



State of the Art: Immersive Technologies for Perioperative Anxiety, Acute, and Chronic Pain Management in Pediatric Patients

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Abstract

Purpose of Review This review summarizes and provides a comprehensive narrative synthesis of the current evidence on immersive technology's (i.e., virtual and augmented Reality) use for perioperative anxiety, acute, and chronic pain in pediatrics.

Recent Findings Researchers have increasingly studied immersive technology as a non-pharmacological alternative for perioperative anxiety, acute, and chronic pain management. We found several research studies published over the last 3 years: almost all studies examined the use of virtual reality for perioperative anxiety and pain; only one case report was about the use of augmented reality for preoperative anxiety. Most studies showed that virtual reality intervention is effective and safe for perioperative anxiety, acute, and chronic pain. However, the studies are heterogeneous with relatively small sample sizes.

Summary This review shows that more high-quality studies (i.e., randomized controlled trials with larger sample sizes and standardized methods for measuring and reporting outcomes) are needed to examine the effectiveness and adverse effects of virtual reality intervention on perioperative anxiety, acute, and chronic pain in pediatrics.

Keywords Immersive technology · Virtual reality · Augmented reality · Preoperative anxiety · Postoperative acute and chronic pain · Procedural pain

Introduction

Anesthesia and surgical procedures impose a potential stressor for pediatric patients, leading to significant perioperative fear and distress. Up to 64% of children experience a high level of preoperative anxiety [1–5]. Before surgery, pediatric patients may feel threatened by the expected parental separation,

unfamiliar environment, new faces with masks on, alarm sounds, and high level of parental anxiety, which can be because of the procedure or their children's fear [3, 4, 6–9]. Ineffective preoperative anxiety management may increase postoperative pain, delirium, analgesic consumption, general anxiety, behavioral problems, and difficulty sleeping [5, 8, 10]. Therefore, alleviating children's preoperative anxiety can improve recovery, mitigate postoperative pain, and improve the overall perioperative experience. Further, up to 30–40% of children experience moderate to severe postoperative pain [11–13] and are at risk for transition to chronic pain, a debilitating and costly public health problem [14–17]. Unrelieved or undertreated pediatric pain can negatively impact all domains of health-related quality of life and also interferes with normative developmental tasks [18–22].

Recent research shows that immersive technology, particularly virtual reality (VR), is an effective intervention to alleviate perioperative anxiety and pain in children [23–31]. Immersive technology, namely VR and augmented reality (AR), refers to technology that aims to extend an individual's sensory environment by emulating or simulating physical reality through technology [32]. VR transposes users to an alternative setting and or a fully digital three-dimensional visualization, which creates

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a sense of immersion by allowing them to interact with the virtual environment [33, 34]. AR enhances an existing physical environment with additional virtual objects embedded in that space (i.e., additional digital information layers) [32, 35].

Over the past years, several review studies have been published about the effect of VR intervention on anxiety, acute, and chronic pain in the pediatric population. These reviews incorporate various medical procedures (e.g., dental care, burn, venipuncture, chemotherapy administration, and various surgical procedures) [29, 44, 45], focus on preoperative anxiety in adult and pediatrics [30], or assess the use of VR distraction interventions for children with acute pain in any healthcare setting [36]. None of these reviews concentrated on the perioperative anxiety, acute, and chronic pain in children. In this review [46], we summarize the findings of the most recent evidence, i.e., studies that have been published in the past 3 years, on the effect of immersive technology on perioperative anxiety, acute, and chronic pain in pediatric patients.

