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The efficacy of virtual reality on pain and anxiety reduction during needle-related procedures in a pediatric emergency department setting: a systematic review and meta-analysis

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Background: Needle-related procedures are a common source of pain, anxiety, and fear in pediatric emergency departments (ED), with negative psychological sequelae. Virtual reality (VR) has emerged as a non-pharmacological distraction tool, but its efficacy in the specific, high-stress ED setting requires further synthesis.

Methods: We conducted a systematic review and meta-analysis of randomized controlled trials (RCTs) to evaluate the efficacy of VR for managing needle-related procedural pain and psychological distress in children in the ED. We systematically searched PubMed, Embase, Cochrane Library, and Web of Science from inception until April 2024 for relevant RCTs. Standardized mean differences (SMDs) with 95% confidence intervals (CIs) were pooled using a random-effects model. The primary outcomes were self-reported or observed pain and anxiety; secondary outcomes included fear.

Results: Nine RCTs involving 944 children were included. VR distraction significantly reduced procedural pain (SMD = -0.64, 95% CI: -1.05 to -0.23, $I^2 = 81.8\%$), anxiety (SMD = -0.67, 95% CI: -1.11 to -0.23, $I^2 = 83.1\%$), and fear (SMD = -0.56, 95% CI: -0.77 to -0.36, $I^2 = 34.1\%$) compared to standard care. Sensitivity analyses confirmed the robustness of these findings. High heterogeneity was observed for pain and anxiety outcomes, which may be attributed to variations in VR content (passive vs. interactive), comparator groups, and outcome measurement tools.

Conclusion: VR is an effective non-pharmacological intervention for alleviating needle-related procedural pain, anxiety, and fear in children within the ED. Despite significant heterogeneity, the consistent beneficial effects support its integration into clinical practice. Future research should focus on standardizing VR protocols and identifying the most effective VR modalities for different pediatric age groups.

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KEYWORDS

anxiety, meta-analysis, pain management, pediatric emergency, virtual reality

1 Introduction

Needle-related procedures, such as venipuncture and intravenous cannulation, are among the most frequently performed and feared experiences for children in the Emergency Department (ED) (Gold et al., 2021). The acute pain and distress associated with these procedures are not merely transient discomforts; they can have immediate and long-term negative consequences. In the short term, unmanaged procedural pain and anxiety can lead to heightened distress, physical resistance, and difficulty in securing venous access, potentially compromising clinical care and increasing procedure time (Puntillo et al., 2018; Hoag et al., 2022). From a developmental psychology perspective, these negative experiences can contribute to needle phobia and medical traumatic stress, which may lead to healthcare avoidance and persistent anxiety into adulthood (McLenon and Rogers, 2019; Hildenbrand et al., 2016; Grasso et al., 2013). Therefore, managing procedural distress is a critical component of pediatric emergency care.

The management of procedural pain and distress has traditionally relied on a combination of pharmacological (e.g., topical anesthetics) and non-pharmacological (e.g., distraction, breathing exercises) strategies. While pharmacological agents are effective, they may have limitations such as delayed onset, cost, and potential side effects (Taddio et al., 2010). Non-pharmacological distraction techniques, championed by child life specialists, are foundational but can vary widely in their efficacy and are often dependent on personnel availability and child engagement (Chen et al., 2024; Suleiman-Martos et al., 2022; Addab et al., 2022). In this context, Virtual Reality (VR) has emerged as a potent, immersive non-pharmacological intervention. By creating a compelling, multi-sensory digital environment, VR leverages the limited capacity of attentional resources, theoretically “distracting” the brain from processing nociceptive signals and anxious thoughts—a concept grounded in the gate control theory of pain and attention-load theory (Merino-Lobato et al., 2023; Melzack and Wall, 1965; Malloy and Milling, 2010). This mechanism is particularly relevant in the ED, where time constraints and high-acuity presentations limit opportunities for prolonged preparatory interventions. VR offers a rapidly deployable, immersive distraction that can be initiated immediately, aligning well with the urgent and unpredictable nature of emergency care. While self-report and behavioral observation scales are the clinical gold standard for assessing procedural distress in children, objective physiological measures (e.g., heart rate variability, cortisol, galvanic skin response) can provide complementary data. This review focuses on synthesized subjective outcomes, as they were the primary endpoints in the identified ED-based RCTs, but we discuss the implication of this focus in the limitations.

The body of research on VR for pediatric procedural pain is growing, and previous systematic reviews and meta-analyses have demonstrated its efficacy across various clinical settings, such as elective venipuncture and oncology (Tran et al., 2022; Czech et al., 2021; Lluésma-Vidal et al., 2022). However, generalizing these findings to the ED remains uncertain due to its distinct environment—marked by high stress, unpredictability, time constraints, and typically unprepared patients—all of which may affect VR’s effectiveness (Rowe and Knox, 2023). Although recent

syntheses like that of Cáceres-Matos et al. (2024) provide valuable evidence, they are not ED-specific, and others combine diverse clinical contexts, thereby obscuring VR’s utility in emergency care (Caceres-Matos et al., 2024; Hany et al., 2025; Yue et al., 2024). This underscores the need for a focused and methodologically rigorous synthesis of evidence on VR applied specifically to needle-related procedures in the pediatric ED.

Furthermore, existing studies exhibit significant heterogeneity in their intervention design. Some utilize passive VR (360° video viewing), while others employ interactive VR (game-based engagement), and the content varies substantially (Gold and Mahrer, 2018; Lo et al., 2024; Hamdy et al., 2024; Comparcini et al., 2023). The comparator groups, often labeled “standard care,” also range from routine nursing care to structured distraction by child life specialists, making it difficult to ascertain the absolute and relative benefit of VR (Kasimoglu et al., 2025; Teh et al., 2024). While some trials show dramatic reductions in pain scores (Cheng et al., 2022; Xiang et al., 2021), others report non-significant findings (Fandim et al., 2021; Dumoulin et al., 2019), underscoring the need to explore sources of heterogeneity and the robustness of the pooled effect.

