REVIEW ARTICLE

Comparative effectiveness of virtual reality and other non-pharmacological distraction strategies for pain and anxiety during pediatric fracture-care procedures: a systematic review and network meta-analysis of randomized controlled trials

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ABSTRACT

Introduction: Children undergoing fracture-care procedures often experience pain and anxiety. Whether immersive virtual reality (VR) outperforms other non-pharmacological distraction strategies remains unclear.

Methodology: We searched MEDLINE/PubMed, Scopus, Web of Science, CENTRAL, and ClinicalTrials.gov from inception to 9 October 2026 for randomized controlled trials of distraction strategies during pediatric closed reduction, casting or splinting, cast removal, and pin removal. Risk of bias (ROB) was assessed with RoB 2. A frequentist network meta-analysis estimated standardized mean differences (SMDs) for procedural pain and anxiety, heart rate, procedure duration, and parent satisfaction, and risk ratios for rescue analgesia.

Results: Of 1,386 records, 12 randomized trials were included. Five trials (877 children) informed procedural pain; only passive VR added to standard care outperformed standard care (SMD −0.54, 95% confidence interval [CI] −1.03 to −0.05), whereas interactive VR, passive VR alone, and screen-based distraction did not. Nine trials informed anxiety; every strategy reduced anxiety versus standard care, with music/audio ranking first (SMD −0.69, 95% CI −1.06 to −0.32; P-score 0.84), followed by other non-pharmacological strategies and therapeutic play. Only music/audio lowered heart rate (SMD −0.82, 95% CI −1.54 to −0.11). Rescue analgesia, procedure duration, and parent satisfaction did not differ. Nine trials (75%) had high risk of bias, networks were sparse, and heart-rate heterogeneity was substantial (I^2 = 76.2%).

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Conclusion: Non-pharmacological distraction may reduce procedural anxiety during fracture care, but evidence that VR is superior to simpler strategies is limited and uncertain. Rankings should be interpreted cautiously, and larger, rigorous head-to-head trials are needed.

Keywords: Virtual reality, pediatric fractures, non-pharmacological distraction, network meta-analysis.

Introduction

Fractures are among the most common injuries of childhood. In classic population-based data, roughly 40% of boys and 25%–30% of girls sustained at least one fracture before the age of 16 years [1], and fractures remain a frequent reason for emergency and orthopedic consultation [2]. Care is usually delivered in the pediatric emergency department, the cast room, or the orthopedic outpatient clinic, where awake children undergo a sequence of procedures: closed fracture reduction (with or without procedural sedation), splinting or casting, cast removal, and removal of percutaneous pins or Kirschner wires (K-wire) after fracture treatment [2].

These encounters are frequently frightening for children. Cast removal is generally not painful, and pain scores are typically low, but the noise and vibration of the saw and the fear of being cut commonly provoke marked anxiety [3,4]. Pin removal and fracture reduction add genuine procedural pain, with mean pain scores of about 3–4 out of 10 reported for office pin removal [5]. Procedural anxiety and poorly controlled pain are not trivial: in children undergoing surgery, preoperative anxiety predicts greater postoperative pain and maladaptive behavior [6], and negatively biased memories of a painful procedure amplify pain and distress at subsequent procedures [7].

Pharmacological options are limited for these brief, high-turnover clinic procedures. Randomized trials of oral paracetamol, oral ibuprofen, and topical liposomal lidocaine before pin removal found no measurable benefit over placebo [5], and procedural sedation requires monitoring and lengthens visits. Non-pharmacological strategies are therefore attractive because they are simple, inexpensive, and largely free of adverse effects. Psychological interventions, including distraction, reduce pain, and distress during needle procedures in children [8], and a range of strategies have been tested in fracture care: music and audio, tablet-based videos and games, therapeutic play and child life specialist support, and noise-reducing ear protection [9,10].

Immersive virtual reality (VR), which occupies the child's visual and auditory fields through a head-mounted display, is thought to divert attention away from noxious stimuli [11] and has reduced pain and anxiety across pediatric procedures [12]. In orthopedic procedures, however, the evidence is inconsistent. Randomized trials have reported lower anxiety with VR than with standard care during cast removal and plaster treatment [4,13] and lower pain during K-wire removal [14], whereas another trial found no effect on heart rate or self-reported pain [3]. Head-to-head trials suggest that VR may be no better than inexpensive alternatives such as a tablet video or game [15,16], which matters given the cost, logistics, and variable tolerance of headsets.

Existing syntheses do not resolve this question. A recent meta-analysis pooled four randomized trials comparing VR with standard care and reported reductions in anxiety, pain, and heart rate [17], while other reviews of VR and augmented reality in orthopedic settings [18] and of entertainment interventions in the cast room [19] were narrative or scoping in design.

We therefore conducted a systematic review and network meta-analysis of randomized controlled trials (RCTs) to compare the effectiveness of VR and other non-pharmacological distraction strategies, against standard care and against each other, for procedural pain and anxiety in children and adolescents undergoing fracture-care procedures.

Methods

Methodology

The conduct and report of this systematic review and network meta-analysis followed the principles of the Cochrane Handbook for Systematic Reviews of Interventions, version 6.5, and the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines [20,21].

Research question

In children and adolescents (0–18 years) undergoing fracture-care procedures (closed reduction, splinting or casting, cast removal, or pin/K-wire removal), what is the comparative effectiveness of immersive VR and other non-pharmacological distraction strategies (screen-based distraction, music or audio, therapeutic play or child life support, noise reduction or ear protection, and other strategies), compared with standard care and with each other, in reducing procedural pain and procedural anxiety? As secondary questions, which strategy ranks highest for each outcome, and how do the strategies compare for heart rate, need for rescue analgesia or sedation, procedure duration, and parent and provider satisfaction?

Research aim

To systematically identify RCTs of non-pharmacological distraction strategies during pediatric fracture-care procedures, to compare and rank these strategies for procedural pain and anxiety using a frequentist network meta-analysis, and to describe how effects vary by setting, age, procedure type, and VR immersion level.

Research objectives

This study aimed to: (1) systematically identify RCTs evaluating non-pharmacological distraction strategies during fracture-care procedures in children and

adolescents; (2) estimate the effect of immersive VR compared with standard care on procedural pain and anxiety; (3) compare VR with other distraction strategies (screen-based distraction, music or audio, therapeutic play or child life support, and noise reduction or ear protection), using direct and indirect evidence; (4) rank the strategies for each primary outcome; (5) synthesize secondary outcomes, including heart rate, need for rescue analgesia or sedation, procedure duration, parent and provider satisfaction; and (6) appraise risk of bias using the Cochrane risk of bias (ROB) 2 tool.

Inclusion Criteria

Types of studies

This network meta-analysis considered RCTs (parallel-group, cluster, or crossover) of any duration that compared at least two of the strategies defined below, one of which could be standard care, during a pediatric fracture-care procedure. Quasi-randomized and non-randomized studies were not eligible.

Participants

Children and adolescents aged 0–18 years undergoing a fracture-care procedure: closed fracture reduction (with or without sedation), splinting or casting, cast removal, or pin/K-wire removal after fracture treatment. Eligible settings were the pediatric emergency department, the cast room, and the orthopedic outpatient clinic.

Intervention

The network nodes were (1) immersive VR (head-mounted display; game or video); (2) screen-based distraction (tablet, iPad, video, cartoons); (3) music or audio, with or without headphones; (4) therapeutic play or child life specialist support; (5) noise reduction or ear protection (earmuffs, noise-cancelling headphones); and (6) other non-pharmacological strategies (e.g., clown care, preparatory information, stress ball), analyzed as a separate node when at least two trials were available. Combined interventions (e.g., noise-cancelling headphones with a personal electronic device, or multimodal distraction) were analyzed as a separate node when at least two trials were available and otherwise described narratively and kept out of the network.

Comparison

Standard care (routine practice, reassurance, or no structured distraction) was the reference node. Any other node above was eligible as a comparator in head-to-head trials. Trials whose control arm was a pharmacological intervention only were excluded, unless the pharmacological treatment was identical in all arms.

