Non-invasive neuromodulation for the treatment of pain in children and adolescents: a systematic review and meta-analysis of randomized controlled trials (RCTs)

Review question

To evaluate the efficacy and safety of non-invasive neuromodulation techniques for the management of pain in children and adolescents.

Specific questions:
1. Do non-invasive neuromodulation interventions (tDCS, rTMS, taVNS, TENS, rPMS) reduce pain intensity in pediatric populations compared to sham or usual care?
2. What are the effects of these interventions on functional disability, quality of life, and other patient-reported outcomes?
3. What stimulation parameters (site, intensity, duration, frequency) are most commonly used and associated with positive outcomes?
4. Are non-invasive neuromodulation techniques safe and well-tolerated in children and adolescents?

Rationale

Children and adolescents frequently experience acute and chronic pain from musculoskeletal, neuropathic, postoperative, or functional conditions. Pharmacological treatments often have limited safety and efficacy, highlighting the need for alternative, non-pharmacological strategies. Non-invasive neuromodulation techniques—such as transcranial direct current stimulation (tDCS), repetitive transcranial magnetic stimulation (rTMS), transcutaneous vagus nerve stimulation (taVNS), transcutaneous electrical nerve stimulation (TENS), and peripheral magnetic stimulation (rPMS)—have demonstrated promising results in adults but remain underexplored in pediatric populations. This systematic review will synthesize evidence from randomized controlled trials to assess the efficacy and safety of these modalities, identify optimal stimulation parameters, and inform clinical and research protocols for pediatric pain management.

Tags / Keywords

Pediatric pain management; chronic pain; acute pain; neuromodulation; non-invasive brain stimulation; transcranial direct current stimulation; repetitive transcranial magnetic stimulation; transcutaneous vagus nerve stimulation; transcutaneous electrical nerve stimulation; peripheral magnetic stimulation; analgesia; rehabilitation; safety; efficacy; children; adolescents.

Participants / Population

Inclusion criteria:
- Children and adolescents aged 0–18 years.
- Diagnosed with acute or chronic pain (neuropathic, musculoskeletal, postoperative, functional, or orofacial).
- Participants enrolled in randomized controlled trials evaluating non-invasive neuromodulation.
- Outcomes include pain intensity, functional status, quality of life, or adverse events.

Exclusion criteria:
- Adults (>18 years) or mixed-age samples without separate pediatric data.
- Invasive neuromodulation (e.g., spinal cord or deep brain stimulation).
- Case reports, reviews, conference abstracts, or animal studies.
- Studies focusing solely on motor or cognitive outcomes unrelated to pain.

Intervention(s)

Non-invasive neuromodulation techniques including:
- Transcranial direct current stimulation (tDCS)
- Repetitive transcranial magnetic stimulation (rTMS)
- Transcutaneous vagus nerve stimulation (taVNS)
- Transcutaneous electrical nerve stimulation (TENS)
- Peripheral magnetic stimulation (rPMS)

Comparator(s) / Control(s)

- Sham or placebo stimulation (inactive or subthreshold stimulation).
- Usual care or standard treatment (pharmacological, physiotherapy, behavioral).
- Other active interventions (e.g., different neuromodulation modalities or physical therapy).

Setting and Study Context

Eligible studies may be conducted in hospital, outpatient, rehabilitation, community, or clinical research settings involving pediatric pain management. No restriction will be placed on geographical location or healthcare system. Exclusion: studies in animal models, laboratory-only designs, or involving healthy participants without pain.