The primary objective of this systematic review and meta-analysis is to quantitatively synthesize the evidence from exclusively RCTs on the efficacy of VR for reducing needle-related procedural pain, anxiety, and fear in children within the ED setting. Our study aims to provide a more precise and context-specific estimate of VR’s effect. The innovation of this work lies in its specific focus on the high-acuity ED environment, its strict inclusion of RCTs to ensure high-quality evidence, and its concurrent evaluation of multiple psychological outcomes (pain, anxiety, fear) to provide a comprehensive picture of VR’s impact. By clarifying VR’s efficacy in this specific context and acknowledging its advantages as a non-invasive, safe, and potentially highly engaging alternative or adjunct to traditional methods, this analysis seeks to inform evidence-based clinical practice in pediatric emergency care.

2 Methods

2.1 Search strategy and data sources

A comprehensive search of the literature was performed across four electronic databases: PubMed, Embase, the Cochrane Library, and Web of Science, covering records from each database’s inception to 30 August 2025. The search strategy was constructed using a combination of controlled vocabulary (including MeSH terms) and free-text keywords to capture relevant studies within four conceptual domains: (Gold et al., 2021): Virtual Reality, (Puntillo et al., 2018), Pediatrics or Child, (Hoag et al., 2022), Pain or Anxiety, and (McLenon and Rogers, 2019) Emergency Service, Hospital. The full search strategies for all databases are available in the [Supplementary Material](#). No language filters were applied during the search to minimize publication bias. However, only studies published in English were included in the final analysis due to feasibility in translation and data extraction. The reference lists of all retrieved articles and relevant review articles were manually screened to identify any additional eligible studies.

2.2 Eligibility criteria

Studies were included based on the following PICOS criteria.

- Population: Pediatric patients (age ≤ 18 years) undergoing any needle-related procedure (e.g., venipuncture, intravenous cannulation) in an emergency department setting.
- Intervention: Any virtual reality-based distraction intervention, regardless of content (passive video or interactive game) or hardware (headset, dome screen).
- Comparator: Standard care or active control (e.g., conventional distraction techniques such as toys, television, or child life specialist support).
- Outcomes: The primary outcomes were patient-reported or observer-rated procedural pain and anxiety. The secondary outcome was fear. Studies had to report quantitative data for at least one of these outcomes using a validated scale.
- Study Design: Only randomized controlled trials (RCTs) were included.

Exclusion criteria comprised: non-randomized studies, studies conducted in non-emergency settings (e.g., outpatient clinics, oncology wards), studies involving adults, review articles, conference abstracts with insufficient data, and studies where the full text was unavailable.

2.3 Study selection and data extraction

The study selection process was performed in accordance with the PRISMA guidelines. All identified records were imported into reference management software, and duplicates were removed. Two reviewers independently screened the titles and abstracts of the remaining records. The full texts of potentially eligible studies were then retrieved and assessed independently by the same two reviewers against the predefined eligibility criteria. Any disagreements at any stage were resolved through discussion or by consultation with a third reviewer.

A standardized, pre-piloted data extraction form was used. The extracted data included: first author, publication year, country, sample size, patient age range, specific needle procedure, details of the VR intervention (type, content, device), details of the control group, and outcome measures with their respective instruments. Key instruments included: for pain—the Faces Pain Scale-Revised (FPS-R, 0–10 scale), the Wong-Baker FACES Pain Rating Scale (WB-FPS, 0–10 scale), and the Visual Analog Scale (VAS, typically 0–100 mm); for anxiety and fear—the Children’s Anxiety Meter (CAM, visual analog scale), the Child Fear Scale (CFS, 0–4 facial expression scale), and the Child Medical Fear Scale (CMFS). For continuous outcomes, the mean, standard deviation (SD), and sample size for each group were extracted. When necessary, corresponding authors were contacted to request missing data.

2.4 Risk of bias assessment

The methodological quality of the included RCTs was independently evaluated by two reviewers using the Cochrane RoB 2 tool for randomized trials (Sterne et al., 2019). This tool assesses five domains: (Gold et al., 2021): bias arising from the

randomization process, (Puntillo et al., 2018), bias due to deviations from intended interventions, (Hoag et al., 2022), bias due to missing outcome data, (McLenon and Rogers, 2019), bias in measurement of the outcome, and (Hildenbrand et al., 2016) bias in selection of the reported result. Each domain was judged as having “low risk,” “some concerns,” or “high risk” of bias. Discrepancies in assessments were resolved by consensus.