Exclusion Criteria

Studies were excluded for any of the following reasons: (1) duplicate publications, including multiple reports of the same trial and registry records of an already included trial; (2) study protocols or trial registrations without reported results; (3) systematic reviews, meta-analyses, and narrative or scoping reviews; (4) conference abstracts or other records without extractable data; (5) full texts that could not be accessed; (6) quasi-randomized or non-randomized designs (quasi-experimental, before-and-after, historical-control, observational, single-arm, retrospective, and case-series studies, and quality-improvement projects without true randomization); (7) populations or procedures outside the scope of the review, namely needle procedures (venipuncture, intravenous placement), dental or burn procedures, operative procedures under general anesthesia (including perioperative or postoperative pain after fracture surgery), non-fracture orthopedic, rehabilitation, or imaging procedures, and adult populations; (8) a control arm consisting of a pharmacological intervention only, unless the pharmacological treatment was identical in all arms; and (9) studies that reported none of the pre-specified outcomes in a usable form.

Search Strategy

Electronic searches

The following electronic databases were searched for eligible studies: MEDLINE/PubMed, Web of Science (WOS), Scopus, CENTRAL/Cochrane Library, and ClinicalTrials.gov. The reference lists of relevant articles and reviews were also searched manually for additional eligible studies. The search was set for all articles published in English from inception until 9th October 2026.

The following search terms were used: ("virtual reality" OR "VR" OR "immersive" OR "head mounted display*" OR "VR headset*" OR "virtual environment*" OR "VR distraction" OR "digital distraction") AND (child* OR pediatric* OR paediatric* OR adolescen* OR infant* OR "young patient*") AND (fracture* OR "fracture reduction" OR cast* OR casting OR splint* OR "cast removal" OR "orthopedic procedure*" OR "orthopaedic procedure*" OR "closed reduction" OR dislocation*) AND (pain OR anxiety OR distress OR fear OR "procedural pain" OR "procedural anxiety").

Other resources

In addition to the electronic database searches, the first reviewer manually searched the reference lists of all retrieved articles and relevant reviews for other potentially eligible studies that were not retrieved by electronic search.

Selection of studies

The first reviewer screened the retrieved reports for eligibility through title and abstract screening, followed by full-text screening. The second reviewer checked the retrieved studies, and discrepancies were resolved through discussion with a third reviewer.

Data extraction

The first reviewer carried out data extraction from the included studies using a standardized data sheet. The extracted data included: study ID (author, year), country,

trial registration, study design, setting (emergency, cast room, or outpatient clinic), procedure type (closed reduction, casting or splinting, cast removal, or pin/K-wire removal), total sample size and sample size by arm, age (mean or median, and range), sex (% male), intervention node and its details (device, content, interactive or passive format, immersive or non-immersive, and duration of exposure), comparator, outcome measures and timing of assessment, outcome data by arm (mean, SD, and number analyzed), and secondary outcomes (heart rate, rescue analgesia or sedation, procedure duration, parent and provider satisfaction). The second reviewer independently checked all collected data for accuracy and completeness. Any disagreements between reviewers were resolved through discussion and, if necessary, arbitration by a third reviewer.

Measured outcomes

The primary outcomes were procedural pain and procedural anxiety. Pain was measured with validated self-report or observer-rated scales such as the Faces Pain Scale-Revised, Wong-Baker FACES scale, visual analogue scale, or numeric rating scale [22]. Anxiety or fear was measured with scales such as the modified Yale Preoperative Anxiety Scale [23], Child Fear Scale [24], visual analogue scale for anxiety, State-Trait Anxiety Inventory for Children, or Child-Adult Medical Procedure Interaction Scale-Revised. Both outcomes were pooled as standardized mean differences (SMD). When several scales were reported, self-report was preferred over observer-rated and then parent-rated measures. Secondary outcomes were heart rate; need for rescue analgesia or sedation; procedure duration; parent satisfaction; and provider satisfaction.

Assessment of the risk of bias

Risk of bias in RCTs was independently assessed using the Cochrane Risk of Bias tool for randomized trials, version 2 (RoB 2) [25], which evaluates five domains: the randomization process, deviations from intended interventions, missing outcome data, measurement of the outcome, and selection of the reported result. Each domain was judged as low risk, some concerns, or high risk, and these judgments were combined into an overall judgment for each study according to the RoB 2 algorithm. The second reviewer independently checked ROB accuracy. Any disagreements between reviewers were resolved through discussion and, if necessary, arbitration by a third reviewer.

Statistical analysis

Network meta-analyses were conducted within a frequentist framework using R software (version 4.6.1). Continuous outcomes were pooled as SMD (procedural pain, procedural anxiety, heart rate, and parent satisfaction) or mean differences (MD; procedure duration), and rescue analgesia as risk ratios (RR), each with 95% confidence intervals. Standard care was the reference node. Random-effects models were used, except for rescue analgesia, for which a common-effects model was applied because only two studies contributed. Treatments were ranked using *p*-scores. Heterogeneity was quantified with τ^2 and I^2, and inconsistency was evaluated with the design-by-treatment interaction test when the network contained closed loops.

Study selection

Electronic database searches initially retrieved 1,386 records. After removing 521 duplicates, 865 records underwent title and abstract screening, and 60 reports were assessed in full text for eligibility, of which 12 RCTs [4,9,10,13–16,26–30] met all inclusion criteria and were included in this network meta-analysis (Table 1). The remaining 48 reports were excluded according to the pre-defined exclusion criteria: study protocol or trial registration without reported results (n = 18); duplicate publication or registry record of an already identified trial (n = 18); full text not accessible (n = 4); quasi-randomized design (n = 4); randomized trial excluded during data extraction (n = 1); non-randomized single-arm design without a comparator (n = 1); conference abstract (n = 1); and review or meta-analysis (n = 1) (Figure 1) [20].

Results

Procedural pain

Five studies [13–16,26] (k = 5; 6 treatments) with a total of 877 patients were pooled for procedural pain (Figure 2). Compared with standard care, only passive VR combined with standard care significantly reduced pain (SMD −0.54, 95% CI −1.03 to −0.05; p = 0.032). Screen-based distraction (SMD −0.54, 95% CI −1.21 to 0.14; p = 0.119), interactive VR (SMD −0.37, 95% CI −0.96 to 0.21; p = 0.210), and interactive VR combined with standard care (SMD −0.18, 95% CI −0.72 to 0.36; p = 0.518) showed non-significant reductions, whereas passive VR alone did not differ from standard care (SMD 0.02, 95% CI −0.70 to 0.75; p = 0.952). Screen-based distraction ranked highest (*p*-score 0.81), followed by passive VR combined with standard care (0.77) and interactive VR (0.61), while passive VR alone (0.19) and standard care (0.19) ranked lowest. Heterogeneity was moderate (τ^2 = 0.046; I^2 = 49.4%, 95% CI 0.0% to 83.3%; Q = 5.93, p = 0.115), and there was no significant inconsistency between designs (Q = 1.63, p = 0.202) (Figure S1).

