effectiveness of augmented reality-based treatments for promoting, supporting, and protecting health and well-being in children and adolescents. Similarly, in the systematic review conducted by Masmuzidin et al. (2022), it was stated that AR-based interventions can be used to increase children's learning performance, motivation, and interest. Such technological interventions stand out as attention-grabbing and motivating tools, especially for the pediatric population. Children's developmental characteristics, sensitivity to visual and auditory stimuli, their predisposition to game-based approaches, and their natural interest in technology make them more interested and eager for AR-based applications. The studies included in the review also support this situation; it is seen that AR-based interventions are generally found to be effective and acceptable in children of different age groups and genders. This flexibility allows AR technologies to be applied in a wide pediatric spectrum, while increasing emotional relief and cooperation with the capacity to attract children's attention and ensure their participation in the process. Thus, AR-based interventions have the potential to increase the effectiveness of pediatric healthcare services. However, while the overall usability and acceptability of AR tools were reported to be high, particularly among children and caregivers, some studies noted technical limitations and usability concerns, especially in interventions involving wearable devices or neurofeedback components. Similarly, Levit et al. (2025) emphasized that although immersive technologies like AR and VR show promise in reducing pain and anxiety and improving satisfaction during minor procedures, the current body of evidence is limited by small sample sizes, inconsistent findings, and variability in the design and application of interventions. Moreover, evidence supporting the use of AR/VR in the context of major surgical procedures remains scarce and warrants further investigation. Taken together, these findings highlight both the promise and current limitations of AR interventions in pediatrics and highlight the clear need for more robust, standardized, and large-scale research to identify best practices and expand their integration into clinical care.

The findings of this review highlight the multifaceted impact of AR-based interventions across a range of outcome domains in pediatric healthcare. Each domain provides evidence on how AR technologies can support a wide range of clinical and psychosocial outcomes for children. One of the most consistently reported effects was the reduction of pain and procedural anxiety, particularly during invasive or distressing interventions such as venipuncture, dressing changes, or preoperative preparation. These results are largely attributed to AR's capacity to redirect attention through immersive and multisensory interaction, which is consistent with established distraction-based pain modulation mechanisms. Numerous studies in the literature report that interventions such as AR and VR reduce negative emotions experienced during painful procedures through distraction (Gerçeker et al., 2021; Mott et al., 2008; Savaş et al., 2024). Additionally, beyond symptom control, AR interventions have also contributed to increased emotional comfort and cooperation. Children exposed to AR-based tools (whether through gamified preparation, interactive storytelling, or educational simulations) demonstrated higher levels of engagement and were more likely to voluntarily participate in clinical procedures. This is also consistent with the findings of Caruso et al. (2021), who demonstrated that using AR during pediatric otolaryngologic procedures reduced fear, improved compliance without restraint, and was highly rated by children, caregivers, and clinicians alike. The impact of AR on emotional engagement have also been noted in the study by López-Faican and Jaen (2020), who found that the multiplayer mobile augmented reality game EmoFindAR triggered positive emotions such as enthusiasm, curiosity, and fun in primary school children, while also improving communication, cooperation, and emotional intelligence through both competitive and collaborative game modes. These emotional regulations and increased collaborations not only benefit the child but also contribute to smoother clinical workflows and reduced procedural time.