2.5 Data synthesis and statistical analysis

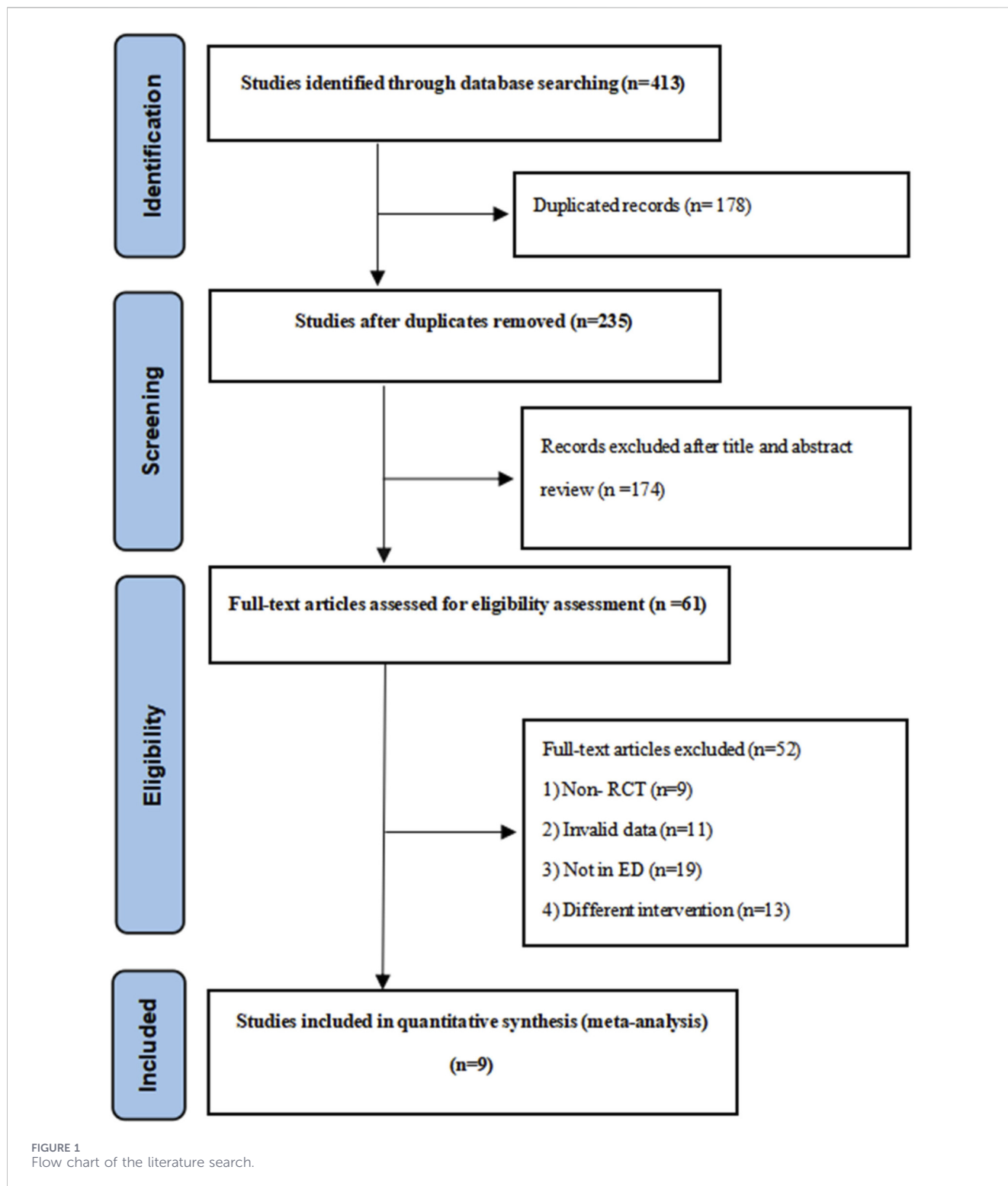
All statistical analyses were performed using Stata software (version 17.0). For outcomes measured on different scales across studies, the treatment effect was estimated using the Standardized Mean Difference (SMD) with 95% Confidence Intervals (CIs). The interpretation of SMD was as follows: <0.2 trivial, 0.2 – 0.5 small, 0.5 – 0.8 medium, and >0.8 large effect. A random-effects model (DerSimonian–Laird method) was employed for all meta-analyses to account for anticipated clinical and methodological heterogeneity among the included studies. Heterogeneity across studies was quantified using the I^2 statistic, where I^2 values of 25%, 50%, and 75% were considered to represent low, moderate, and high heterogeneity, respectively (Migliavaca et al., 2022). The Cochran’s Q test ($p < 0.10$ indicating significant heterogeneity) was also used. To test the robustness of the findings, a sensitivity analysis was conducted by sequentially omitting each study from the meta-analysis and recalculating the pooled estimate. This “leave-one-out” approach assessed whether any single study exerted a disproportionate influence on the overall results. To explore sources of heterogeneity, we planned subgroup analyses based on VR modality (passive vs. interactive) and comparator type (standard care vs. active distraction). However, due to the limited number of studies in each subgroup, these were not formally performed but are discussed narratively in the context of high heterogeneity.

3 Results

3.1 Study selection and characteristics

The initial database search yielded 413 records. After the removal of 178 duplicates, 235 records underwent title and abstract screening. Of these, 61 full-text articles were assessed for eligibility. Fifty-two articles were excluded with reasons, primarily for being conducted in a non-ED setting ($n = 19$) or employing a different intervention ($n = 13$). Ultimately, nine RCTs (Can et al., 2024; Chen et al., 2020; Dumoulin et al., 2019; Goldman and Behboudi, 2021; Goktas and Avci, 2023; Lee et al., 2021; Lee et al., 2023; Litwin et al., 2021; Yıldırım and Gerçeker, 2023) met all inclusion criteria and were incorporated into the quantitative synthesis (meta-analysis). This selection process is detailed in the PRISMA flow diagram (Figure 1).

The characteristics of the nine included studies are summarized in Table 1. The studies, published between 2019 and 2024, were conducted across various countries (Turkey, Canada, South Korea, Taiwan, USA) and enrolled a total of 944 pediatric patients. The age of participants ranged from infants to adolescents (0.5–17 years). The targeted procedures were primarily intravenous cannulation



and venipuncture. The VR interventions varied, including both passive 360° videos (e.g., roller coasters) and interactive games, delivered *via* headsets or dome screens. The control groups received standard care, which typically involved verbal distraction, topical anesthetics, toys, or tablet-based entertainment. Outcome measures included the Faces Pain Scale-Revised (FPS-R), Wong-Baker Faces Pain Scale (WB-FPS), Visual

Analog Scale (VAS) for pain; the Children’s Anxiety Meter (CAM), Child Fear Scale (CFS) for psychological distress.

3.2 Risk of bias assessment

The summary of the risk of bias assessment is presented in Figures 2, 3. The majority of studies were judged to have a low risk of

TABLE 1 Baseline characteristics and primary results of included trials.

