CEP Clin Exp Pediatr Vol. 67, No. 2, 92-103, 2024
https://doi.org/10.3345/cep.2022.00731

Original article

Virtual, augmented, and mixed reality: potential clinical and training applications in pediatrics

Suyoung Yoo, BS[1], Meong Hi Son, MD[1,2]

[1]Department of Digital Health, Samsung Advanced Institute for Health Sciences and Technology (SAIHST), Sungkyunkwan University, Seoul, Korea; [2]Department of Emergency Medicine, Samsung Medical Center, Sungkyunkwan University School of Medicine, Seoul, Korea

Background: COVID-19 pandemic has significantly impacted the field of medical training, necessitating innovative approaches to education and practice. During this period, the use of novel technologies like virtual reality (VR), augmented reality (AR), and mixed reality (MR) has become increasingly vital. These technologies offer the advantage of transcending the limitations of time and space, thus enabling medical professionals to access various personalized programs for both education and service delivery. This shift is particularly relevant in the realm of pediatric medicine, where traditional training and clinical methods face unique challenges.

Purpose: The primary aim of this study is to explore the application of VR, AR, and MR technologies in pediatric medical settings, with a focus on both clinical applications and the training of pediatric medical professionals. We aim to comprehensively search and review studies that have utilized these technologies in the treatment of pediatric patients and the education of healthcare providers in this field.

Methods: Peer-reviewed articles published in PubMed, the Cochrane Library, ScienceDirect, Google Scholar, and Scopus from January 1, 2018, to March 1, 2023, were comprehensively searched. The review was conducted according to the PRISMA (Preferred Reporting Items for Systematic review and Meta-Analyses) guidelines. Among the 89 studies, 63 investigated the clinical applications of VR (n=60) or AR (n=3) in pediatric patients, and 25 investigated the applications of VR (n=19), AR (n=5), or MR (n=1) for training medical professionals.

Results: A total of 36 randomized controlled trials (RCTs) for clinical application (n=31) and medical training (n=5) were retrieved. Among the RCTs, 21 reported significant improvements in clinical applications (n=17) and medical training (n=4).

Conclusion: Despite a few limitations in conducting research on innovative technology, such research has rapidly expanded, indicating that an increasing number of researchers are involved in pediatric research using these technologies.

Key words: Virtual reality, Augmented reality, Application, Education

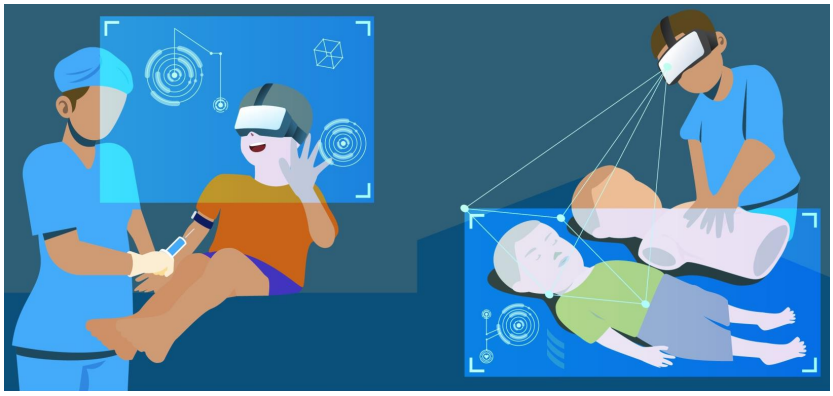
Key message

- Review of articles that investigated the applications of virtual, augmented, or mixed reality in pediatric clinical settings and in the training of pediatric medical professionals was conducted.
- A total of 89 studies were retrieved, with 36 randomized controlled trials.
- In most studies, intervention using the novel technology was at least as effective or more effective than the traditional method.
- Use of virtual, augmented, and mixed reality has potential in pediatrics.

Introduction

In the healthcare industry, virtual reality (VR), augmented reality (AR), and mixed reality (MR) are being extensively used for various purposes.[1)] Digital technology, with its pervasive use and relentless advancement, is considered a promising source of effective and efficient training and education for health professionals.[2)] In particular, the integration of digital strategies has led to a paradigm shift in healthcare education.[3)] Furthermore, the research results demonstrate the ability of VR, AR, and MR to ameliorate the inconveniences often associated with traditional medical care; reduce the number of incidents of medical malpractice caused by unskilled operations, and decrease the cost of medical education and training.[4)] Moreover, higher

Corresponding author: Meong Hi Son, MD. Department of Emergency Medicine, Samsung Medical Center, Sungkyunkwan University School of Medicine, 81, Irwon-ro, Gangnam-gu, Seoul 06351, South Korea
✉ Email: meonghison@gmail.com, https://orcid.org/0000-0002-3505-5576
Received: 20 May 2022, Revised: 9 May 2023, Accepted: 18 May 2023



Graphical abstract. The review includes the applications of new technologies for medical services targeting pediatric patients and training methods for medical professionals. There are programs designed to reduce children's pain, anxiety, and fear during in-hospital treatment (left), and medical staff's education for child patients (right).