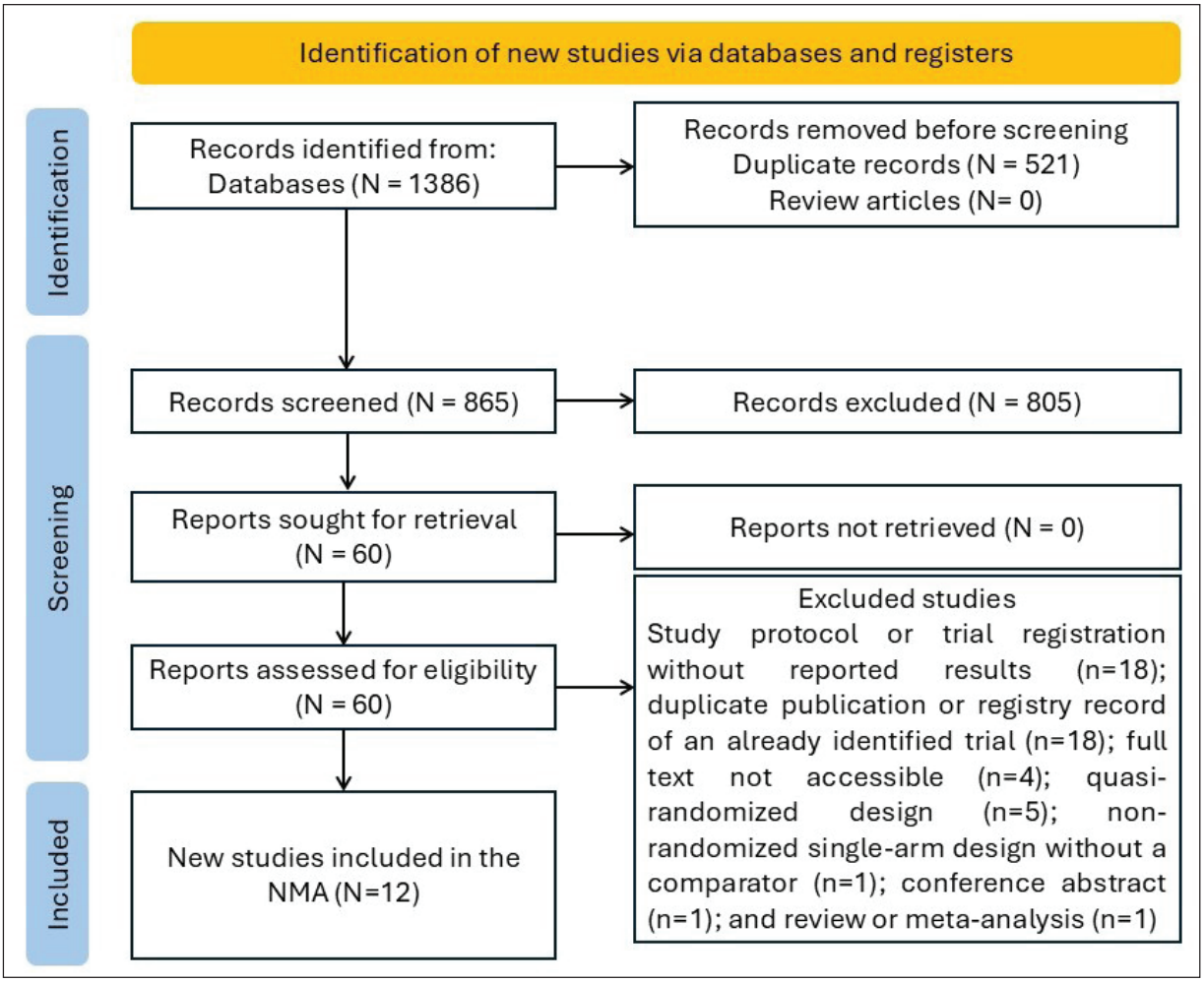
Procedural anxiety

Nine studies [4,9,13,15,16,26,28–30] (k = 9; 7 treatments) including 1,003 patients contributed to the anxiety network (Figure 3). All interventions significantly reduced anxiety compared with standard care. Music/audio distraction had the largest effect (SMD −0.69, 95% CI −1.06 to −0.32; p = 0.0002), followed by other non-pharmacological interventions (SMD −0.64, 95% CI −1.13 to −0.14; p = 0.011), therapeutic play (SMD −0.56, 95% CI −0.95 to −0.17; p = 0.005), passive VR (SMD −0.40, 95% CI −0.65 to −0.15; p = 0.002), interactive VR (SMD −0.39, 95% CI −0.64 to −0.14; p = 0.002), and screen-based distraction (SMD −0.29, 95% CI −0.57 to −0.01; p = 0.044). Music/audio distraction ranked highest (*p*-score 0.84), followed by other non-pharmacological interventions (0.75) and therapeutic play (0.68), while

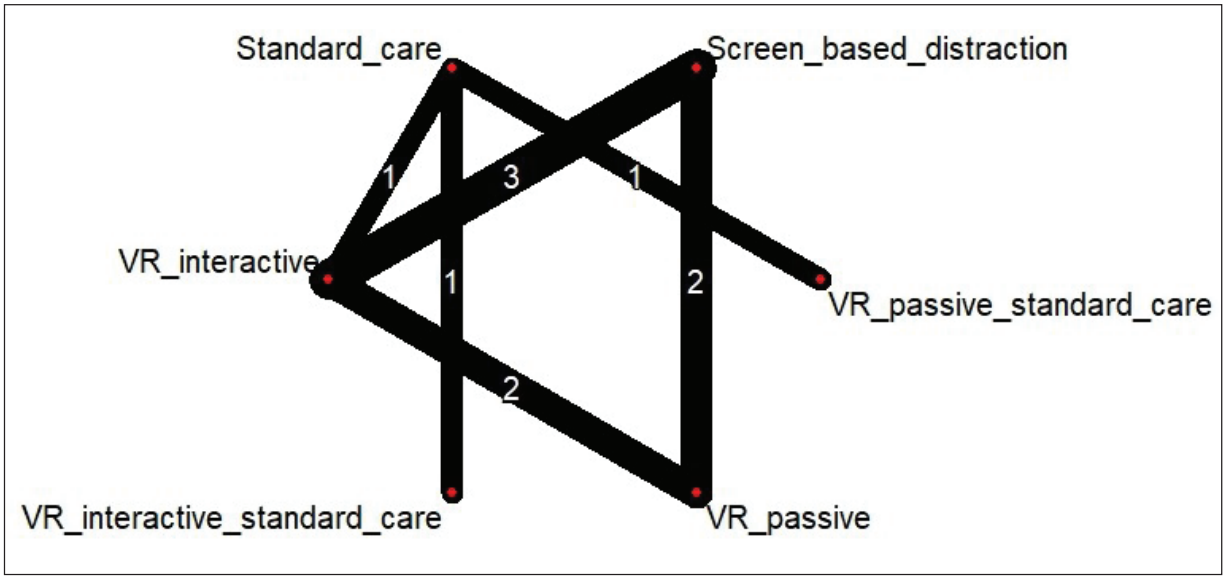
Table 1. *Summary of the characteristics and main findings of the included studies.*