Study/country	Sample size	Age (year)	Procedure	Intervention	Compare	Outcome/instruments	Mean (SD) pain score (VR vs. control)
Can 2024 (Turkey)	160	4–10	Peripheral intravenous catheter (PIC) insertion	Passive virtual reality distraction (roller coaster video) + Veinlite PEDI2	Standard care with verbal distraction	Pain: FACES, CAS Anxiety: CAM-S Fear: CFS	4.4 ± 2.3 vs. 6.0 ± 2.3 (FACES, 0–10)
Chen 2020 (Taiwan)	136	7–12	Intravenous injection	Immersive VR: Choice of 4 environments (roller coaster, space, etc.) via headset	Standard care (routine IV with verbal comfort)	Pain: WB-FPS Anxiety: CFS	3.35 ± 2.38 vs. 4.35 ± 2.95 (FPS-R, 0–10)
Dumoulin 2019 (Canada)	59	8–17	Venipuncture and/or IV placement	Interactive VR game: “Shoot the Flies” in a virtual apartment	1. Child life specialist 2. Watching TV	Pain: VAS Anxiety: VAS	33.2 ± 27.2 vs. 36.5 ± 26.7 (VAS, 0–100)
Goldman 2020 (Canada)	66	6–16	Intravenous catheterization	Passive VR: “VR roller coaster” app on a smartphone headset	Standard of care (e.g., TV, iPad, child life specialist, parental comfort)	Pain: FPS-R Anxiety: VSAS	2.1 ± 1.4 vs. 4.2 ± 2.1 (FPS-R, 0–10)
Goktas 2023 (Turkey)	144	7–12	Venipuncture, phlebotomy, or vaccination	VR group: 360° video (“the spacewalker”) via VR headset	Standard care (no VR)	Pain: WB-FPS Anxiety: CAM-S Fear: CMFS	0.42 ± 0.65 vs. 2.72 ± 1.32 (WB-FPS, 0–10)
Lee 2021 (Korea)	19	2–6	Intravenous placement	VR dome screen: “Pororo” animation projected on dome	Standard care (no VR)	Pain: FLACC (Guardian rating)	2.3 ± 2.1 vs. 3.3 ± 3.1 (FLACC, 0–10)
Lee 2023 (Korea)	88	0.5–4	Intravenous placement	VR dome ceiling screen: Custom animal animation	Standard care (no VR)	Pain: FLACC (observer rating)	6.1 ± 3.5 vs. 7.1 ± 5.8 (FLACC, 0–10)
Litwin 2021 (Canada)	60	8–17	Intravenous insertion	Interactive VR: Underwater environment with controller (KindVR Aqua)	Attention control: Video on tablet (ocean video)	Pain: NRS Distress: NRS Fear: CFS	3.0 ± 3.0 vs. 4.0 ± 3.7 (NRS, 0–10)
Yildirim 2022 (Turkey)	150	4–10	Intravenous insertion	VR group (samsung Gear Oculus headset)	Control group (distraction by talking and asking questions)	Pain: WBS Anxiety: CAM Fear: CFS	5.6 ± 1.9 vs. 6.1 ± 1.1 (WBS, 0–10)

CAM, Children’s Anxiety Meter; CAM-S, Children’s Anxiety Meter-State; CFS, Child Fear Scale; CMFS, Child Medical Fear Scale; FLACC, face, Legs, Activity, Cry, Consolability; FPS-R, Faces Pain Scale-Revised; IV, Intravenous; NRS, Numerical Rating Scale; PBCL, Procedure Behavior Check List; VAS, Visual Analog Scale; VAT, visual analogue thermometer; VNRS, Verbal Numerical Rating Scale; VSAS, Venham Situational Anxiety Score; WBS, Wong-Baker Faces Scale; WB-FPS, Wong-Baker Faces Pain Rating Scale.

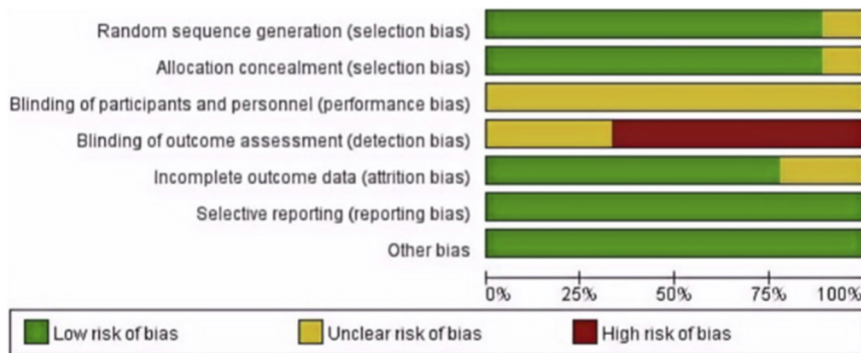
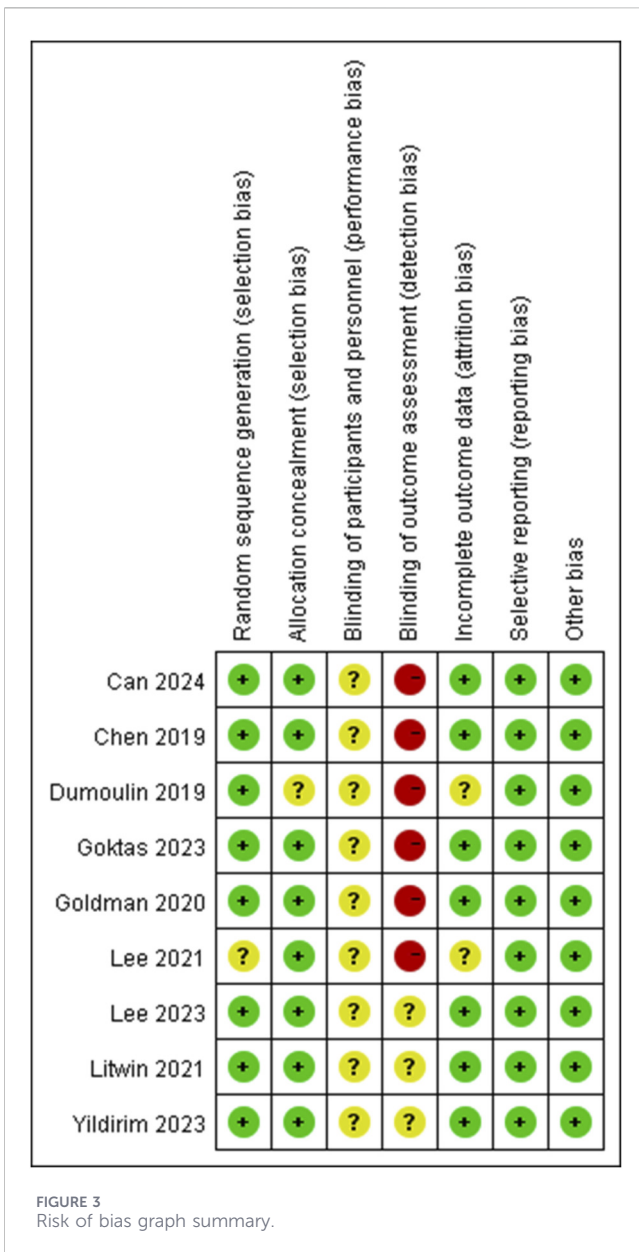


FIGURE 2 Risk of bias graph.

bias concerning the randomization process and selective reporting. However, performance bias was a common area of concern. Due to the nature of the VR intervention, blinding of participants and

personnel was largely not feasible, leading to a rating of “high risk” or “some concerns” for this domain in most studies. Attrition bias was generally low, as most studies reported complete outcome data.