Table 1. PICOS (population, intervention, comparison, outcome, study design) framework[70]

PICOS	Description	Inclusion	Exclusion
Population	Pediatric patients who received nontraditional care through technologic devices, health professionals who received nontraditional training through technologic devices	Patients – infant, child, adolescent Health professionals- physicians, nursing and midwifery professionals, medical or nursing students	
Intervention	VR, AR, or MR	All types of devices based on VR, AR, or MR	
Comparison	Modern vs. traditional methods for medical education to evaluate effectiveness of VR, AR, and MR tools	Books, pen and paper, chalkboard, face-to-face teaching, traditional lectures	
Outcome	The primary purpose of the study is maintaining or improving health condition of patients or improving training outcomes of medical personals	Concrete learning outcome/evaluation of effectiveness in learning or progress in professionals. The study on patients was not limited with the outcome results.	No concrete outcome
Study	Literature in English, published from January 1, 2018, to March 1, 2023	Literature as identified via the search strategy	Literature reviews, meta-analyses, opinion papers, only surveys, editorials, conference papers and letters; non-English literature; literature published before January 1, 2018

VR, virtual reality; AR, augmented reality; MR, mixed reality.

acceptance of the latest technologies by children can render new technologies more easily applicable to them than to older populations,[5] and help increase treatment compliance in pediatric populations that have a lower understanding of the disease and treatment within the traditional medical care setting.[6]

Differentiation between VR, AR, and MR is important for proper analysis of the field, and VR is the use of computer modeling and simulation, which enable a person to interact with an artificial three-dimensional visual or other sensory environment.[7] It immerses the user by making them feel as if they if they are experiencing simulated reality first, primarily by stimulating vision and hearing in real-time.[8] The two primary features of VR are immersion and interaction. Immersion refers to the sense of presence in a virtual setting and interaction, which involves the operator's ability to modify performance.[9] By contrast, AR superimposes a computer-generated virtual element on existing to enhance sensory sensory perception.[10] MR is the merging of real and virtual worlds to produce new environments and visualizations in which physical and digital objects coexist and interact in real-time. MR is not confined exclusively in either the physical or the virtual world.[11]

To date, most reviews have focused on research using VR, AR, and MR technologies in adults.[12] Therefore, this study has focused on pediatric research, aiming to map the literature on the clinical applications of VR, AR, and MR technologies for pediatric patients and the training of pediatric medical professionals.[13,14]

Methods

This study was conducted in accordance with the Preferred Reporting Items for Systematic review and Meta-Analyses (PRISMA) guidelines.[15] A meta-analysis was not possible due to the heterogeneity of the publications. It was conducted by two independent reviewers with diverse

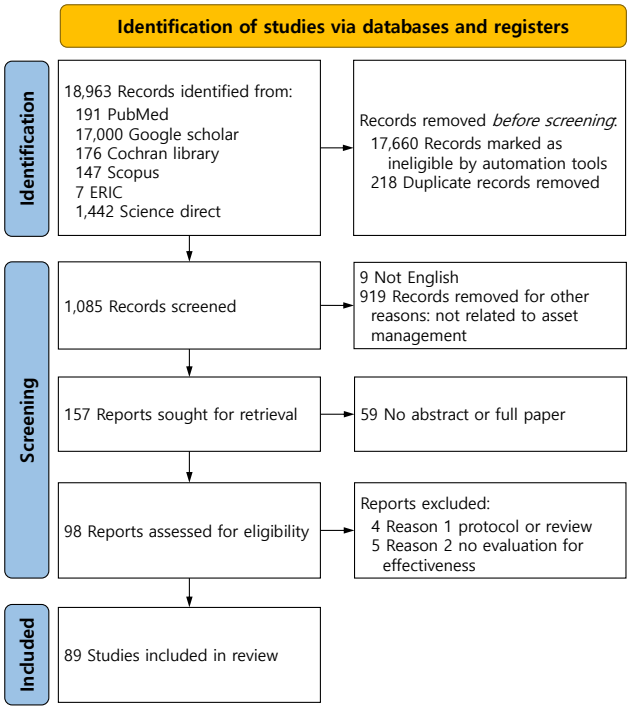


Fig. 1. PRISMA (preferred reporting items for systematic reviews and meta-analyses) flowchart of the screening process.

academic backgrounds to ensure inter-rater reliability and comprehensive coverage of various research perspectives on VR, AR, and MR applications.