It is not always easy to include children in pediatric clinical settings, but involving children in the process through methods that interest them, such as play and proper communication, is crucial for clinical functioning, caregiver workload and stress, and most importantly, for the clinical perception experienced by the child. This situation is also consistent with the findings of our study, where AR is used in the field of motor and functional rehabilitation by embedding it in interactive games or visual feedback systems to increase the effectiveness of therapeutic exercises. This approach encourages active participation, repetition, and motivation, which are critical factors for pediatric rehabilitation compliance and outcomes. Again, according to the included studies, AR tools consistently contributed to increased participation, enjoyment, and satisfaction with the healthcare experience. Children reported greater satisfaction with care when AR was used, and caregivers and providers found these tools to be useful in improving overall interaction and mood during care encounters. In our study, AR was also shown to facilitate knowledge acquisition and positive health behaviors. Several studies included in this review applied AR in health education contexts, such as teaching children about asthma, oral hygiene, or surgical preparation. These interventions can be interpreted as improving children's understanding, recall, and compliance by making abstract medical concepts more concrete and memorable. Many studies in the literature also use AR interventions for educational purposes. These findings are consistent with a growing body of literature supporting the use of immersive technologies in pediatric populations. For example, Privorotskiy et al. (2022) showed that AR can significantly reduce preprocedural anxiety in children and provide a noninvasive alternative to pharmacological sedation. Levit et al. (2025) similarly concluded that evidence from randomized controlled trials supports the effectiveness of immersive technologies such as AR and VR in minimizing procedural pain, reducing anxiety, and improving patient satisfaction, especially during minor procedures. Additionally, in their systematic review, Umaç and Semerci (2023) found that VR-based interventions used as non-pharmacological tools in pediatric healthcare were effective in significantly reducing both pain and anxiety, highlighting the broader benefit of immersive technologies in improving child-centered care. Given these findings, it is clear that integrating age-appropriate, interactive technologies such as augmented reality can play an important role in addressing the emotional and procedural challenges faced by pediatric patients. Recognizing the specific clinical contexts in which AR is most effective (such as preprocedural preparation, health education, or rehabilitation) is important to maximize its therapeutic benefit. Personalized approaches that align AR content with children's developmental levels, interests, and medical needs may further improve engagement and clinical outcomes. Future studies should focus on standardizing intervention protocols, identifying the most susceptible patient groups, and exploring how AR can be implemented sustainably across healthcare settings to support child-centered, technology-enabled care.

### *Limitations*

Despite the encouraging findings, this review has several limitations. Only studies published in English were included, which may have introduced language bias and excluded relevant data from non-English sources. Additionally, significant heterogeneity in intervention design, outcome measures, and clinical settings among included studies limited the ability to conduct a meta-analysis. Additionally, some studies lacked control groups or blinding, which may have impacted the robustness of their findings. Future studies with standardized protocols, validated outcome measures, and larger sample sizes are needed to strengthen the evidence base for AR interventions in pediatric healthcare.

## Conclusion

AR is an emerging and increasingly utilized tool in pediatric healthcare, offering promising benefits across clinical and psychosocial domains. This systematic review demonstrates that AR interventions are generally effective in reducing procedural pain and anxiety, enhancing emotional comfort and cooperation, promoting health-related knowledge, and supporting motor and functional rehabilitation. Despite these benefits, the variability in intervention design, outcome measures, and methodological quality limits the generalizability of current findings. Additionally, while most AR tools have been found acceptable and engaging due to their interactive and playful nature, ethical considerations must not be overlooked, particularly when working with children, a highly vulnerable population. Future AR interventions must be carefully designed to ensure age-appropriate, non-distressing content that aligns with children's developmental stages. Excessive sensory stimulation should be avoided to protect emotional well-being, and content should be culturally sensitive and inclusive. Moreover, disparities in access to AR-compatible devices and reliable internet may disproportionately affect children from socioeconomically disadvantaged backgrounds. Ensuring equitable access, alongside the use of standardized protocols and validated assessment tools, is essential for advancing AR as a safe, ethical, and effective component of child-centered care.

## CRediT authorship contribution statement

**Eyşan Hanzade Savaş:** Writing – review & editing, Writing – original draft, Data curation, Conceptualization. **Adnan Batuhan Coşkun:** Writing – review & editing, Writing – original draft, Data curation, Conceptualization. **Erhan Elmaoğlu:** Writing – review & editing, Writing – original draft, Methodology, Conceptualization. **Remziye Semerci:** Writing – review & editing, Writing – original draft, Supervision, Methodology, Conceptualization. **Nejla Canbulat Şahiner:** Writing – review & editing, Writing – original draft, Supervision, Methodology, Data curation, Conceptualization.

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## Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

## Appendix A. Supplementary data

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