Search Strategy and Selection Criteria

We searched PubMed, Google Scholar and Google (for gray literature), and the Cochrane database using the following search terms: “immersive technology,” “perioperative,” “perioperative care,” “anxiety,” “pain management,” “pediatric or pediatrics or paediatric or Paediatrics,” “children,” “children surgery,” “child,” “child surgery,” “immersive technology*,” “virtual reality*,” “augmented reality*,” “perioperative*,” “preoperative*,” “postoperative*,” “surgery* or after surgery*,” “anxiety*,” “pain*,” “pain management*,” “pediatric*,” “paediatric*,” and “Child.” We reviewed papers that have published since January 1, 2017. Articles were also identified through the authors’ reference lists of selected articles (e.g., systematic review and meta-analysis) found in the literature search. Papers published in English were reviewed. The final reference list was generated based on originality and relevance to this narrative review’s broad scope.

Immersive Technology and Preoperative Anxiety in Children

We identified eight RCTs that investigated the effect of VR on alleviating preoperative anxiety in pediatrics from 5 countries: South Korea ($n=4$), Iran ($n=1$), Netherlands ($n=1$), The USA ($n=1$), and Japan ($n=1$) (Table 1). In six RCTs [28, 37–40, 47], researchers used VR as exposure (i.e., VR tour of the operating room) to allow pediatric patients to become familiar with the operating room before induction of anesthesia. Two RCT examined the use of VR as a distraction tool [48, 49]. Hashimoto et al. (2020) asked pediatric patients ($n=29$) to

practice how to use the VR headset the day before the surgery by watching their favorite cartoon animation, and on the day of the surgery, the researchers ask them to use the VR headsets again while staying in the pre-anesthetic holding area until after the induction of anesthesia. In the other RCTs, researchers asked the participants to use VR just before the surgery, of which, the exact timing was reported in three RCTs as 1 h before entering the OR [37, 38, 47]. In most RCTs (7/8), the modified Yale Preoperative Anxiety Scale [50] was used to measure the preoperative anxiety, while in one RCT, the Yale Preoperative Anxiety Scale [51] was used.

Almost all RCTs compared VR (i.e., intervention group) with care as usual (i.e., control group), except for one RCT [47]. In that RCT, Park et al. examined the effectiveness of VR as exposure to the operating room on preoperative anxiety for both patients and their parents. The researchers asked parents ($n=40$) in the intervention group to watch a 4-min VR tour concurrently with their children (i.e., mirroring display) while escorted from the pre-anesthetic holding area to the operating room. Parents and children were able to talk with each other and discuss what they were seeing. The results showed that the preoperative anxiety scores for children and their parents were significantly lower in the intervention group than the control group (i.e., children watched the same tour alone; $n=40$).

Although the reviewed RCTs are heterogeneous (i.e., content and duration of VR intervention, timing of administering the intervention, sample size, different mechanisms of VR, and type of surgery), almost all RCTs (7/8) showed that the preoperative anxiety score was significantly lower in the VR groups than in the control groups. Several limitations were reported in these studies including most of the RCT was open-label or not blinded [39, 48, 49] and repeated measures analysis of variance (i.e., ANOVA) was not used for comparison groups in all studies since the data was not normally distributed, technical issues (e.g., battery depletion), and small sample sizes. Only one RCT by Eijlers et al. showed that there was no significant difference in preoperative anxiety scores between the intervention group (i.e., VR exposure tour to the operating room) and the control group (i.e., “care as usual”). The researchers highlighted in the limitation section that 22% (21/94) of children in the intervention group discontinued the VR by frequently taking off the headset. Most of these children (15/21) were 4 or 5 years old, and the headset may have been large and heavy on them.