Study (country)	Setting and procedure	Analyzed, *n* (age, *y*)	Intervention	Comparator	Main outcomes	Main findings
Desai et al., 2024 [26] (USA)	Outpatient orthopedic clinic; cast removal, cast application, pin removal, fracture reduction	95 (VR 48; control 47); 5–17 (mean 10.4)	Interactive immersive VR (Oculus headset, rock-skipping game)	Standard care	Heart-rate rise (primary); Wong-Baker FACES pain; VAS anxiety	Smaller heart rate rise with VR (10.6 *vs.* 18.4 bpm; $p < 0.001$); pain and anxiety lower with VR but not significant ($p \approx 0.07$)
Fabricant et al., 2024 [15] (USA)	Outpatient orthopedic clinic; cast removal (cohort 1) or pin removal (cohort 2)	210 (105 per cohort); 4–14 (mean 9)	Interactive VR game; passive VR video	Tablet video (active comparator)	Heart-rate change (primary); VAS pain; VAS anxiety	No differences among arms in heart rate, pain, or anxiety in either cohort; VR no better than tablet video
Guingo et al., 2026 [16] (Canada)	Outpatient clinics (3 hospitals); removal of bone pins and/or sutures	180 (VR 91; tablet 89); 6–17 (mean 10.4)	Interactive VR (Oculus Quest, DREAM game)	Tablet game	Pain (NRS) and anxiety (Child Fear Scale) (primary)	No difference in pain (3.7 *vs.* 3.7; $p = 0.90$) or anxiety ($p = 0.69$); lower anxiety with VR in children ≥13 y (exploratory)
Jivraj et al., 2020 [4] (Canada)	Outpatient cast room; cast removal	90 (45 per arm); 4–18 (mean 10.3)	Interactive VR (Oculus Go) with noise-cancelling headphones, added to standard care	Standard care	Anxiety: SAIS (self-report), CEMS (observer) (primary)	Lower post-procedure anxiety with VR (SAIS 9.0 *vs.* 11.0; $p = 0.03$) and lower observer-rated distress (CEMS $p = 0.01$)
Kelly et al., 2025 [14] (Germany)	Outpatient fracture clinic; K-wire removal	135 for primary outcome (VR 67; control 68); 6–15	Interactive VR (Oculus Go, Seagull Splash) added to standard care	Standard care	Observer-rated Wong-Baker pain (primary); FLACC; mYPAS; heart rate	Lower observer-rated pain with VR (OR 0.23; $p < 0.001$) and lower observer-rated anxiety; patient-reported pain after removal similar
Ko et al., 2016 [27] (USA)	Cast room; mixed procedures (cast removal, cast application, others)	146 (no iPad 47; iPad video 52; iPad game 47); 1–18 (mean about 9)	Screen-based distraction (iPad video or game)	No iPad (standard care)	Heart rate (only outcome)	No consistent reduction in heart rate; video lowered heart rate before the procedure but not during cast removal
Mokhtari et al., 2026 [28] (Iran)	Hospital cast room; cast removal	105 (35 per arm); 8–12 (mean about 9.9)	Music via headphones; tablet video game	Routine care	Facial Anxiety Scale (primary); CEMS; heart rate	Music reduced anxiety ($p = 0.006$) and heart rate (−7.2 bpm; $p = 0.014$) versus control; game not significantly different from control
Poppelaars et al., 2024 [13] (Netherlands)	Outpatient plaster room; plaster removal or replacement	255 (VR 130; control 125); 5–17 (mean about 10.6)	Passive VR (comedy episode with headphones) added to standard care	Standard care	Child Fear Scale (primary); NRS pain; heart rate; satisfaction	Lower post-procedure fear with VR ($p < 0.001$); pain low and similar; satisfaction high in both arms
Richey et al., 2022 [29] (USA)	Outpatient cast room; cast and/or pin removal	66 (BERT 29; control 37); 2–6 (mean 4.9)	Screen-based: projector video (BERT) with noise-cancelling headphones	Standard care	Child Fear Scale; Childhood Anxiety Meter; NRS pain	Less fear ($p = 0.009$) and anxiety ($p = 0.015$) after the procedure with BERT (unadjusted); pain not different
Sayar et al., 2025 [30] (Turkey)	Emergency department procedure room; cast application	66 (33 per arm); 6–12 (mean 8.5)	Stress ball (other non-pharmacological strategy)	Standard casting procedure	Child Fear Scale; state anxiety; heart rate	Lower fear and state anxiety with stress ball (post-procedure fear 1.30 *vs.* 3.15; $p < 0.001$)
Schlechter et al., 2017 [10] (USA)	Outpatient cast room; cast or splint placement and removal	86 (CCLS 42; no CCLS 44); 2–10 (mean about 6)	Therapeutic play: certified child life specialist	Standard care (no CCLS)	Heart rate; observed behavior score; parent satisfaction	Better behavior score with CCLS (1.78 *vs.* 1.04; $p < 0.001$); heart rate and parent satisfaction similar
Wong et al., 2018 [9] (Hong Kong)	Outpatient cast room; cast removal	208 (play 103; control 105); 3–12 (mean about 7.6)	Therapeutic play by a hospital play specialist (preparation and distraction play)	Standard care	Anxiety (VAS or CSAS-C); CEMS; heart rate; duration; satisfaction	Lower anxiety in children aged 3–7 y ($p = 0.010$) but not 8–12 y; lower CEMS ($p < 0.001$) and smaller heart-rate rise ($p = 0.008$)

BERT: bedside entertainment and relaxation theater; CCLS: certified child life specialist; CEMS: Children's Emotional Manifestation Scale; CSAS-C: Children's State Anxiety Scale; NRS: numeric rating scale; mYPAS: modified Yale Preoperative Anxiety Scale; SAIS: Short State Anxiety Inventory Scale; VAS: visual analogue scale; VR: virtual reality.



364 ***Figure 1.*** *PRISMA flow chart. NMA: network meta-analysis.*

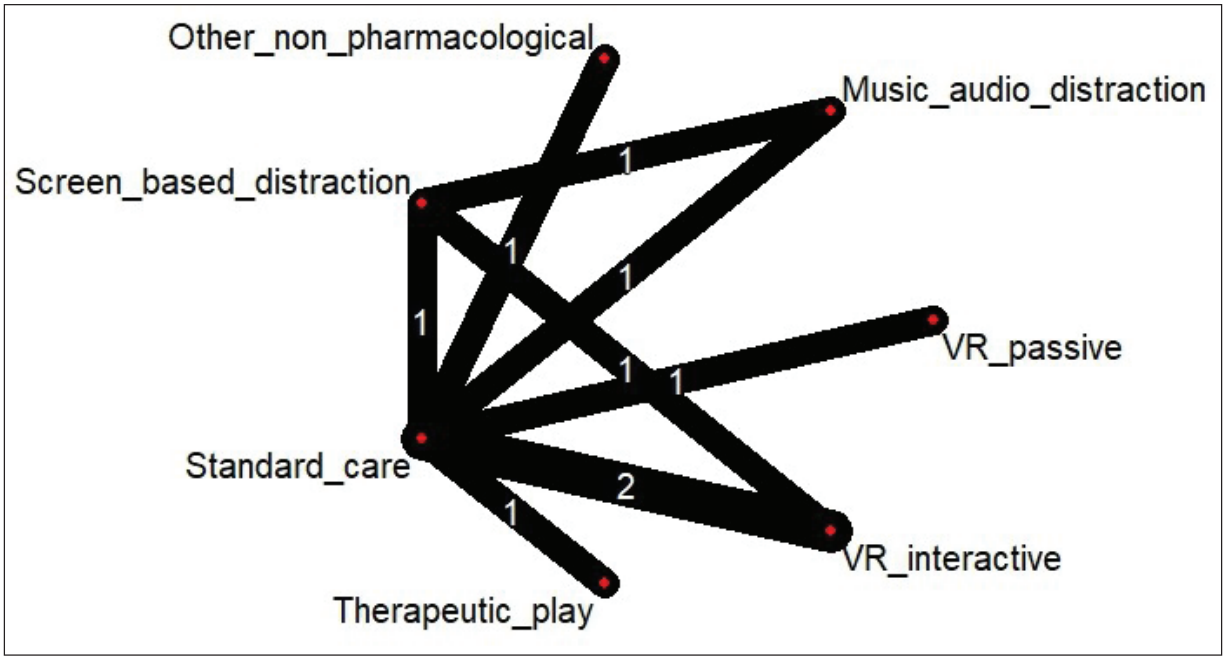


365 ***Figure 2*** *Network plot of the interventions evaluated for procedural pain. VR: virtual reality.*