1. Data source, search strategy, and inclusion and exclusion criteria

The initial search was conducted on March 1, 2023, using six electronic databases: PubMed, Cochrane Library, ScienceDirect, Google Scholar, ERIC, and Scopus. The WorldCat database was searched,[16] and 105 papers obtained using three search keywords: VR, AR, and MR. The following search terms or keywords were used in combination: pediatric, virtual reality, augmented reality, mixed reality, practice, training, and education (Supplementary Table 1). To identify detailed search terms, we used the PICOS (population, intervention, comparison, outcome, study design) search strategy (Table 1).[17-19] Publications were only included if they were published between January 1, 2018, and March 1, 2023, and restricted to English. Papers published in peer-reviewed journals were included; surveys, editorials, conference proceedings, and letters were excluded, as were literature and systematic reviews that that lacked an abstract or full text were excluded. The analytical PRISMA flowchart was used for screening (Fig. 1).[20]

2. Eligibility criteria

A 2-stage screening process was utilized to assess the relevance of studies identified in the search.[21] Studies on VR, AR, or MR applications for education, training, or practice in pediatric departments were included and screened to identify and characterize the subjects and objects of the studies. When the same data was reported in multiple publication (for example, in journal article or electronic report), only articles reporting the most comprehensive datasets were used.

3. Data extraction and study quality assessment

Supplementary Table 1 presents a comprehensive outline of the study selection process employed in this scoping review. The initial search yielded a total of 18,963 articles, of which 218 were identified as duplicates and were subsequently excluded. Among the remaining 18,745 articles, 17,660 were deemed ineligible for inclusion based on the criteria applied through automated tools. additionally, any non-English language papers were excluded. Consequently, 2 authors independently evaluated the identified studies, ensuring adherence to the predetermined inclusion and exclusion criteria primarily through the examination of titles and abstracts. As a result, 157 out of the initial pool of 1,085 studies were selected for further analysis. Subsequently, both authors independently screened the full texts of these selected articles. Any discrepancies or conflicts that arose during this screening process were resolved through discussions between the 2 screening authors. Relevant characteristics were extracted from the included studies, encompassing information such as authorship, publication year, journal sources, countries of study, study designs, evaluation methods, number of evaluation methods employed, types of data analysis, effectiveness outcomes, study population characteristics, medical disciplines under investigation, type of learning approaches utilized, study durations, and references used.[22,23] Other reasons for exclusion, detailed in Supplementary Table 1, included but were not limited to studies focusing on a different age group or those not involving pediatric patients. Consequently, the final selection comprised 89 studies deemed suitable for inclusion in this scoping review.

Results

The review incorporated a total of 89 studies, in which the utilization of VR, AR, and MR technologies was observed in 80, 8, and 1 study, respectively. All included studies were conducted within academic or hospital settings and predominantly focused on comparing VR or AR environments with conventional clinical applications or traditional face-to-face training methods.[24]

The scoping review revealed that the mean sample size of participants in the reviewed publications was 62.69, with

Table 2. Characteristics of reviewed studies (n=89)

Characteristic	No. of studies (%)
Purpose of the study	
Clinical application for pediatric populations	64 (71.91)
Training for medical professionals	25 (28.09)
Study population	
Medical students	11 (12.36)
Residents	8 (8.99)
Physicians	6 (6.74)
Nurses	3 (3.37)
Pediatric patients	61 (68.54)
Reported study design	
Quantitative	69 (77.53)
Qualitative	6 (6.74)
Mixed methods	14 (15.73)
Evaluation methods	
Skill tests	14/244 (5.74)
Questionnaires	22 (9.02)
Recordings	1 (0.41)
Knowledge tests	13 (5.33)
Interview	20 (8.20)
Observation	20 (8.20)
Self-assessment	18 (7.38)
Measuring tool	79 (32.38)
Physical assessment (vital signs)	34 (13.93)
Counting by standard (time, count)	23 (9.43)
Type of technology	
Virtual reality	80 (89.89)
Augmented reality	8 (8.99)
Mixed reality	1 (1.12)
Year of publication	
2018	7 (7.87)
2019	12 (13.48)
2020	16 (17.98)
2021	35 (39.33)
2022	17 (19.10)
2023	2 (2.25)
Country	
Peru	1 (1.12)
New Zealand	1 (1.12)
Hongkong	1 (1.12)
Spain	1 (1.12)
India	1 (1.12)
Estonia	1 (1.12)
Multiple	1 (1.12)
Belgium	1 (1.12)
Taiwan	1 (1.12)
Serbia	1 (1.12)
UK	2 (2.24)
Egypt	2 (2.24)
Iran	2 (2.24)
Netherlands	3 (3.37)
Poland	3 (3.37)
Canada	4 (4.49)
Australia	4 (4.49)
Italy	4 (4.49)
China	4 (4.49)
Turkey	9 (10.11)
Korea	10 (11.23)
USA	32 (35.95)
No. of participants	
0–10	5 (5.62)
11–20	14 (15.73)
21–30	11 (12.36)
31–40	13 (14.61)
41–50	9 (10.11)
51–60	7 (7.87)
61–70	2 (2.25)
71–80	3 (3.37)
>81	25 (28.09)
Reported effectiveness	
Effective	65 (73.03)
Partially effective	15 (16.85)
Useful only as an additional tool	4 (4.49)
No proven effectiveness	5 (5.61)

a standard deviation of 55.20. Among the total studies, 25 articles (28.08%) reported a participant pool exceeding 80 individuals. Furthermore, 32 studies (35.95%) were conducted in the United States, with a significant number of studies originating from Korea (10 studies) and Turkey (9 studies), as specified in Table 2.