3.3 Primary outcome 1: procedural pain

Nine studies reported data on procedural pain. The pooled analysis demonstrated that VR distraction significantly reduced pain scores compared to control conditions (SMD = -0.64, 95% CI: -1.05 to -0.23). The effect was statistically significant ($p < 0.01$), favoring the VR group. Considerable heterogeneity was observed among the studies ($I^2 = 81.8\%$, $p < 0.001$) (Figure 4).

3.4 Primary outcome 2: Procedural anxiety

Eight studies assessed procedural anxiety. The meta-analysis revealed a significant beneficial effect of VR on reducing anxiety (SMD = -0.67, 95% CI: -1.11 to -0.23, $p < 0.01$). Similar to the pain outcome, the analysis exhibited high heterogeneity ($I^2 = 83.1\%$, $p < 0.001$) (Figure 5).

3.5 Secondary outcome: procedural fear

Five studies measured procedural fear. The pooled result indicated a statistically significant reduction in fear associated with VR use (SMD = -0.56, 95% CI: -0.77 to -0.36, $p < 0.001$). The heterogeneity for this outcome was low to moderate ($I^2 = 34.1\%$, $p = 0.194$) (Figure 6).

3.6 Sensitivity analysis

Sensitivity analyses employing the leave-one-out method were conducted for all three outcomes. For pain (Figure 7) and anxiety (Figure 8), the sequential exclusion of individual studies did not materially alter the direction or statistical significance of the pooled SMDs. The overall estimates remained stable, with the upper limit of the 95% CI consistently below zero, confirming the robustness of the primary findings. The sensitivity analysis for fear (Figure 9) similarly affirmed the stability of the result for that outcome.

4 Discussion

This systematic review and meta-analysis provide a comprehensive synthesis of the current evidence regarding the efficacy of VR as a non-pharmacological intervention for managing needle-related procedural distress in the pediatric ED. By pooling data from nine randomized controlled trials involving 944 children, our findings offer robust, quantitative evidence supporting the integration of VR into clinical practice. The discussion that follows will interpret these findings, elucidate the underlying mechanisms, contextualize the clinical and policy implications, acknowledge the study's limitations, and propose directions for future research.

The primary finding of this meta-analysis is that VR distraction produces a statistically significant and clinically meaningful reduction in pain, anxiety, and fear during painful needle procedures in the ED. The pooled effect sizes, with SMDs of -0.64 for pain, -0.67 for anxiety, and -0.56 for fear, all fall within the range of a medium effect according to conventional benchmarks. This consistency across all three core domains of procedural distress is noteworthy, as it suggests that VR's benefits are not limited to a single dimension but provide a holistic mitigation of the negative experience. The result for pain and anxiety is particularly compelling given the challenging context of the ED, characterized by its high-acuity, unpredictable nature, and limited pre-procedural preparation time, which often differs from more controlled settings like elective day surgery units (Koller and Goldman, 2012).

A pivotal aspect of our results is the pronounced heterogeneity observed for the pain ($I^2 = 81.8\%$) and anxiety ($I^2 = 83.1\%$) outcomes. Rather than merely a statistical limitation, this heterogeneity is informative and likely reflects the authentic clinical and methodological diversity of the nascent field. Key sources include the spectrum of VR modalities, ranging from passive 360° videos to immersive, interactive games. Key sources of heterogeneity include the nature of the VR experience. While often categorized as passive (e.g., 360° videos) or interactive (e.g., games), this dichotomy may be simplistic. The therapeutic content

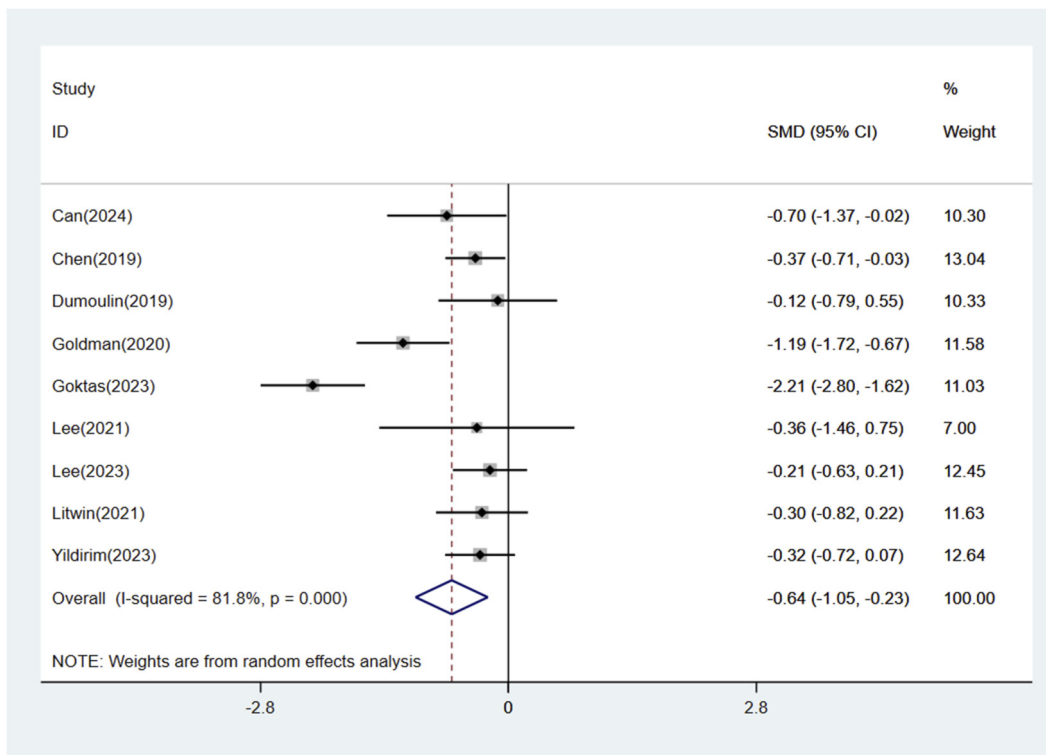


FIGURE 4 Forest plot effect of VR on pain.