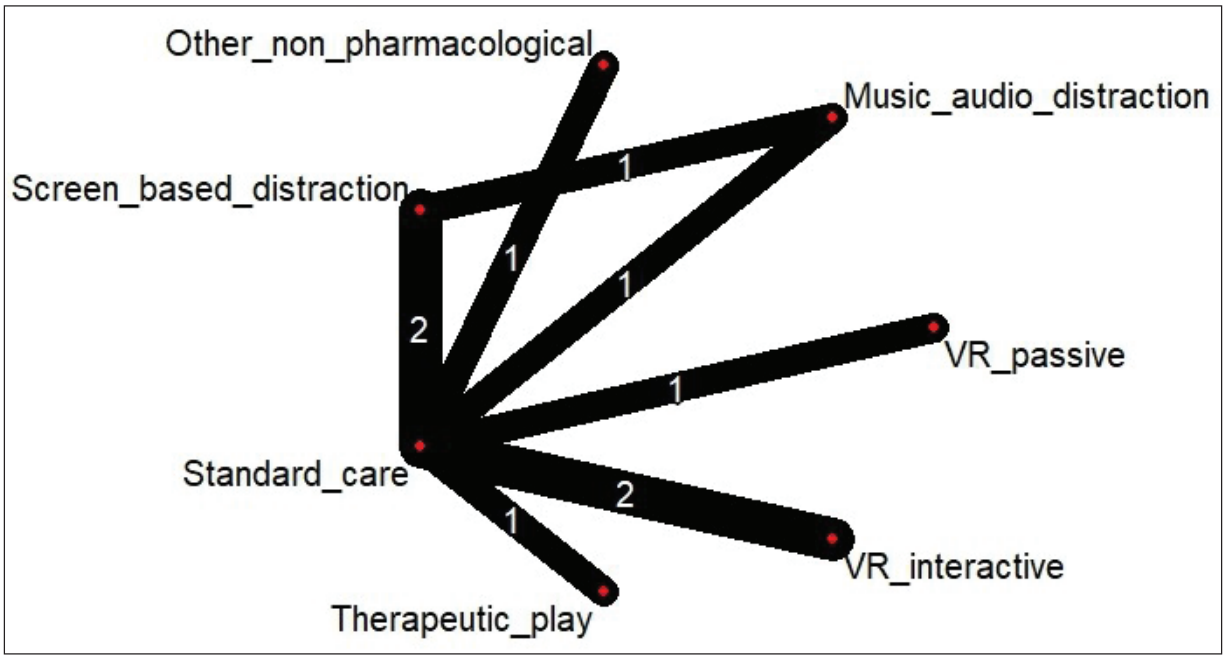
366 standard care ranked lowest (0.005). No heterogeneity
367 was detected ($\tau^2 = 0$; $I^2 = 0\%$, 95% CI 0.0% to 84.7%; $Q =$
368 0.30, $p = 0.961$), and there was no inconsistency between
369 designs ($Q = 0.18$, $p = 0.916$) (Figure S2).

Heart rate

370
Seven studies [9,10,13,15,26,28,30] ($k = 7$; 7 treatments) 371
including 952 patients were pooled for heart rate (Figure 372
4). Only music/audio distraction significantly lowered 373



374 ***Figure 3*** *Network plot illustrating the direct evidence and treatment comparisons contributing to the network meta-analysis of*
375 *procedural anxiety. VR: virtual reality.*



376 ***Figure 4*** *Network plot of interventions evaluated for procedural heart rate. VR: virtual reality.*

377 heart rate compared with standard care (SMD −0.82,
378 95% CI −1.54 to −0.11; p = 0.024). The remaining
379 interventions showed non-significant reductions: other
380 non-pharmacological interventions (SMD −0.70, 95%
381 CI −1.63 to 0.23; p = 0.140), therapeutic play (SMD
382 −0.56, 95% CI −1.44 to 0.31; p = 0.210), screen-based
383 distraction (SMD −0.33, 95% CI −0.91 to 0.26; p =
384 0.274), interactive VR (SMD −0.32, 95% CI −0.94 to
385 0.30; p = 0.309), and passive VR (SMD −0.30, 95%
386 CI −1.12 to 0.52; p = 0.477). Music/audio distraction
387 had the highest p-score (0.81), followed by other non-
388 pharmacological interventions (0.69) and therapeutic
389 play (0.61), with standard care ranking lowest (0.12).
390 Heterogeneity was substantial (τ^2 = 0.161; I^2 = 76.2%,
391 95% CI 34.7% to 91.3%; Q = 12.61, p = 0.006) and
392 originated mainly from within designs (Q = 12.07, p =
393 0.002). There was no significant inconsistency between
394 designs (Q = 0.55, p = 0.460; Figure S3).

Rescue analgesia

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396 Two studies [16,26] (k = 2; 3 treatments) with a total
397 of 283 patients were pooled for the need for rescue
398 analgesia using a common-effects model (Figure 5).

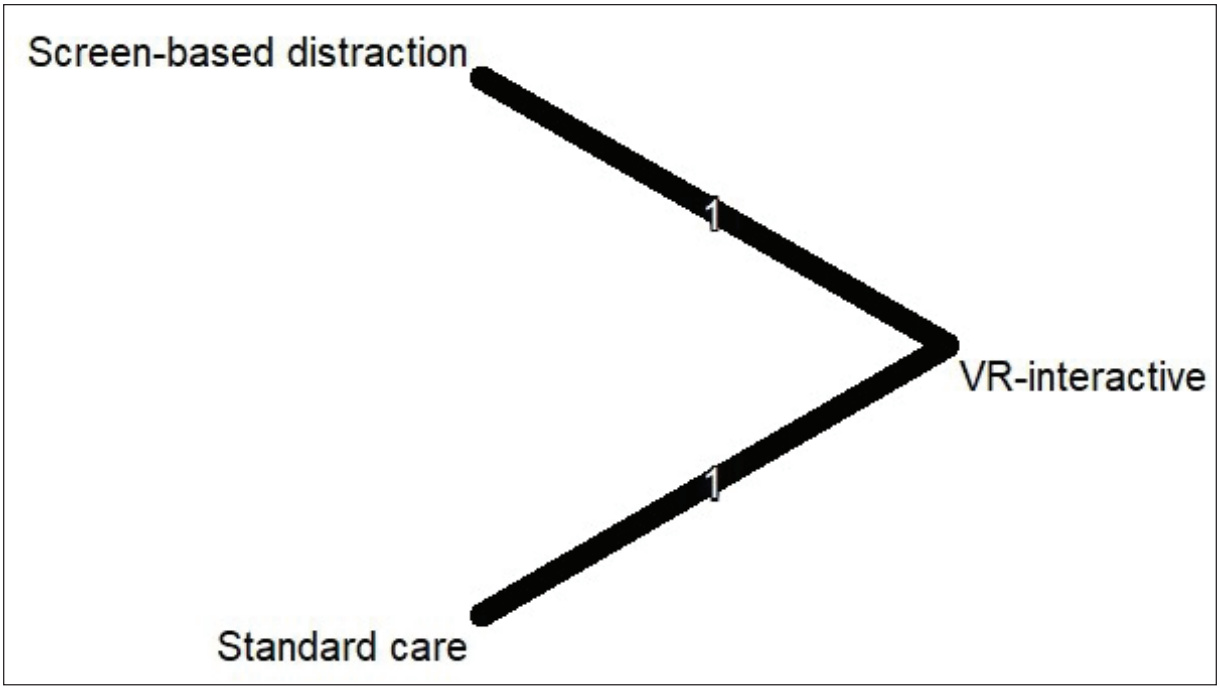


Figure 5 *Network plot illustrating the evidence structure for rescue analgesia. VR: virtual reality.*

With interactive VR as the reference, neither screen-based distraction (RR 3.13, 95% CI 0.13 to 75.85; p = 0.483) nor standard care (RR 1.02, 95% CI 0.02 to 50.42; p = 0.992) differed significantly in the risk of requiring rescue analgesia. Screen-based distraction had the highest p-score (0.71), followed by standard care (0.42) and interactive VR (0.37). The CIs were extremely wide, however, so the data are compatible with both a large benefit and a large harm of any of the interventions (Figure S4). Heterogeneity and inconsistency could not be estimated because the network contained no closed loops.

Procedural duration

Two studies [9,30] (k = 2; 3 treatments) including 274 patients were pooled for procedural duration (Figure 6). Neither other non-pharmacological interventions (MD −2.31, 95% CI −5.76 to 1.14; p = 0.189) nor therapeutic play (MD −0.50, 95% CI −1.11 to 0.11; p = 0.109) significantly shortened procedural duration compared with standard care. Other non-pharmacological interventions had the highest p-score (0.87), followed by therapeutic play (0.55) and standard care (0.07) (Figure S5). Heterogeneity and inconsistency could not be estimated because the network contained no closed loops.

Parent satisfaction

Two studies [9,13] (k = 2; 3 treatments) including 463 patients were pooled for parent satisfaction (Figure 7). Neither passive VR (SMD −0.24, 95% CI −0.49 to 0.01; p = 0.057) nor therapeutic play (SMD −0.22, 95% CI −0.49 to 0.05; p = 0.110) differed significantly from standard care, although both point estimates favored standard care. Standard care had the highest p-score (0.96), followed by therapeutic play (0.30) and passive VR (0.25) (Figure S6). Heterogeneity and inconsistency could not be estimated because the network contained no closed loops.