1. Object of the study

Out of the 89 studies included in the scoping review, a total of 64 focused on the clinical applications of VR (n=61) or AR (n=3) in pediatric patients. Additionally, 25 studies examined the utilization of VR (n=19), AR (n=5), or MR (n=1) in the training of medical professionals or students.

The 89 studies included in the scoping review were classified into five primary categories: clinical assessment or management, patient treatment, educational skills, educational knowledge, and practical educational attitudes. Among these, 38 studies specifically addressed clinical assessment or management, focusing on aspects such as patient pain and anxiety. Additionally, 24 studies explored patient treatment, encompassing rehabilitation and other medical care approaches. Education skills were the focus of 16 studies, targeting both patients and medical staff. Furthermore, educational knowledge was examined in six studies, while five studies delved into practical educational attitudes.

A total of 36 randomized controlled trials (RCTs) were analyzed in the scoping review, with 31 studies focusing on clinical applications and 5 studies focusing on medical

Table 3. Study outcomes of 36 randomized controlled trials

Study/Country	No. of participants	Technology	Object of the intervention	Outcome measure result	Subject of evaluation
Clinical application for pediatric population					
Chen et al.[40] 2020/China	136	VR	Distraction during IV injection	Pain and fear scores were significantly lower in the VR group, as were the children's ratings as perceived by their caregivers and nurses. The time required for successful IV insertion was shorter in the VR group. The control group had a routine IV injection procedure.	Children, caregivers, and nurses
Han et al.[43] 2019/Korea	112	VR	Education before chest radiography	Children assigned to receive VR education before chest radiography had significantly lower anxiety and distress scores during the procedures. The control group was given a simple verbal instruction.	Children, caregivers, and nurses
Gerçeker et al.[46] 2020/Turkey	42	VR	Distraction during the port needle insertion	Self-reported pain, fear, and anxiety scores after port needle insertion were significantly lower in the VR group. The control group was given standard care.	Patient
Gerçeker et al.[32] 2018/Turkey	121	VR	Distraction during phlebotomy	Pain score in the VR group was lower than in the control group, but it was not different from that in the external cold and vibration group. No intervention was applied for the control group	Patient, Parent, and nurse
Kamel and Basha[54] 2021/Egypt	50	VR	Improvement of hand function and activity performance in pediatric hand burns	There was a significant increase in Durouz Hand Index, Canadian Occupational Performance Measure, and palmer pinch strength in the intervention group. The control group only received traditional rehabilitation.	N/A
Semerci et al.[45] 2021/Turkey	71	VR	Distraction during venous port access	Patients and proxy in the VR intervention group reported significantly lower pain scores. Standard care was given to the control group	Patient and parent
Gerçeker et al.[31] 2020/Turkey	46	VR	Distraction during blood draw	The VR-Rollercoaster and VR-Ocean Rift groups reported significantly lower pain score after the blood draw. No intervention was applied for the control group.	Patient and parent
Tennant et al.[60] 2020/Austrailia	90	VR	Enhancement of psychological well-being in pediatric oncology	Patients benefited from both immersive VR and iPad (control) intervention, with no significant difference between the groups. The control group was given iPad control conditions.	Patient and parent
Jha et al.[57] 2021/India	38	VR	Improvement of balance and gross motor function in children with bilateral spastic cerebral palsy	Pediatric Balance scale and Kids-Mini-Balance Evaluation System test improved significantly in the intervention, and there was no significant difference in other outcomes. The control group underwent physiotherapy alone.	N/A
Erdogan and Aytekin Ozdemir[33] 2021/Turkey	142	VR	Distraction during venipuncture	The VR intervention group reported significantly lower visual analog scale (VAS) score than the no intervention group but higher score than the Buzzy® group (vibration and cold application). The control group (n=34) received no intervention during venipuncture.	Patient and parent
Koç Özkan and Polat[34] 2020/Turkey	139	VR	Distraction during venipuncture	Pain and anxiety scores were significantly lower in the virtual reality goggle and kaleidoscope group than in the control group. The control group received no intervention.	Patient and parent
Schlechter et al.[39] 2021/USA	116	VR	Distraction during IV line placement	There was no significant difference in the first-attempt IV success rate, number of IV attempts, and time to successful IV placement. The control group was given standard care.	Patient and parent
Chan et al.[37] 2019/Australia	252	VR	Distraction during venous needle procedures	There was significant reduction in pain from baseline in the VR group, and there was no change in the standard of the care group.	Medical staffs and caregivers
Wong et al.[38] 2021/ Hongkong	108	VR	Distraction during peripheral IV cannulation	Pediatric cancer patients in the intervention group demonstrated a significantly greater reduction in pain and anxiety levels compared with the control group. The control group received standard care	Patient
Choi et al.[55] 2021/Korea	80	VR	Improvement of rehabilitation outcome in children with brain injury	Both VR and conventional groups significantly improved after intervention; however, the VR group showed more significant improvements in upper-limb dexterity functions, performance of daily living, and forearm supination by kinematic analysis.	N/A
Rajavi et al.[58] 2021/USA	50	VR	Therapy for amblyopia	The mean best corrected visual acuity (BCVA) based on logarithm of the minimum angle of resolution units improved significantly in both group but change in BCVA in the VR group was significantly higher than the patching group. The control group was applied patching only for 1 month.	N/A
Ryu et al.[44] 2021/Korea	120	VR	Education before chest radiography	The number of less distressed children (Observational Scale of Behavioral Distress score<5) was significantly higher in the VR group than in the tablet group. The control group experienced the process of chest radiography indirectly with a 3 min video using a tablet PC.	Children, caregivers, and nurses