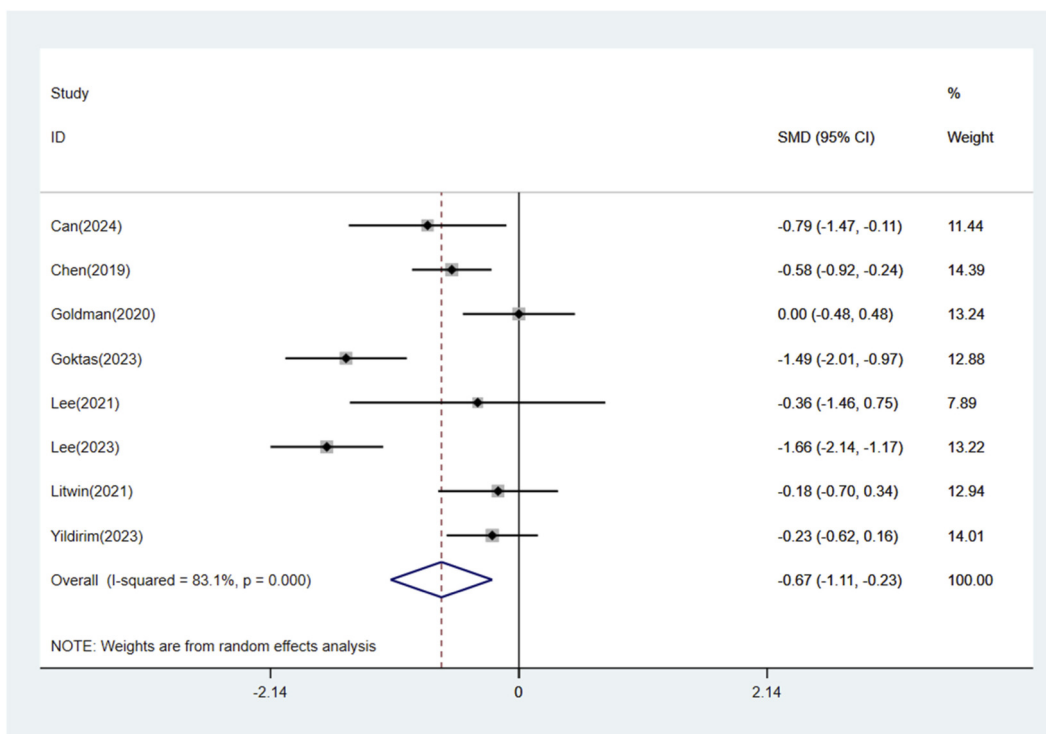


FIGURE 5 Forest plot effect of VR on anxiety.

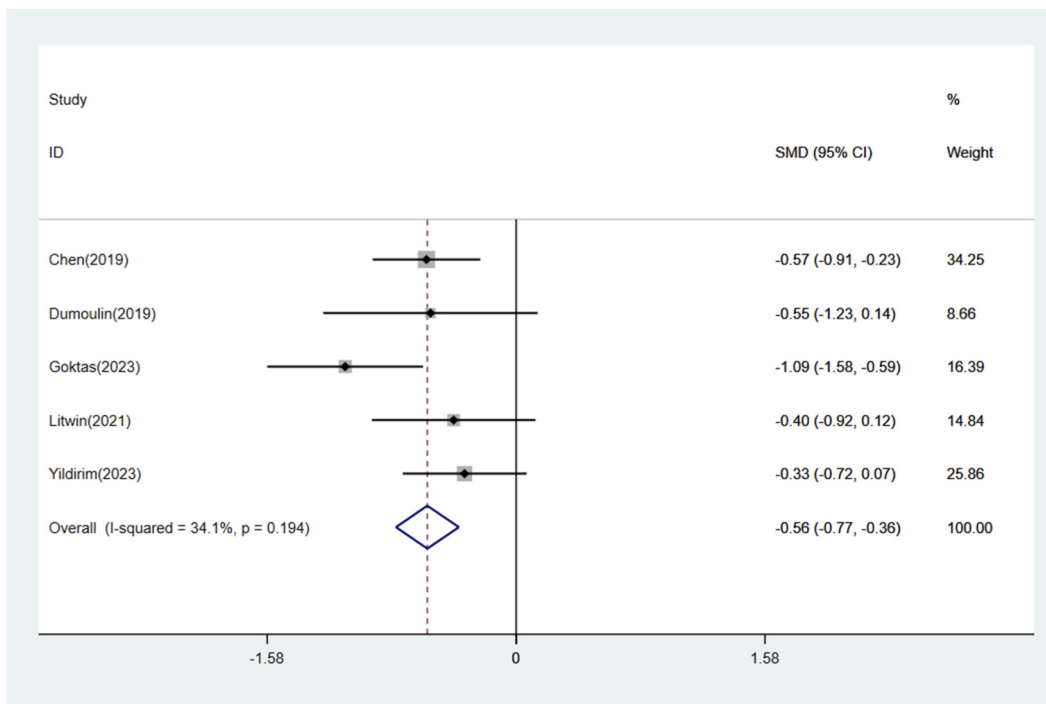


FIGURE 6 Forest plot effect of VR on fear.

