

A Randomized Controlled Clinical Trial Comparing Eye Movement Desensitization and Binaural Beats For Anxiety Management in Pediatric Dental Patients

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Abstract

Background: Dental anxiety is a major barrier to successful pediatric dental treatment. Although Eye Movement Desensitization (EMD) and binaural beats have individually demonstrated anxiolytic benefits, no randomized clinical trial has directly compared their effectiveness during pediatric dental extractions.

Aim: To compare the effectiveness of Eye Movement Desensitization and binaural beats in reducing anxiety among children undergoing primary tooth extraction under local anesthesia.

Methods: Fifty healthy children aged 8–13 years requiring primary tooth extraction were randomly allocated to either an EMD group (n=25) or a binaural beats group (n=25). Participants received a 5-minute intervention immediately before treatment. Anxiety was assessed using the Facial Image Scale (FIS), physiological stress was measured by pulse rate, and behaviour was evaluated using the Frankl Behaviour Rating Scale (FBRs). Measurements were recorded at baseline, post-intervention, post-local anesthesia administration, and post-extraction. Data were analyzed using non-parametric statistical tests with a significance level of $p < 0.05$.

Results: Both interventions significantly reduced anxiety from baseline ($p < 0.001$). The binaural beats group demonstrated significantly lower FIS scores than the EMD group immediately after the intervention (median 1 vs. 2; $p = 0.004$) and after extraction (median 1 vs. 2; $p = 0.012$). Pulse rate was significantly lower in the binaural beats group after extraction (92.60 ± 8.97 vs. 100.08 ± 12.30 bpm; $p = 0.020$), indicating faster physiological recovery. No significant differences were observed between groups in pulse rate at earlier time points or in behavioural cooperation, with both groups achieving comparable FBRs scores ($p = 0.094$).

Conclusions: Both Eye Movement Desensitization and binaural beats are effective non-pharmacological behaviour guidance techniques for reducing dental anxiety in children undergoing primary tooth extraction. However, binaural beats provided superior anxiety reduction and faster physiological recovery, suggesting that it may be the preferred adjunctive intervention for managing pediatric dental anxiety in routine clinical practice.

Keywords: Pediatric dentistry; Dental anxiety; Binaural beats; Eye movement desensitization; Behaviour guidance; Primary tooth extraction; Randomized controlled trial.

1. INTRODUCTION

Dental anxiety and fear represent one of the most frequently encountered barriers to the delivery of quality oral healthcare in the pediatric age group. Epidemiological data indicate that dental fear (DF) affects approximately 24%-37% of children globally, with consequences ranging from avoidance behavior and treatment delays to compromised oral health outcomes^{1,2}. Association between anxiety and poorer oral health has been demonstrated in the Indian pediatric population, where higher dental anxiety scores correlate significantly with greater caries experience and unmet treatment needs³. In the clinical context, anxiety manifests as a complex physiological storm: elevated pulse rate, altered oxygen saturation, activation of the sympathetic fight-or-flight response, and consequent resistance or non-cooperation during dental procedures⁴.

Tooth extraction under local anesthesia (LA) represents one of the most anxiety-provoking dental experiences for the pediatric patient. Anxiolysis through pharmacological behaviour guidance is the prime choice to manage heightened anxiety; however, associated costs, need for specialized monitoring, and risk profiles have renewed interest in evidence-based non-pharmacological alternatives⁵.

Two such emerging behavior guidance techniques include Eye Movement Desensitization (EMD) and Binaural beats. They offer distinct yet complementary neurological mechanisms for anxiety attenuation. EMD, derived from Eye Movement Desensitization and Reprocessing (EMDR) therapy, employs bilateral visual stimulation of working memory, facilitate the reprocessing of distressing memories, thereby reducing emotional charge and perceived vividness through Adaptive Information Processing mechanisms^{6,7}. This mechanism mimics the

consolidation function of REM sleep, enabling the prefrontal cortex to attenuate amygdala-mediated fear responses⁷. Binaural beats, an auditory perceptual phenomenon, involve the simultaneous delivery of two slightly different pure-tone frequencies to each ear via stereo headphones; the brain perceives a third 'beat' frequency equal to the difference between the two tones. When this resultant frequency falls within the alpha range (8–12 Hz) or theta range (4–8 Hz), cortical entrainment is postulated to induce neural synchronization, endorphin release, and measurable clinical relaxation^{8,9,10}.

While individual studies have demonstrated the efficacy of EMDR^{11,12} and binaural beats^{13,14} in pediatric populations, no study to date has directly compared these two modalities head-to-head in pediatric dental extraction setting. This randomized comparative clinical study aimed to fill this gap by systematically evaluating and comparing the effectiveness of EMD and binaural beats in reducing subjective anxiety (Facial Image Scale), objective physiological stress (pulse rate), and behavioral cooperation (FBRs), in children aged 8–13 years undergoing primary tooth extraction under local anesthesia¹⁵.