(Contuned)

Table 3. Study outcomes of 36 randomized controlled trials (Contined)

Study/Country	No. of participants	Technology	Object of the intervention	Outcome measure result	Subject of evaluation
Alarcón-Yaquetto et al.[59] 2021/Peru	29	AR	Reduction of salivary cortisol level	Cortisol levels significantly decreased after the AR intervention; however, the decrease was not greater than that in the standard book. Children allocated to the 'AR-first' group received the book and a tablet and were left to interact independently with the technology for 1 hour. After a 48-hour wash-out period, children received a standard book. The 'Standard-book-first' group received only the standard book and after wash-out received the tablet and the AR book.	N/A
Richey et al.[26] 2022/USA	210	VR	Distraction during procedures included cast and/or pin removals	Patients in the VR group reported significantly lower average fear scores (P<0.001) and anxiety scores (P=0.003) as compared with controls. There were no differences between the groups in fear and anxiety scores before and after the procedure, or pain scores before, during, or after the procedure. Overall, patients and caregivers in the VR group reported high satisfaction scores, with 97% of patients and 95% of caregivers recommending this intervention to others.	Patients and care givers
Ryu et al.[35] 2022/Korea	60	VR	Distraction during venipuncture procedure	The pain and anxiety score during the procedure was significantly lower in the VR group.	Patients and care givers
Khadra et al.[52] 2020/Canada	38	VR	Examine the effect of a water-friendly Projector-Based Hybrid Virtual Reality (VR) dome environment combined with standard pharmacological treatment on pain in young children undergoing burn wound care in hydrotherapy.	VR significantly reduced procedural pain levels measured by the FLACC (P=0.026) and significantly increased patients' comfort levels (P=0.002).	Patients and nurses
Moraes et al.[56] 2022/Brazil	22	VR	To evaluate virtual and real activity practice improves ASD motor skills and activity enjoyment.	Sequence A (virtual first) presented an improvement in accuracy and precision and transferred this when changing environment.	patients
Xiang et al.[51] 2021/USA	90	VR	To evaluate the efficacy of a smartphone VR game on dressing pain among pediatric patients with burns.	Participants in the active VR group had significantly lower reported overall pain (VAS score, 24.9 [95% CI, 12.2–37.6]) compared with participants in the standard care control group (VAS score, 47.1 [95% CI, 32.1–62.2]; P=0.02).	Nurses and patients
Hsu et al.[41] 2022/Taiwan	134	VR	To evaluate the effectiveness of an interactive VR in reducing children's pain and fear during IV placement.	Children's pain (P=0.028) and fear scores (P=0.004) were significantly lower in the intervention group than in the comparison group.	Children and caregivers
Buyuk et al.[49] 2021/Turkey	40	VR	To examine the effects of VR to alleviate circumcision-related anxiety, fear, and pain in children.	Children in the experimental group had significantly lower mean scores of CAM-S and CFS in the pre- and postoperative periods than those in the control group.	Children
Luo et al.[50] 2022/China	106	VR	To evaluate the effects of the biophilic virtual reality (BVR) method on children's pain and anxiety undergoing circumcision.	The CmYPAS scores during surgery were significantly lower in the BVR group and the IVR group versus the blank control group (25.0 [22.9–29.2], 22.9 [22.9–29.2], 33.3 [33.3–38.5] respectively; P<0.001).	Children
Ryu et al.[47] 2018/Korea	69	VR	Reduce preoperative anxiety for elective surgery	Sixty-nine children were included in the final analysis (control group=35, gamification=34). Preoperative anxiety (28.3 [23.3–36.7] vs. 46.7 [31.7–51.7]; P<0.001) and intraoperative compliance measured using ICC (P=0.038) were lower in the gamification group than in the control group.	Children and caregivers
Yıldırım et al.[36] 2023/USA	150	VR	To evaluate VR as distraction methods on IV insertion success.	There were no significant differences in first-attempt IV insertion success rates (virtual reality=47.2%, Buzzy=50%, control=46.9%), preprocedural emotional appearance scores, and procedure-related pain and anxiety scores.	Nurses, Patients
Basha et al.[53] 2022/Egypt	40	VR	To determine the impact of the Xbox Kinect on cardiopulmonary fitness, muscle strength, lean mass, quality of life and enjoyment in severely burned children	The groups significantly differed in VO_{2peak}, peak torque, quality of life (P<0.001), lean mass and leg lean mass (P<0.05) in favor of Xbox training. The Xbox training group reported significantly more enjoyment than did the control group (P<0.001).	Children
Tennant et al.[60] 2020/ Austrailia	90	VR	To investigate whether immersive VR has a greater positive influence on oncology patients' physical and emotional mood	Patients benefited from both Immersive VR and novel iPad intervention with no statistically significant differences found between conditions on child outcomes. However, patients accessing Immersive VR consistently reported greater positive shifts in mood state and reductions in negative symptoms when compared with iPad.	Patients