We identified two case studies from the USA [52, 53] and one game development study from Belgium [54]. Libaw et al. described the use of AR as a distraction technique during the induction of general anesthesia in a case study of three children (mean age=8.7). The AR software was designed to show the real operating room with an avatar that encourages patients to take deep breaths during mask induction. The researchers reported that patients felt less anxiety in comparison with their

Table 1: Studies about the effect of immersive technology on preoperative anxiety and chronic pain
Studies about the effect of immersive technology on preoperative anxiety

Author	Country	Study design	SimplePara>Sample size (VR/control)	Age (VR/control)	VR mechanism	Intervention	Anxiety measure	Surgery	Results
Ryu et al., 2017	South Korea	RCT	69 (34/35)	6/6	Exposure	Intervention: a 4-min video of a famous local avatar who give orientation about the OR Control: care as usual	mYPAS	Elective surgery	Children in the VR group had a significantly lower mYPAS score than those in the control group
Ryu et al., 2018	South Korea	RCT	69 (34/35)	5/6	Exposure	Intervention: a 5-min VR game reflect the preoperative experience Control: care as usual	mYPAS	Elective day surgery	Children in the VR group had a significantly lower mYPAS score than those in the control group
Ryu et al. 2019	South Korea	RCT	80 (41/39)	6/6	Exposure	Intervention a 4-min video of a famous local avatar who give orientation about the OR Control: care as usual	mYPAS	Elective surgery	Children in the VR group had a significantly lower mYPAS score than those in the control group
Dehghan et al., 2019	Iran	RCT	40 (20/20)	7.35 (Mean)	Exposure	Intervention: a 5-min video to the operating room using VR (eyeglass) Control: care as usual, and parents were allowed to touch and caress their children	YPAS	Abdominal surgery	Children in the VR group had a significantly lower mYPAS score than those in the control group
Eijlers et al., 2019	Netherlands	RCT	191 (94/97)	8.3/7.5 (mean)	Exposure	Intervention: 15-min child-friendly exposure to the operating room using VR Control: care as usual	mYPAS	Elective day surgery	No differences between groups were found
Park et al., 2019	South Korea	RCT	80 (40/40)	6.8/7.1 (median)	Exposure	Intervention: a 4-min video of a famous local avatar that gives orientation about the OR. Parents and children watch the same video using the mirroring display Control: a 4-min video of a famous local avatar that gives orientation about the OR	mYPAS	Elective surgery	Children and parents in the VR group had a significantly lower mYPAS score than those in the control group
Hashimoto et al., 2020	Japan	RCT	58 (29/29)	5/5 (mean)	Distraction	Intervention: video glasses was used to display the patients' chosen movie	mYPAS	Elective surgery	Children in the VR group had a significantly lower mYPAS score

Table 1: (continued)

Studies about the effect of immersive technology on preoperative anxiety

Author	Country	Study design	Sample size (VR/control)	Age (VR/control)	VR mechanism	Intervention	Anxiety measure	Surgery	Results
Jung et al., 2020	USA	RCT	71 (34/37)	(8.2/7.8)	Distraction	Control: portable multimedia player Intervention: VR audiovisual distraction with Control: care as usual	mYPAS	Elective surgery	than those in the control group Children in the VR group had a significantly lower mYPAS score than those in the control group
Gupta et al., 2019	USA	Case study	1	10	Distraction	VR multiuser application, Oculus Rooms, patient and his mother joined each other in the multiuser virtual space and played a VR board game together. While interacting in VR, the patient and his mother were able to talk with each other and hear each other's voices	None	Elective surgery	Child and parent described that their anxiety was low in comparison with previous preoperative anxiety
Vrancken et al., 2019	Belgium	3-phase game development	181	4 to 7	NA	No intervention	None	Elective surgery	Promising game to help young children and their parents during the preparation for admission at the hospital for elective surgery
Libaw et al., 2020	USA	Case report	3	8.7 (mean)	Distraction	AR Software created by Miney Moe (San Francisco, CA) featured Jenny the Robot, encouraging patients to take deep breaths during mask induction	None	Elective surgery	Patients and parents described less patient anxiety as compared to previous inductions
Studies about the effect of virtual reality in pediatric chronic pain									
Author	Country	Study design	Sample size (VR/control)	Age (VR/control)	VR mechanism	Intervention	Measures	Pain conditions	Results
Won et al., 2015	USA	Case series	4	13–17	Distraction, embodiment	6-sessions VR where patients were tasked with kicking a balloon with their leg. Software was	Limb movements	CRPS, lower limb	Authors report the intervention was safe (no adverse events) and feasible, patient