Publication bias

Publication bias could not be reliably assessed because fewer than 10 studies contributed to each outcome network.

Risk of bias

Across the 12 included studies, the overall risk of bias was predominantly high (9 studies, 75%) with the remainder raising some concerns (3 studies, 25%), driven mainly by substantial methodological limitations in outcome measurement and reporting (Figures 8 and 9). In Domain 1 (Randomization Process), half of the studies (6/12, 50%) demonstrated some concerns, whereas the remaining six studies achieved a low risk profile. Domain 2 (Deviations from Intended Interventions) was predominantly characterized by some concerns (9/12, 75%), with only three studies [4,16,26] maintaining a low risk. In contrast, Domain 3 (Missing Outcome Data) presented favorable quality overall, with most studies judged as low risk (9/12, 75%), while two studies showed high risk [15,29] and one study presented some concerns [14]. The most prominent source of potential bias arose in Domain 4 (Measurement of the Outcome), where a majority of studies were assessed as high risk (7/12, 58.3%) and the remaining five studies (41.7%) raised some concerns, with no study achieving a low risk level. Finally, Domain 5 (Selection of the Reported Result) was overwhelmingly marked by some concerns across 10 studies (83.3%), with only two studies [13,16] meeting the criteria for low risk.

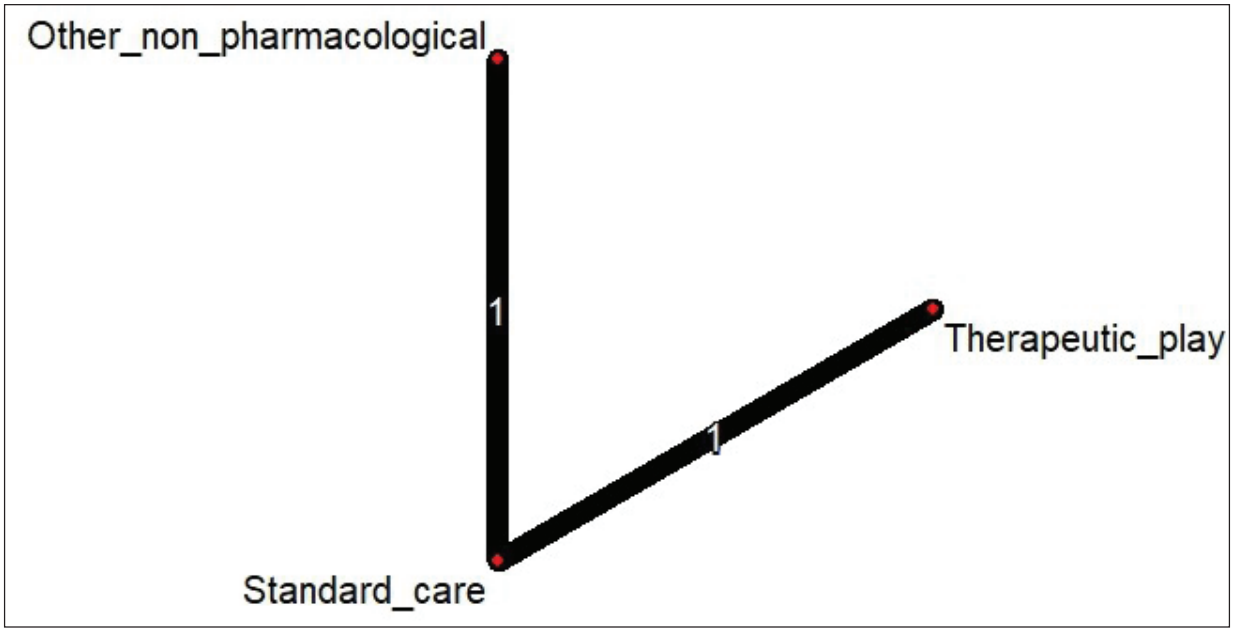


Figure 6 *Network plot showing the available treatment comparisons for procedural duration.*

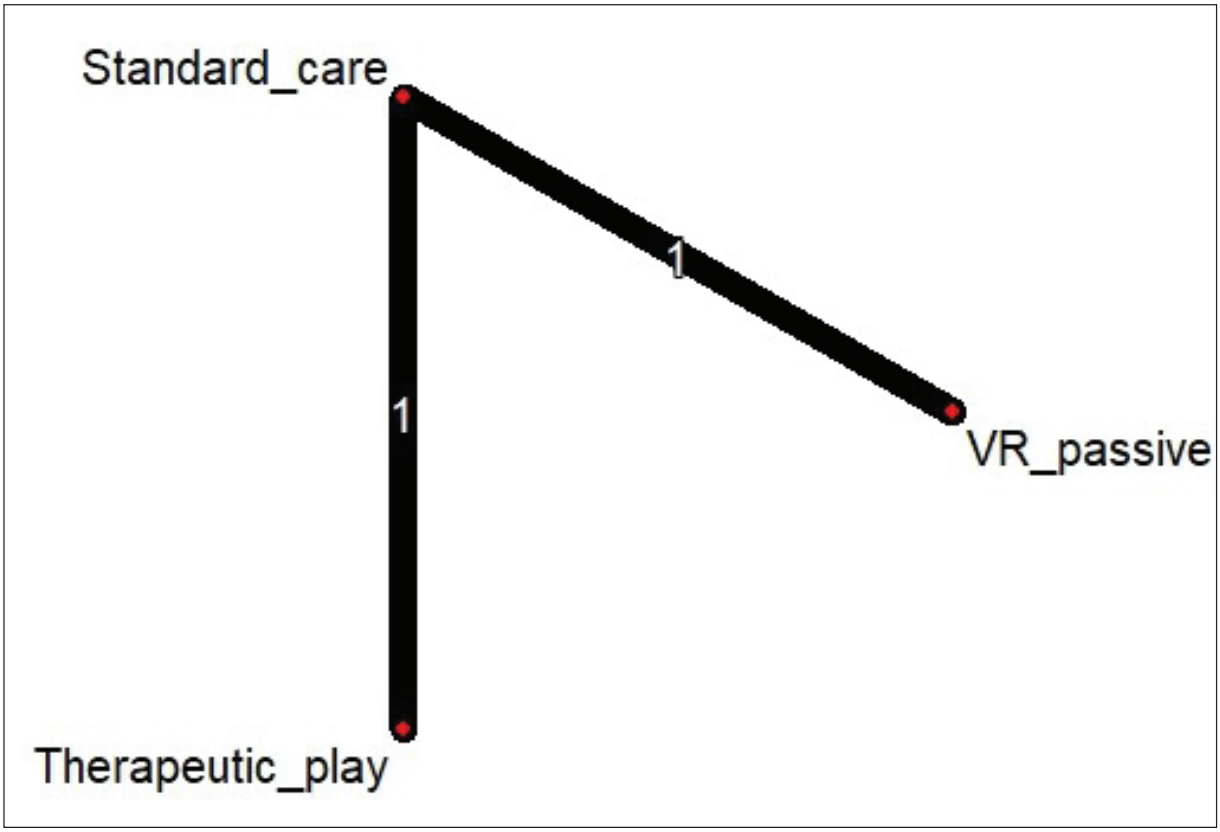


Figure 7 *Network plot illustrating the available evidence comparing interventions for parent satisfaction. VR: virtual reality.*

Discussion

The present network meta-analysis demonstrated differential effects of non-pharmacological interventions on procedural pain, anxiety, and physiological outcomes in pediatric patients. For procedural pain, only passive VR combined with standard care significantly outperformed standard care, whereas passive VR alone, interactive VR, and interactive VR combined with standard care did not demonstrate statistically significant benefits. This finding differs somewhat from recent systematic reviews and meta-analyses that have generally reported reductions in pediatric procedural pain with VR compared with usual care [31,32]. However, this discrepancy may reflect differences in the analytical approach, as the present network distinguished between specific VR modalities