(Contuned)

Table 3. Study outcomes of 36 randomized controlled trials (Contined)

Study/Country	No. of participants	Technology	Object of the intervention	Outcome measure result	Subject of evaluation
Wong et al.[38] 2021/China	108	VR	To determine whether virtual reality distraction intervention can alleviate pain and anxiety and reduce length of procedure among pediatric cancer patients undergoing PIC.	Pediatric cancer patients in the intervention group demonstrated a significantly greater reduction in pain (estimated mean difference=-1.69, P=0.007) and anxiety levels (estimated mean difference=-3.50, P< 0.001) compared with the control group.	Patients
Training method for medical professionals who take care of pediatric patients					
Abulfaraj et al.[27] 2021/USA	42	VR	Training interns at pediatric emergency medicine to manage status epilepticus	There was no statistical difference in time-to-critical actions for VR vs. standard groups. The control group participated in 2 mannequin-based simulation sessions while the intervention group had a VR session followed by a mannequin-based session.	The time-to-critical actions were measured.
Zackoff et al.[28] 2020/USA	168	VR	Education for third-year medical students on recognition of pediatric respiratory distress	Significant differences between intervention and control group were demonstrated for consideration/interpretation of mental status, assignment of the appropriate respiratory status assessment, and recognition of a need for escalation of care All students received standard training on respiratory distress through didactics and high-fidelity mannequin simulation. Intervention students underwent an additional 30-minute immersive virtual reality curriculum	Responses were scored on standardized rubrics by physician experts.
Zackoff et al.[29] 2021/USA	26	VR	Defining objective observable behaviors as standards for evaluation of medical student recognition of impending respiratory failure	Fourth-year medical students' performance on 8 observable behaviors was highly predictive of a rating of competent, with 91% probability. Correctly identifying the need for escalation of care was the most significant factor, followed by observations of increased heart rate, low oxygen saturation, increased respiratory rate, and respiratory distress.	Experienced physicians and pediatric student clerkship directors (AG, CL) conducted blind reviews of each student's video session and provided global performance assessments.
Umoren et al.[25] 2021/Multiple	274	VR	Training nurses and midwives for neonatal resuscitation	Neonatal resuscitation skills pass rates were similar between groups, but in the VR group, there was a greater retention of bag-and–mask ventilation skill test 6 months The control group was trained using a neonatal resuscitation video.	OSCE Skill test scored on standardized rubrics by physician experts.
Toto et al.[30] 2021/USA	50	AR	Training pediatric septic shock simulation for pediatric care providers	There was no significant difference regarding time to administration of IV fluids, time to verbalized recognition of patient status or desired management steps between the 2 groups. The control group was given traditional simulation.	Time to administer and verbalize test were scored

VR, virtual reality; IV, intravenous; AR, augmented reality; N/A, not available; FLACC, face, legs, activity, cry, and consolability scale; ASD, autism spectrum disorder; CI, confidence interval; CAM-S, confusion assessment method for the intensive care unit; CFS, child fatigue scale; CmYPAS, Chinese version of the modified Yale preoperative anxiety acale; BVR, biophilic virtual reality;IVR, indoor virtual reality; ICC, induction compliance checklist; VO_{2peak}, peak oxygen uptake; OSCE, objective structured clinical examination; PIC, peripheral intravenous cannulation.

training. The majority of the RCTs utilized VR (n=34) as the intervention, except for 2 studies,[25,26] that employed AR.