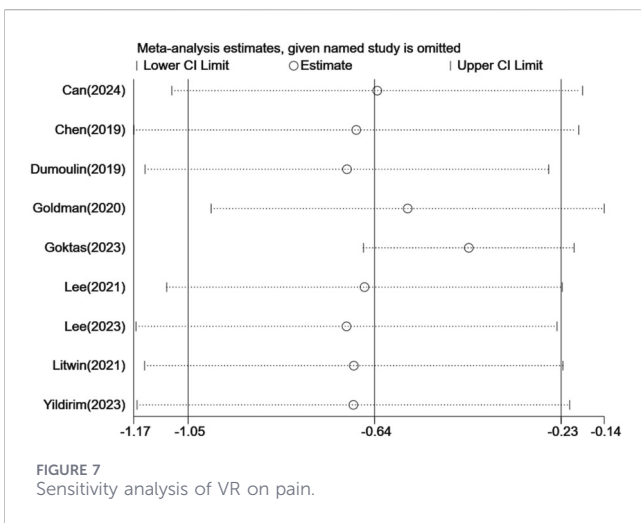


FIGURE 7 Sensitivity analysis of VR on pain.

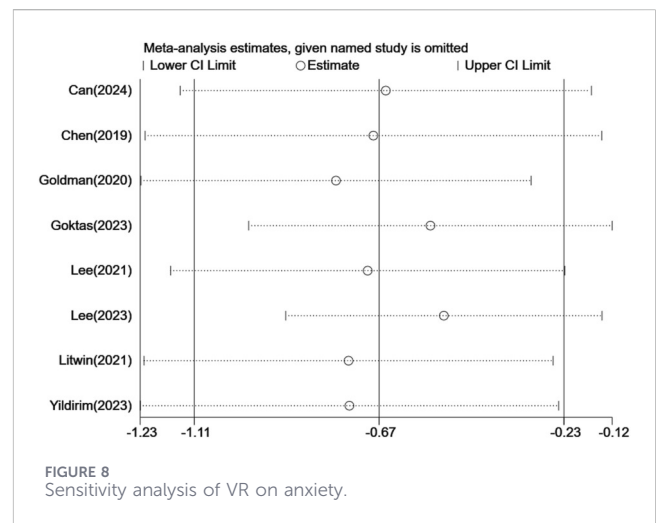
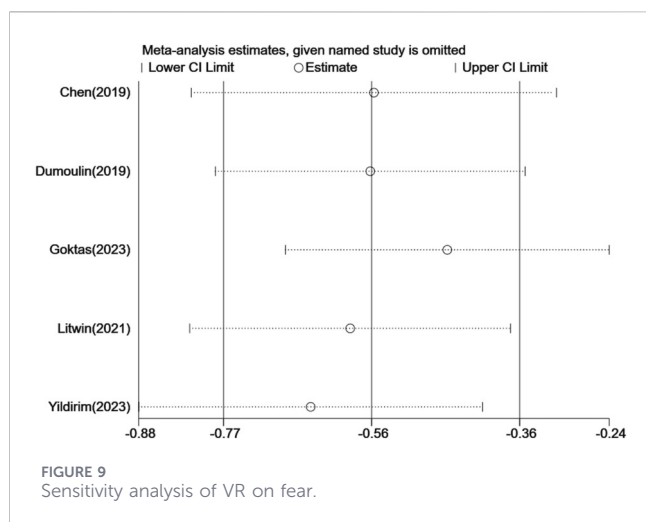


FIGURE 8 Sensitivity analysis of VR on anxiety.

itself—whether it is designed for high-arousal distraction (e.g., a roller coaster), relaxation (e.g., a tranquil forest), or mindful engagement—and the degree of cognitive absorption it requires are likely pivotal moderators. For example, Lier et al. (2023) found passive VR to be particularly effective, suggesting immersive relaxation may be highly potent (Elisabeth et al., 2023). Our analysis could not formally dissect these elements, but their variability undoubtedly contributes to the observed heterogeneity in effect sizes. The “dose” and quality of immersion may vary significantly between these formats, potentially influencing their efficacy. Furthermore, the “standard care” comparator was not uniform across studies, ranging from basic verbal distraction to

structured interventions by child life specialists. A larger effect size might be expected when VR is compared to minimal distraction than when it is compared to a robust, active control. Finally, the use of different outcome assessment tools (e.g., self-report vs. observer-rated scales) and the wide age range of participants, who have vastly different cognitive capacities and fears, further contribute to the variable effect sizes (von Baeyer, 2006). In contrast, the lower heterogeneity for the fear outcome ($I^2 = 34.1\%$) may indicate a more consistent effect of VR on this specific emotional state, perhaps because fear is more directly targeted by the immersive distraction from the threatening needle stimulus.



The efficacy of VR is not serendipitous but is grounded in well-established psychological and neurobiological theories. The most prominent explanation is the Gate Control Theory of Pain, which posits that cognitive-affective processes can modulate nociceptive transmission at the spinal cord level (Melzack and Wall, 1965). VR acts as a powerful non-pharmacological “gate closer” by consuming a substantial portion of the brain’s limited attentional resources. This is explained by the Limited Capacity Model of Attention, which suggests that immersing a patient in a compelling virtual world leaves fewer cognitive resources available to process incoming pain signals (McCaul et al., 1992). Functional MRI studies have provided empirical support for this, demonstrating that VR distraction can lead to reduced activity in pain-processing brain regions, such as the insula and anterior cingulate cortex, while engaging networks associated with visual attention and executive control (Hoffman et al., 2004). Beyond simple distraction, VR’s immersive nature can facilitate relaxation and a sense of presence, which may be particularly effective in mitigating anxiety. Content featuring calming narratives or natural environments may operate through different psychological pathways (e.g., promoting parasympathetic activation) compared to fast-paced interactive games (Cieslik, 2025; Ishitani et al., 2025).

Beyond simple distraction, VR’s immersive nature facilitates presence—the subjective feeling of “being there” in the virtual environment (Triberti et al., 2025). A strong sense of presence is thought to be a key mediator of VR’s analgesic effect, as it enhances the emotional and cognitive engagement with the virtual world, thereby creating a more effective perceptual disconnect from the clinical environment (Indovina et al., 2018). Moreover, from a psychological perspective, VR can empower the child by providing them with a sense of “agency and control” within the virtual environment, which stands in stark contrast to the passive and often helpless experience of a medical procedure (Ahmadpour et al., 2024). This shift from a passive victim to an active explorer in a virtual world can directly counter feelings of anxiety and fear. Neurobiologically, engaging and enjoyable distractions like VR are believed to activate the brain’s endogenous opioid systems and the descending pain modulatory pathways, providing a natural, analgesia that complements the attentional mechanisms (Fields, 2018; Pappalettera et al., 2024). Therefore, VR is not merely a “distraction” but a complex neuromodulatory intervention that

operates at the intersection of attention, emotion, and pain perception.