2. MATERIALS AND METHODS

2.1 Study Design and Ethics

A randomized two-arm, parallel groups comparative clinical study was conducted in the Department of Pedodontics and Preventive Dentistry, Government Dental College and Hospital, Kadapa, India. Eligible participants were randomly allocated into two equal groups (Group I: Eye Movement Desensitization and Group II: Binaural Beats) using the lottery method, wherein each participant selected one of the folded chits labeled with the group assignment from an opaque container, ensuring an equal chance of allocation to either group. The study was conducted in accordance with the Declaration of Helsinki. Informed written consent was obtained from the parents/guardians of all participating children, and assent was obtained from the children prior to enrollment.

2.2 Sample Size Calculation

The sample size was estimated using G*Power software (Version 3.1) for comparison of two independent groups (one-tailed t-test). Assuming an effect size of 0.80, a significance level (α) of 0.05, a statistical power ($1-\beta$) of 80%, and an allocation ratio of 1:1, the minimum required sample size was calculated to be 42 participants (21 per group). To enhance the study power and account for possible dropouts, the sample size was rounded off to 50 participants, with 25 children allocated to each group.

Inclusion criteria:

- (i) Children aged 8–13 years;
- (ii) Frankl Behaviour Rating Scale (FBRs) score of 3 at baseline;
- (iii) Systemically healthy (ASA Class I);
- (iv) Requiring primary tooth extraction under infiltration local anesthesia.

Exclusion criteria:

- (i) Children with special healthcare needs;
- (ii) History of allergy to local anesthetic agents;
- (iii) Parents/guardians unwilling to provide informed consent.

2.3 Group Allocation and Interventions

Group I – EMD (n=25): The child was seated comfortably in the dental chair. The operator guided the child to focus on a moving stimulus (finger or pen) at approximately 30 cm from the face. Smooth bilateral eye movements were performed in horizontal, vertical, and diagonal directions at a rhythmic pace for 5 minutes immediately before the procedure.

Group II – Binaural Beats (n=25): The child was seated comfortably wearing stereo headphones. A binaural beats audio track in the alpha frequency range (8–12 Hz) was delivered at a comfortable volume for 5 minutes immediately before the procedure.

Group I : EMD

Group II : Binaural beats

2.4 Outcome Measures



Primary outcomes:

(a) Subjective anxiety — Facial Image Scale (FIS), a validated pictorial self-report scale scored 1 (least anxious) to 5 (most anxious), recorded at

- T1 (Baseline),
- T2 (Post-intervention),
- T3 (Post-LA administration), and
- T4 (Post-extraction).

(b) Objective physiological anxiety — pulse rate (bpm) measured by pulse oximeter at respective four different time points.

Secondary outcome: Child behaviour during procedure assessed by the Frankl Behaviour Rating Scale (FBRS; scored 1–4).

2.5 Statistical Analysis

Data were analyzed using IBM SPSS Statistics 26.0. Normality was assessed by the Shapiro-Wilk test. Due to non-normal distribution of FIS scores and for consistency, non-parametric tests were applied throughout. The Friedman test was used for intra-group longitudinal comparison; significant results were followed by pairwise Wilcoxon Signed-Rank tests with Bonferroni correction (adjusted $\alpha=0.0083$). Inter-group comparisons were performed using the Mann-Whitney U test. Significance level was set at $p<0.05$.

3. RESULTS

3.1 Normality Testing

The Shapiro-Wilk test confirmed non-normal distribution for FIS anxiety scores in both groups at all time points ($p<0.05$), justifying non-parametric statistical analysis throughout.

3.2 Subjective Anxiety levels measured by Facial Image Scale (FIS)

Median FIS scores and inter-group comparisons are presented in Table 1 and illustrated in Graph 2. At baseline (T1), the binaural beats group reported significantly higher anxiety, with a median FIS of 4.0 (IQR 2.0) compared