The scoping review included a variety of studies that focused on training methods for medical professionals in pediatric care. These studies covered a range of topics, including managing epilepsy,[27] recognizing childhood conditions involving difficulty in breathing,[28,29] providing neonatal resuscitation education,[25] and offering septic shock simulation training.[30]

The aim of the major clinical study was to alleviate fear, pain, and anxiety experienced by children during invasive procedures such as blood drawing,[31] phlebotomy,[32] and venipuncture.[33-35] Intravenous injection[36-41] PIVC insertion,[42] chest radiography,[43,44] and port needle insertion[45,46] in pediatric patients. Some studies also focused on surgical fear, such as pre- or postoperative scenarios[47,48] and circumcision.[49,50] Serve various purposes, such as enhancing rehabilitation capabilities with distraction techniques in burned patients,[47,51-54] physical rehabilitation,[55-57] therapy for amblyopia,[58] psychological well-being,[59,60] and stress reduction during orthopedic cast room procedure.[26]

Within the realm of clinical applications, the primary objective across studies was to alleviate pain and anxiety in pediatric patients through the implementation of distracting interventions during medical procedures. Nine of ten researchers reported the intervention as effective in reducing pain or anxiety experienced during painful procedures. In medical training settings, four studies employed VR and 1 study utilized AR [30] implementing scenario-based learning approaches in diverse clinical settings for medical

students, nurses, and interns. Detailed information regarding the 36 RCTs can be found in Table 3.

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2. Evaluation methods

Of the 89 identified studies, the majority (n=69, 77.52%) used a quantitative study design, followed by mixed methods (n=14, 15.73%),[61-74] and a small number of studies utilized a qualitative study design (n=6, 6.74%).[24,75-79]

The findings of the scoping review indicated a preference for objective measurement and data analysis methods in the included studies. Qualitative studies focused on exploring the subjective experiences and perceptions of the participants, while mixed-method studies utilized both quantitative and qualitative data collection and analysis techniques to provide a more comprehensive understanding of the investigated topic.

In contrast to other classification standards that solely rely on factors such as country, year of publication, and effectiveness, the present evaluation method employed multiple evaluation techniques. Across the 89 studies, a total of ten evaluation methods were utilized to assess the effects of VR, AR, and MR interventions. These evaluation methods encompassed skills tests, surveys, recordings, knowledge tests, interviews, observations, self-assessments, measuring tools, physical assessments (including vital signs and cortisol levels), and counting by standard (e.g., time and count). Each evaluation method was counted separately, even if it was utilized in multiple studies. As a result, a total of 244 evaluation methods were identified within the 89 studies included in the analysis.

Among the evaluation methods used, 14 studies (5.74%) employed skills tests, while 22 studies (9.02%) utilized questionnaires. Recordings were employed in a single study, accounting for 0.41% of all evaluations. Knowledge tests were employed in 13 studies (5.33%), interviews in 20 studies (8.2%), observations in 20 studies (8.2%), and self-assessments in 18 studies (7.38%). Measuring tools were employed in 79 studies, representing 32.38% of the evaluations. Physical assessments, including vital signs, length of stay, and cortisol levels, were utilized in 34 studies, accounting for 13.93% of the evaluations. Counting by standard, such as measuring time or count, was employed in 23 studies, representing 9.43% of the evaluations.

The measuring tools used in the studies encompassed the evaluation of children's anxiety, enjoyment, and fear during magnetic resonance imaging on a ten-point scale, as well as the use of verbal evaluation tools to assess anxiety in children with concerns about academic achievement. Studies evaluated through observation involved experts or experienced evaluators determining the educational effects of VR devices through observation, or guardians and medical staff evaluating children's pain, distraction, and social behavior. Questionnaire-based evaluations involved medical staff, parents, and guardians providing assessments of fear and loneliness in children receiving inpatient care, or medical staff with training and experience in device usage evaluating feasibility and usability through questionnaires.

3. Effectiveness of the applied methods

Out of the 89 studies included in the review, a significant majority of 80 studies (89.8%) reported the effectiveness or partial effectiveness of VR or AR interventions. Among these, 65 studies (73.03%) reported full effectiveness, while 15 studies (16.85%) reported partial effectiveness. Four studies recognized the utility of VR or AR devices as supplementary tools. However, five studies either did not report the effectiveness of the interventions or did not observe any significant differences between the experimental groups.[29,62,67,69,80]

Among the 65 studies deemed effective, various evaluation methods were employed. Measurement tools were utilized in 20 studies, observations in 11 studies, knowledge tests in ten studies, and skill tests in nine studies. Notably, out of the effective studies, 18 focused on evaluating the impact of VR and AR interventions on medical staff, while 47 studies assessed their effectiveness in pediatric patients.

However, it is important to acknowledge that despite most studies reporting positive effectiveness, there were limitations to the research. Specifically, four studies indicated a lack of conclusive evidence regarding the effectiveness of VR and AR interventions, highlighting the necessity for further investigation in this area.

4. Devices

A comprehensive analysis of the studies revealed that a total of 78 devices utilized across the various research investigations. The most frequently employed device was the Oculus Rift, which featured in 19 studies, accounting for 24.36% of the total. The Samsung Gear VR ranked second, utilized in 7 studies (8.97%). Other frequently employed devices included the HTC VIVE Cosmos Elite, HoloLens, and Oculus Go, each utilized in three studies (3.85%). Additionally, several studies incorporated a combination of devices including the Oculus Rift Touch, Oculus Rift DK2, Google Daydream, MediqVR, and RAPAEL Smart Kids.