The findings of this meta-analysis carry significant practical implications. For clinicians in the bustling ED environment, VR represents a safe, non-invasive, and highly engaging tool that can be readily deployed alongside standard care. Its particular value lies in situations where pharmacological agents are contraindicated, have delayed onset, or are insufficient to address the accompanying psychological distress (Taddio et al., 2009). It can serve as a powerful adjunct for child life specialists and nurses, augmenting their toolkit for procedural support. The consistent positive effects across multiple studies suggest that investing in VR technology could lead to tangible improvements in patient experience, potentially reducing procedure times and improving first-attempt success rates by minimizing child movement stemming from fear and pain.

Our findings align with and extend the evidence from previous systematic reviews evaluating VR for pediatric needle-related pain across various settings. For instance, Czech et al. (2021) and Lier et al. (2023) also reported significant pain reduction with VR (Czech et al., 2021), with Lier et al. noting a potentially larger effect for passive formats (Elisabeth et al., 2023). Similarly, Gao et al. (2023) concluded VR is effective for acute procedural pain (Yan et al., 2022). The medium effect sizes (SMDs -0.56 to -0.67) we observed in the ED are consistent with these broader syntheses, suggesting VR’s efficacy is robust even in the high-stress, unpredictable emergency context. However, our focused analysis reveals that heterogeneity remains particularly high in the ED setting, potentially more so than in elective or oncology contexts, underscoring the unique moderating factors (e.g., acuity, lack of preparation) at play in emergency care.

From a policy perspective, this synthesis provides the robust, Level-1 evidence needed to inform clinical guidelines and funding decisions. Healthcare administrators and policymakers may consider VR implementation as a potential strategy to enhance patient-centered care. However, formal cost-effectiveness was not assessed in this review and is likely to vary across settings depending on factors such as equipment costs, staffing models, and local willingness-to-pay. Future research should include robust economic evaluations to determine VR’s value in pediatric emergency care.

The innovative contribution of this review is its specific and rigorous focus on the emergency department setting. While previous meta-analyses have established the efficacy of VR in pediatrics, they have often amalgamated data from diverse settings such as oncology wards and outpatient clinics (Cheng et al., 2022; Eijlers et al., 2019). The ED presents a unique set of challenges—acuteness, lack of prior relationship with the patient, and high ambient stress—that may influence intervention effectiveness. By isolating this context, our analysis provides a more precise and applicable estimate of VR’s utility for emergency care providers. Furthermore, by concurrently evaluating pain, anxiety, and fear, we offer a more holistic view of VR’s impact than reviews focusing solely on pain intensity, thereby underscoring its role as a comprehensive psychological intervention.

Several limitations of this study must be acknowledged. First, the high statistical heterogeneity, while exploratory, indicates that the magnitude of VR’s benefit is not uniform and is influenced by moderating factors we could not fully account for in a meta-analysis. Second, the general inability to blind participants and personnel to the intervention is an inherent limitation in RCTs of behavioral

interventions like VR, potentially introducing performance bias. Third, the majority of included studies utilized observer-rated scales for younger children, which, while validated, may not fully capture the child's internal subjective experience compared to self-report. Fourth, our analysis could not formally investigate the impact of specific VR features (e.g., level of interactivity, content type, headset vs. dome screen) due to the limited number of studies and inconsistent reporting. This “lumping” of different VR modalities, while necessary for a pooled analysis, may obscure the optimal protocol for maximum efficacy. Fifth, the high or unclear risk of performance and detection bias in most studies, due to the inherent challenge of blinding participants and personnel to VR, is a significant limitation. This may have particularly influenced subjective self-reports of anxiety and pain. The absence of objective physiological data in the included studies means we cannot triangulate the subjective findings with unbiased measures, potentially inflating the estimated effect sizes. Future trials should strive to incorporate such objective endpoints where feasible. Sixth, our analysis relied exclusively on subjective measures of pain, anxiety, and fear. While these are patient-centered and clinically meaningful, the inclusion of objective physiological correlates (e.g., heart rate, cortisol) could have provided a more comprehensive, multi-modal assessment of the stress response. The general absence of such data in ED-focused RCTs highlights an important gap for future research. Furthermore, the inability to blind participants may have introduced expectancy effects; children assigned to control groups might have felt disappointed or ‘unlucky,’ potentially elevating their baseline anxiety compared to the VR group. Finally, the economic aspect of VR implementation—cost, staff training, and equipment maintenance—was not evaluated but is a critical consideration for real-world adoption.

5 Conclusion

In conclusion, this meta-analysis consolidates high-quality evidence that Virtual Reality is an effective intervention for mitigating the pain, anxiety, and fear associated with needle-related procedures in the pediatric emergency department. Despite variability in its application, the overall beneficial effect is clear and compelling. The beneficial effects of VR are consistent with established psychological frameworks such as the gate control theory and limited capacity model of attention, which posit that immersive engagement can modulate the perception of nociceptive and anxious stimuli. While our review synthesizes clinical outcomes, the precise neurophysiological mechanisms warrant further investigation in pediatric ED populations.

Data availability statement

The original contributions presented in the study are included in the article/[Supplementary Material](#), further inquiries can be directed to the corresponding author.

Author contributions

JJ: Writing – review and editing, Formal Analysis, Methodology, Data curation, Writing – original draft, Conceptualization, Software, Validation. JS: Supervision, Data curation, Investigation, Methodology, Writing – original draft, Writing – review and editing. WS: Writing – original draft, Software, Methodology, Writing – review and editing. SG: Software, Writing – original draft, Formal Analysis, Methodology, Data curation. KY: Software, Writing – original draft, Data curation, Methodology. JR: Writing – review and editing, Supervision, Conceptualization, Visualization, Methodology.

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Supplementary material

The Supplementary Material for this article can be found online at: <https://www.frontiersin.org/articles/10.3389/frvir.2026.1759834/full#supplementary-material>

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