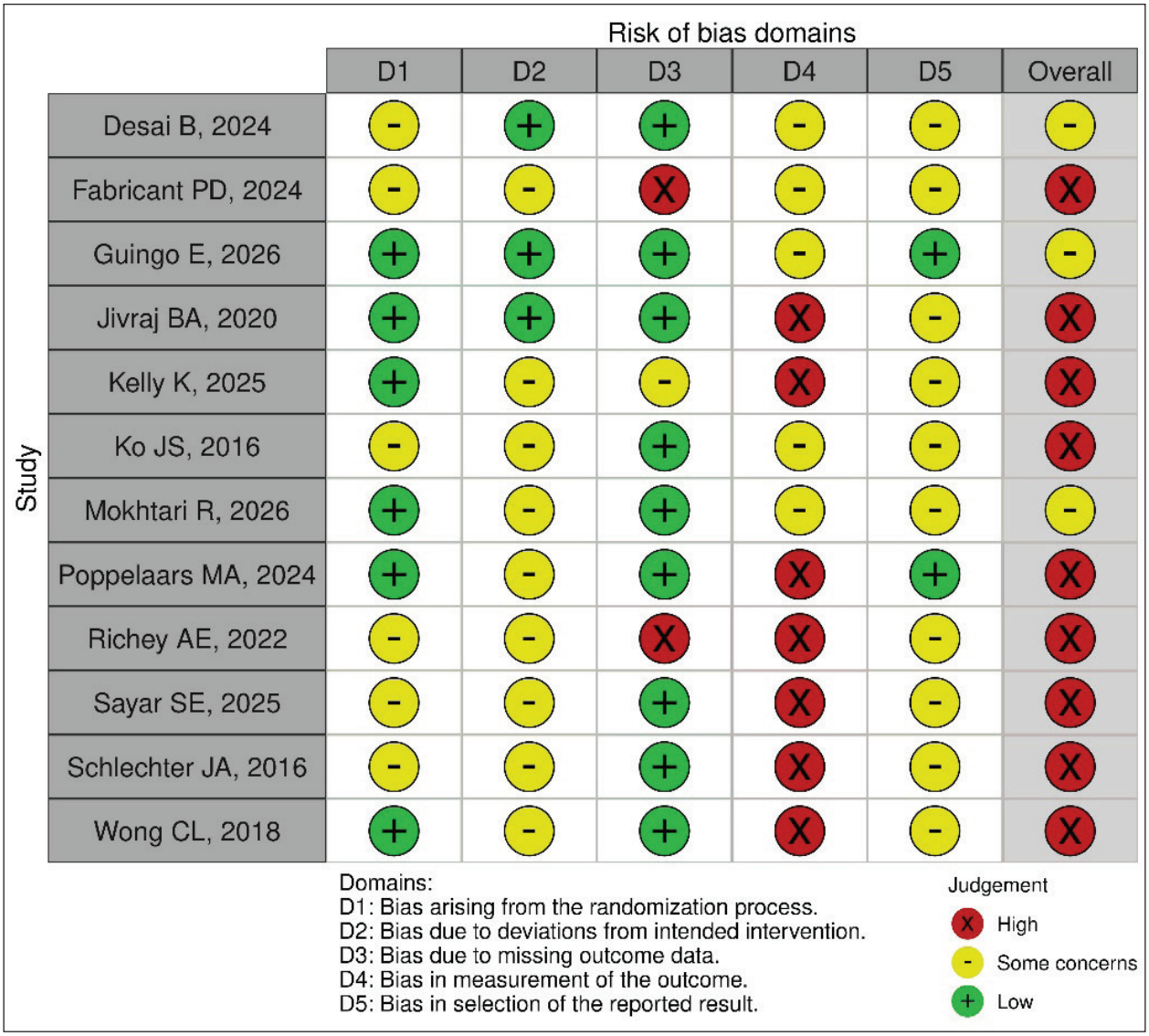


Figure 8 *Risk-of-bias traffic light plot for the 12 included studies assessed using the Cochrane Risk of Bias 2 (RoB 2) tool.*

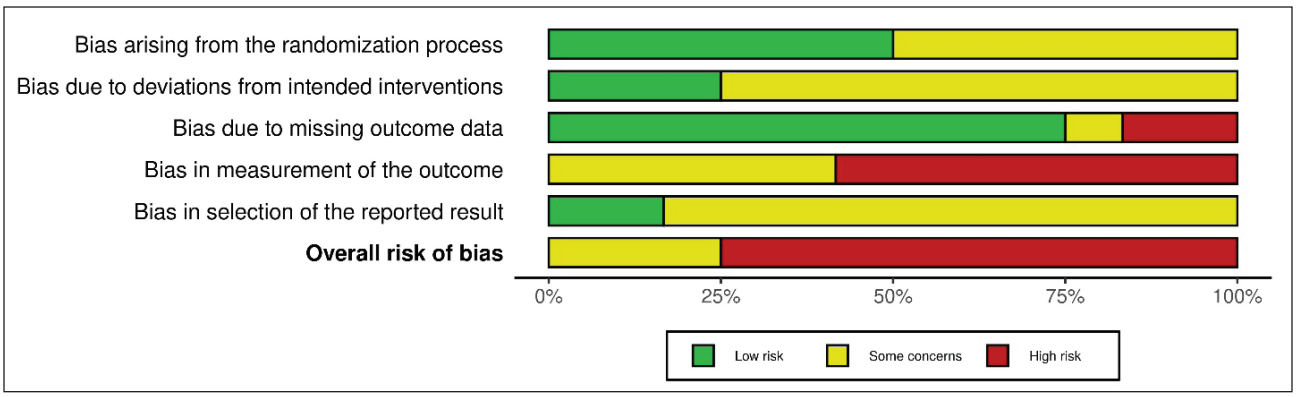


Figure 9 *Risk-of-bias summary for the 12 included studies assessed using the Cochrane Risk of Bias 2 (RoB 2) tool.*

and their combination with standard care rather than treating VR as a single intervention category. Previous research has similarly highlighted variability in VR effectiveness according to delivery format, clinical setting, procedural characteristics, and comparator intervention. In particular, Nordgård et al. [33] reported findings suggesting that non-interactive VR may provide pain relief comparable to or greater than that achieved with interactive formats. The present results therefore suggest that the analgesic effect of VR may depend not only on the technology itself but also on how it is

delivered and whether it complements routine clinical care [34].

Although screen-based distraction achieved a relatively favorable ranking for procedural pain, its comparative effect against standard care was not statistically significant. This distinction highlights the importance of interpreting treatment rankings alongside effect estimates and their associated uncertainty. Ranking probabilities reflect the relative performance of interventions within the evidence network but do not necessarily establish statistically meaningful superiority, particularly when the available evidence is limited or imprecise. Accordingly, the favorable ranking of screen-based distractions should be considered hypothesis-generating rather than definitive evidence of superior analgesic efficacy. More broadly, the findings support the possibility that combining distraction-based techniques with standard care may provide greater benefit than relying on some behavioral interventions alone, although the present results do not establish a consistent advantage for all combined approaches. This interpretation is compatible with the broader principle of multimodal pediatric pain management, in which psychological and behavioral strategies complement rather than replace routine clinical care [31,33,35].

The anxiety outcomes demonstrated a more consistent pattern of benefit across interventions. All evaluated interventions significantly reduced anxiety compared with standard care, with music/audio distraction achieving the highest ranking, followed by other non-pharmacological approaches and therapeutic play. Both passive and interactive VR also demonstrated significant benefits, supporting their potential role in alleviating procedural distress. These findings are consistent with recent pediatric systematic reviews and network meta-analyses reporting that distraction-based interventions, including music, audiovisual stimulation, VR, animation, and psychologically enriched approaches, can reduce peri-procedural anxiety [18,35]. The consistent benefit across different intervention types suggests that procedural anxiety may be particularly responsive to strategies that redirect attention away from threatening stimuli and reduce anticipatory distress. Nevertheless, the relative effectiveness of individual interventions may vary according to developmental stage, procedure type, patient preferences, and the extent to which the intervention engages the child.