However, a significant portion of the devices used in

the studies was not specifically identified in the provided list. Seven studies did not mention the name of the device, while 11 entries simply referred to the device as a "monitor," "smartphone," or "tablet." These unspecified devices accounted for 17.95% of the total number of devices employed in the studies.

Discussion

The utilization of VR, AR, and MR technologies is extending beyond their traditional recreational and gaming applications and finding increased usage in various domains, including the medical field. This scoping review specifically examines the application of VR, AR, and MR technologies in pediatric research. The review was conducted by a team comprising two researchers and one pediatrician, employing a methodology akin to that used in previous review papers.

The field of pediatrics has witnessed the undertaking of diverse and significant studies. In contrast to studies focusing on adult patients, which extensively employ VR, AR, and MR technologies to assist in treatment, numerous studies have focused on providing supportive care to alleviate pain and anxiety in children. Children, due to their comparatively limited understanding of their disease and treatment processes, often exhibit lower treatment compliance.[71] Moreover, the experience of pain and fear in children can induce excessive stress in patients, guardians, and medical staff, potentially resulting in treatment refusal. These factors not only subject children to considerable stress but may also lead to decreased sociability and feelings of alienation. Accordingly, most studies have endeavored to address these specific challenges and characteristics associated with children.

Moreover, the evaluation of research effects in the context of pediatric patients presents distinct challenges. Due to the nature of pediatric patients, it is relatively difficult to employ devices, patient self-reports, and standardized evaluation indices for evaluating research outcomes. Consequently, studies in this area have primarily relied on evaluations conducted through the observation of medical staff or guardians. It is plausible that these factors have influenced researchers to employ observational evaluations by guardians or medical staff more frequently as a means of assessing the outcomes of interventions in pediatric populations.

These technologies are also used in various fields to train medical staff in performing medical activities involving children. Education employing VR, AR, and MR devices can provide an immersive environment that surpasses traditional approaches such as books or person-to-person training, thereby overcoming time constraints, preventing ethical concerns, and offering nearly unlimited practice opportunities. This not only represents a new paradigm for educational methods but also sees VR, AR, and MR applied as educational evaluation tools, either replacing or supporting existing evaluation systems.

Similar to reviews of studies involving adult populations, a majority of the research in this domain has been conducted in a few countries, particularly the United States. This trend can be attributed to the nature of the research, which necessitates the use of cutting-edge devices and is influenced by device availability. Furthermore, most studies have primarily focused on VR, reflecting the stage of technological development and research conducted thus far. In comparison with other clinical studies, the majority of studies reviewed here evaluated interventions after a relatively brief application period. Moreover, most studies assessed the effectiveness of training interventions following a short duration ranging from a day to a month.

Among the 5 studies that utilized VR and AR for medical staff education, three confirmed the effectiveness of interventions in enhancing objective competence in assessing respiratory distress and recognizing the need for escalated care for patients,[28] and standards for assessment of entrustable professional activity attainment[27] and neonatal resuscitation skills.[25] Two studies showed no significant difference in time-to-critical actions for VR verus standard groups,[29] and no difference in primary outcomes, but only in secondary outcomes.[30] This does not imply that learning with VR, AR, or MR is less effective than traditional learning methods. However, comparing and assessing the learning effects of novel devices based solely on a short duration of experience can be challenging. Furthermore, environmental constraints may impede the smooth utilization of new technologies and hinder the determination of their effectiveness in educational settings.

Despite certain limitations inherent in conducting research on innovative technologies, such research has experienced rapid expansion after 2020, indicating an increasing involvement of researchers in pediatric research employing these technologies. Furthermore, given that most studies have reported positive self-contained effectiveness, further studies pertaining to this subject should be pursued. The realm of research involving VR, AR, and MR devices for pediatric patients and medical professionals is expected to expand to encompass a variety of clinical and training purposes.

Footnotes

Supplementary material: Supplementary Table 1 can be

found via https://doi.org/10.3345/cep.2022.00731.

Conflicts of interest: No potential conflict of interest relevant to this article was reported.

Funding: This research was supported by a grant of the Korea Health Technology R&D Project through the Korea Health Industry Development Institute (KHIDI), funded by the Ministry of Health Welfare, Republic of Korea (grant number: HR21C0885).

Acknowledgments: We are grateful to HI Jung for her assistance in searching for and processing the data, and HH Hwang for illustrating the graphical abstract.

Author contribution: Conceptualization: MHS; Data curation: YS; Formal analysis: YS, Funding acquisition: MHS; Methodology: MHS; Project administration: MHS; Visualization: HHH; Writing-original draft: YS; Writing-review & editing: MHS

ORCID:
Suyoung Yoo https://orcid.org/0000-0002-1617-6719
Meong Hi Son https://orcid.org/0000-0002-3505-5576

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How to cite this article: Yoo S, Son MH. Virtual, augmented, and mixed reality: potential clinical and training applications in pediatrics. Clin Exp Pediatr 2024;67:92-103.