Table 1: (continued)

Author	Country	Study design	SimplePara>Sample size (VR/control)	Age (VR/control)	VR mechanism	Intervention	Anxiety measure	Surgery	Results
Shiri	Israel	Cohort study	9	10–17	Biofeedback	manipulate to exaggerate the limb movements or mirror the limb movements 10-sessions VR (30 min) combined with biofeedback technology. Patients viewed an image of themselves that reflected their emotional state (using GSR data) and were tasked with relaxing their body to reduce pain	Pain intensity (VAS), QOL (PedsQL), patient satisfaction	Headache	qualitative feedback was positive Significant reductions in pain intensities and improvements in QOL (post-intervention and 3-month follow-up)
Griffin	USA	Cohort study	17	7–17	Distraction graded exposure	VR software (Fruity Feet) developed by Mighty Immersion (New York, NY) motivated children to use their limbs in rehabilitation sessions	Multiple measures including pain, function, immersion, and limb movements	Mixed	Patients reported Fruity Feet was highly engaging, felt distracted from pain, and perceived greater mobility

mYPAS modified Yale Preoperative Anxiety Scale (observational scale with five domains: activity, vocalization, emotional, expressivity, D: state of apparent arousal, and use of parents. The total adjusted score is calculated as $(A/4 + B/6 + C/4 + D/4 + E/4) \times 100/5$. The score ranges from 23.3 to 100, with the higher score indicating a higher level of anxiety

YPAS Yale Preoperative Anxiety Scale (observational scale with four domains: activity, vocalization, emotional expressivity, and state of apparent arousal). Each domain has four items that are scored from 1 to 4, which sum to the minimum score of 4 and the maximum score of 16

*Studies about the effect of virtual reality in pediatric acute pain are summarized in a systematic review Lambert 2020

**GSR* galvanic skin response, a measure of sweat gland activity to approximate relaxation

**QOL* quality of life

previous experience. In the second case study by Gupta et al., the researchers used a VR multiuser application, Oculus Rooms, which allowed a 10-year-old patient ($n=1$) and his mother to play and interact together virtually during patient transportation from the preoperative area to the operating room. The patient and his mother were able to hear and talk to each other. The researchers concluded that this approach of using VR reduced the child's preoperative anxiety by keeping the child-parent connection until anesthesia induction. Finally, Vrancken et al. developed and tested a game, "HospiAvontuur," to help children (4–7 years) and their parents prepare for elective surgery admission.

The current evidence showed that immersive technology (i.e., VR and AR) is a promising intervention to alleviate preoperative anxiety in children. Further RCTs with larger sample sizes and standardized protocol (e.g., multicenter RCT) are needed to establish evidence (i.e., with high-certainty) on immersive technology and its effect and adverse effects on preoperative anxiety. This is crucial since suboptimal management of preoperative anxiety can intensify postoperative pain.

Immersive Technology in Acute and Procedural Pain

Immersive technologies in the pediatric acute and procedural pain setting have largely focused on VR technologies for children undergoing needle pokes, wound, or burn dressing changes [36•]. Distraction and affect modulation are the purported mechanisms that drive the effectiveness of VR interventions in the context of acute and procedural pain. Distraction through VR allows children experiencing pain to shift their attentional resources towards stimuli in VR, producing a hypoalgesic effect. VR can also stimulate a positive affective state, enhancing distraction and hypoalgesia [41••]. In a recent Cochrane review, Lambert et al. reviewed 17 RCTs and concluded that there is little evidence for the use of VR in reducing acute pain in children; the effectiveness of VR intervention on acute pain in children undergoing clinical treatments and procedures has been ranked as low to very low certainty [36•]. Therefore, they highlighted that there is a need for larger high-quality RCTs (i.e., at least 200 participants in each arm) to investigate the effectiveness and the adverse effect of VR intervention in this population.