The favorable ranking of music/audio distraction for anxiety is particularly noteworthy because it is supported by evidence from several pediatric clinical settings. In pediatric dentistry, Kong et al. [36] identified music as a leading intervention for reducing dental anxiety in a network meta-analysis, while Ramirez et al. [37] reported evidence supporting the potential anxiolytic effects of audio distraction, although the certainty of some outcomes was limited. Other studies have demonstrated improvements in anxiety, fear, and cooperation following music-based interventions during medical procedures, including cardiac catheterization [38,39]. These findings suggest that music may offer a practical and relatively accessible approach to procedural anxiety management. Its potential advantages include ease of implementation, minimal equipment requirements, and applicability across different clinical environments. However, a favorable ranking does not establish that music is universally superior to other interventions, and its effectiveness may depend on the clinical context, the child's preferences, and the characteristics of the comparator.

The anxiety findings also support a broader distinction between the effects of passive and interactive distraction. Music and audiovisual interventions can engage attention without requiring active participation, whereas interactive games and VR may require cognitive effort and active responses. Both approaches may reduce perceived procedural threat by diverting attentional resources from unpleasant stimuli, but their relative effectiveness may differ depending on the child's developmental abilities and the demands of the procedure. Recent network meta-analytic evidence has similarly evaluated music and video as passive distraction and games or VR as interactive approaches, demonstrating the relevance of intervention format when comparing psychological strategies [18]. The significant benefits observed with both passive and interactive VR in the present anxiety network further indicate that active engagement is not necessarily required for an intervention to alleviate procedural distress. However, because the present analysis does not establish a consistent superiority of one VR format over another for anxiety, direct comparisons in adequately powered randomized trials remain necessary.

The physiological outcomes provided additional evidence of intervention-specific effects. Only music/audio distraction significantly reduced heart rate compared with standard care, suggesting that its potential benefits may extend beyond subjective anxiety reduction to measurable autonomic responses. This finding is consistent with previous pediatric studies reporting reductions in heart rate or pulse rate following music-based interventions in dental and medical settings [37,40]. Music may influence physiological arousal by promoting relaxation and reducing the emotional and attentional responses associated with procedural stress [41]. Nevertheless, heart rate is a nonspecific physiological measure influenced by several factors, including age, baseline autonomic activity, procedural invasiveness, movement, medication exposure, and the timing of measurement. Therefore, a reduction in heart rate should not be interpreted as direct evidence of analgesia or as a substitute for validated measures of pain and anxiety.

The substantial heterogeneity observed in the heart-rate network further emphasizes the complexity of interpreting physiological outcomes across different procedures and interventions. Subjective distress and autonomic responses do not necessarily change in parallel, as interventions may influence emotional appraisal, attentional engagement, and physiological arousal to different degrees. For example, Altınbezer et al. [42] reported that music reduced heart rate during pediatric echocardiography without a corresponding reduction in self-reported anxiety, while other studies of audiovisual distraction have demonstrated clearer improvements in subjective anxiety than in objective physiological

measures. Such differences may reflect variations in measurement timing, intervention duration, procedural characteristics, and individual responses to distraction. Consequently, future trials should assess physiological and patient-reported outcomes concurrently and use standardized measurement protocols to determine whether observed changes represent consistent improvements across different dimensions of procedural distress.

Evidence regarding rescue analgesia, procedural duration, and parental satisfaction remained insufficient to support firm conclusions. Although these outcomes are important for determining the practical value of non-pharmacological interventions, the existing literature has predominantly focused on short-term pain and anxiety measurements. Recent reviews of VR have similarly highlighted the limited availability of evidence concerning feasibility, satisfaction, subsequent analgesic requirements, and effects on clinical workflow [43,44]. These outcomes are particularly relevant in pediatric practice because an intervention that produces modest improvements in pain or anxiety may still be clinically valuable if it reduces the need for additional analgesia, facilitates procedural completion, improves cooperation, or enhances the experience of children and their parents. Conversely, interventions requiring substantial preparation, specialized equipment, or additional personnel may be less practical despite favorable efficacy estimates. The absence of sufficient evidence for these secondary outcomes therefore represents an important gap rather than evidence that the interventions have no effect on them.

Several limitations should be considered when interpreting the comparative findings. First, the observed effects and rankings are dependent on the number and distribution of studies contributing to each intervention comparison. Sparse networks and imprecise estimates can produce unstable rankings, particularly when multiple interventions have overlapping CIs. Second, clinical and methodological heterogeneity across studies may arise from differences in patient age, procedural setting, baseline distress, intervention content, treatment duration, comparator conditions, and outcome assessment methods. These differences may limit the comparability of results and complicate the interpretation of pooled estimates. Third, the broader literature on VR and distraction-based interventions has reported concerns regarding risk of bias, inconsistent intervention protocols, and potential publication bias, which may reduce confidence in comparative estimates [31,41]. Accordingly, statistical significance and treatment rankings should be interpreted in the context of the underlying evidence quality, and the absence of a statistically significant effect should not automatically be interpreted as evidence of equivalence or ineffectiveness.

Future randomized trials should distinguish passive from interactive VR, standardize intervention delivery and outcome measurement, and include sufficiently powered head-to-head comparisons. They should also assess rescue analgesia, procedural completion and duration, cooperation, parental satisfaction, and implementation requirements alongside pain, anxiety, and physiological outcomes. Such research would help establish not only which interventions are statistically effective but also which offer the greatest clinical benefit and practical value in routine pediatric procedural care.

Limitations

This network meta-analysis has several limitations. First, the number of studies contributing to individual outcomes was small, ranging from two studies for rescue analgesia, procedural duration, and parent satisfaction to nine studies for procedural anxiety. Consequently, several treatment comparisons were informed by sparse evidence, limiting the precision and reliability of effect estimates. This was particularly evident for rescue analgesia, for which the CIs were extremely wide (RR 3.13, 95% CI 0.13–75.85, for screen-based distraction and RR 1.02, 95% CI 0.02–50.42, for standard care versus interactive VR). Second, substantial heterogeneity was observed for heart rate (I^2 = 76.2%), suggesting variability across studies that may reflect differences in interventions, procedural settings, patient characteristics, or outcome assessment. Although no significant statistical inconsistency was detected in the pain, anxiety, or heart-rate networks, the limited evidence reduces the ability to exclude inconsistency confidently. Third, the overall risk of bias was high in nine studies (75%), particularly because of concerns regarding outcome measurement and selective reporting, potentially affecting the credibility of the findings. Fourth, publication bias could not be reliably assessed because fewer than ten studies contributed to each outcome. Finally, treatment rankings based on *p*-scores should be interpreted cautiously because rankings do not establish statistically significant superiority. Further adequately powered, methodologically rigorous randomized trials are needed to confirm these findings.

Conclusion

This network meta-analysis suggests that non-pharmacological interventions may improve selected procedural outcomes in children. Passive VR combined with standard care significantly reduced procedural pain compared with standard care (SMD −0.54, 95% CI −1.03 to −0.05; p = 0.032), while music/audio distraction significantly reduced both procedural anxiety (SMD −0.69, 95% CI −1.06 to −0.32; p = 0.0002) and heart rate (SMD −0.82, 95% CI −1.54 to −0.11; p = 0.024). All evaluated interventions significantly reduced anxiety, although their relative effectiveness remains uncertain. No statistically significant differences were demonstrated for rescue analgesia, procedural duration, or parent satisfaction. Despite favorable *p*-score rankings for certain interventions, these rankings should not be interpreted as definitive evidence of superiority. Substantial heterogeneity in heart-rate outcomes, sparse evidence for several endpoints, and high overall risk of bias in 75% of included studies warrant cautious interpretation. Larger, well-designed randomized trials are required to establish comparative effectiveness and inform evidence-based clinical implementation.

List of Abbreviations

K-wire	Kirschner wires
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
RCT	Randomized controlled trial
SMD	Standardized mean differences
VR	Virtual reality

Conflict of interests

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Supplementary content (if any) is available online.

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