Immersive Technology in Chronic Pain Management

The role of immersive technologies in pediatric chronic pain is not only to provide distraction from pain, but also uses biofeedback, graded exposure, and motivation [55, 56]. Physical

activity for children with chronic pain is often painful and avoided [57]. Engaging in physical activity using immersive technology while distracted from pain may be better tolerated. Graded exposure is utilized to overcome fear of pain and gradually improve physical function over time [58]; this can be employed through VR with modifiable gaming parameters gradually expose children to exercises. Technology with features such as music, cues, rewards, and performance metrics can provide motivation to perform painful movements. Technology that uses *biofeedback* provides patients information about a physiological parameter to prompt behavior modification, such as the VR application DEEP [59]. DEEP is a biofeedback, meditative, and psychoactive VR game that is controlled by breathing. Users don the VR headset and following onscreen and biofeedback cues, allow the game to teach them breathing techniques that can relieve stress, anxiety, and mild depression

Immersive technologies in pediatric chronic pain are an emerging practice and science, heavily focused on VR. Evidence from studies of VR in adults with chronic pain show promising results. A scoping review (research methodology that provides an overview of the available research evidence without necessarily producing a summary answer to a discrete research question) [60] and systematic review [61] of controlled trials evaluating VR in adults with chronic pain report that VR is effective in pain reduction and functional improvements, but there is insufficient data to show long-lasting effects.

There are a handful of studies evaluating VR in pediatric chronic pain. Won et al. conducted a pilot study evaluating VR for children ($n=4$) with complex regional pain syndrome [62]. VR was used to engage the children in lower limb exercises (6 sessions) and used motion sensors to track limb movements during the intervention. The authors conclude that VR was well tolerated and feasible to use; however, in the absence of a comparator group, it is unclear whether VR enhanced limb movements compared to traditional forms of exercise. Shiri et al. conducted a pilot feasibility study in children with headaches ($n=9$) using VR (10 sessions) for biofeedback targeting relaxation [63]. In addition to feasibility, pre-post measures demonstrated improvements in pain intensity and quality of life post-intervention [63], although unclear if this differs from other biofeedback technologies.

Griffin et al. conducted a pre-post study of using a custom-developed VR technology (Fruity Feet) with 17 youths with chronic pain (63 sessions total) in the rehabilitation setting [56]. Fruity Feet uses gaming features to motivate children to engage in physical activity; game settings can be manipulated to target the painful body part. The authors report that VR was safe to use and achieved high levels of patient satisfaction and improvements in pain and function post intervention. Mesaroli et al. (unpublished study) implemented Fruity Feet in Canada with a cohort of youth ($n=8$) with chronic pain

in the context of physiotherapy, and similarly reported high levels of physiotherapist and patient acceptance and feasibility.

Current evidence for VR in pediatric chronic pain, although limited, is promising. Future studies are needed to evaluate the effectiveness of VR in reducing pain or improving function, ideally through controlled trials comparing VR to standard of care. The INOVATE-Pain consortium has outlined guiding principles for VR interventions in pediatric chronic pain with suggested measures and study procedures [41••, 64]. This is critical so comparisons across studies, such as through a systematic review, will be possible. Furthermore, in the context of the COVID-19 pandemic and the shift towards virtual care for chronic pain management [23], the future of immersive technologies should shift accordingly to remote delivery. Adapting VR for at-home use is currently underway through a collaboration with The Hospital for Sick Children in Toronto, Canada, and Stanford Chariot VR in California, USA, funded by Johnson and Johnson.

Mechanism of Action of Immersive Technology in the Pediatric Population

Researchers have postulated the effect of VR on perioperative anxiety and pain by two mechanisms: exposure and distraction [30, 36•]. VR can expose patients and their parents to the perioperative settings (e.g., operating room and recovery area), which allows them to become familiar with the physical environment. The findings of recent randomized controlled trials (RCTs) showed that VR was effectively used as exposure therapy to reduce children's preoperative anxiety (5 to 8 years old) [28, 37–40]. On the other hand, VR can distract and divert pediatric patients' attention away from stressful or painful procedures with engaging materials and direct patients' attention to more pleasant stimulus [36•]. This is because children can be captivated by audiovisual content. In a recent review study [41••], Trost et al. described the VR approaches to pain and discussed the three interrelated dimensions of VR; these dimensions are frequently described as the three key features or pillars of VR [42]: presence, immersion, and interactivity. Presence is the "subjective experience of being in one place or environment, even when one is physically situated in another" [43]. Immersion refers to the user's sense of being engaged and captivated by the digital audiovisual content [41••]. Interactivity is the user's ability to interact and manipulate the virtual space using the technical configuration [41••]. Trost et al. suggested a model (i.e., heuristic model) that can be used as a framework for future VR pain research focusing on VR mechanisms [41••]. This model indicates that VR pain applications can be investigated from the perspective of having VR hardware and software, which enable the production of the pillars of VR. The pillars of VR moderate and mediate

the subsequent changes in the users' cognitive, emotional, social, behavioral, and physiological outcomes (i.e., targets of pain-related therapy), leading to more considerable outcomes such as reduced pain intensity [41••]. Using such a standardized conceptual framework in future research may facilitate reflective and purposeful progress in the immersive technology pain field, which enhances the methodological consistency across studies.

Challenges in Establishing Immersive Technologies in the Pediatric Population

Despite the advance of immersive reality, several challenges exist limiting its use in routine pediatric care [65]. The availability of age-, patient-, and culturally appropriate VR applications, size and weight of the headsets, patient isolation status, and infection control consideration are factors' this group of authors have encountered with clinical and research implementation [65]. The development of VR environments can be costly and requires a team of experts to execute. Pediatric centers may leverage low-cost alternatives such as 360 video environments [65]. Also, the pediatric centers may identify industry partnerships and collaborations to leverage co-design and co-development. The headsets' size may cause headaches and eye aches as most devices' interpupillary distance is designed for older children and adults. As such, most headset developers recommend children over 8 years old to use VR. However, there has been no evidence provided on the effects of VR on younger children. As a result, concerns regarding the use of VR in younger children still exist. The COVID-19 pandemic highlighted the risks of disease transmission and further underlined the importance of infection control during VR among patients. Our institution developed protocols for cleaning devices that include single-use disposable covers, non-fabric headsets, wiping processes, and the use of UV light for disinfecting VR devices and partnering with infection prevention experts was critical. The use of Google Cardboard VR headsets that are single-use can also mitigate infection risk as patients can keep their own devices [65]. Similarly, dedicated reusable devices for the duration of a patient's hospital encounter can be used following consultation with infection control experts and approved cleaning processes.

Conclusions

The current evidence on immersive technology in pediatric perioperative anxiety, acute, and chronic pain is promising despite the limitation of VR technology and current studies. Immersive technology for anxiety and pain in children is a relatively new field driven by rapid technological advancements. Thus, more high-quality RCTs with large sample sizes are needed to investigate the effectiveness and adverse effects

of VR intervention on perioperative anxiety, acute, and chronic pain in pediatrics. Further, standardized theoretical frameworks that facilitate the design of VR trials, the measurement, and reporting of outcomes are essential. In addition, these efforts should include the comparison of VR with other types of technology like AR.

Given the COVID-19 pandemic, we also recommend research on the role of immersive technology for managing in pain using remote VR by children at home.

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Declarations

Conflict of Interest Mohammad Alqudimat declares that he has no conflict of interest.

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Clyde Matava declares that he has no conflict of interest.

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- Of importance
- Of major importance

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