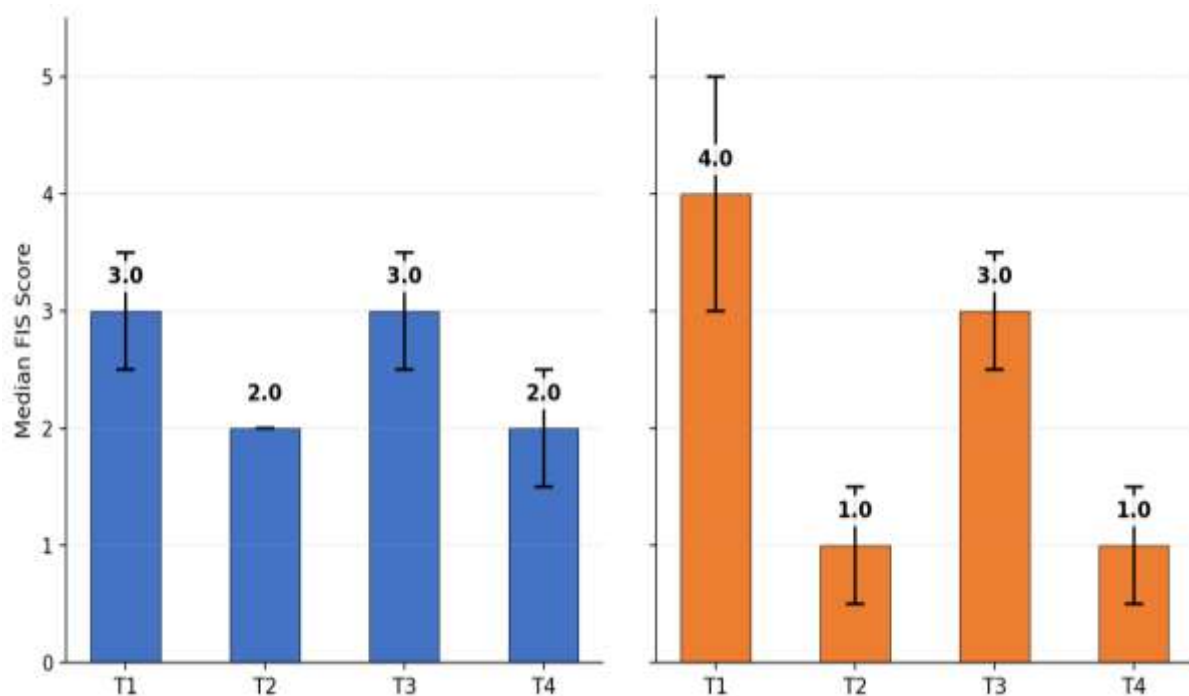
to 3.0 (IQR 1.0) in the EMD group ($p=0.023$). Following intervention (T2), binaural beats achieved a significantly lower median FIS of 1.0 (IQR 1.0) compared to 2.0 (IQR 0.0) in the EMD group ($p=0.004$). The expected anxiety rebound at T3 (post-LA) produced equivalent median scores of 3.0 (IQR 1.0) in both groups, with no significant inter-group difference ($p=0.604$). At T4 (post-extraction), binaural beats again demonstrated significantly lower anxiety, with a median FIS of 1.0 (IQR 1.0) versus 2.0 (IQR 1.0) in the EMD group ($p=0.012$).

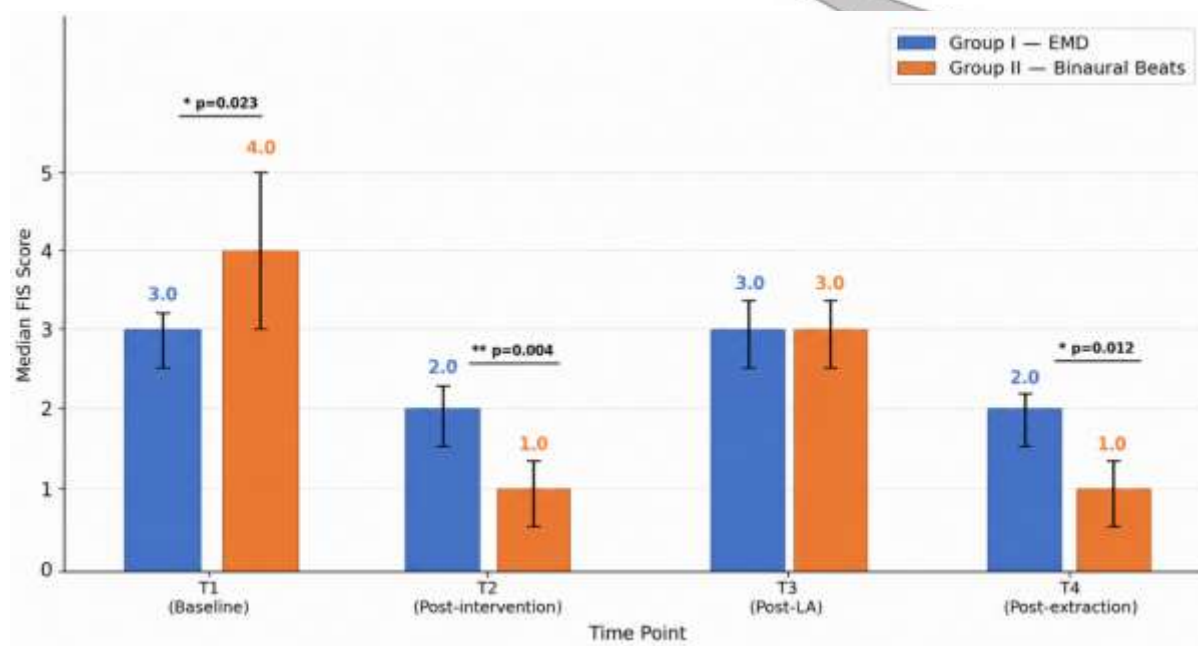
Table 1. Descriptive Statistics and Inter-group Comparison – Anxiety Scores (FIS)

Time Point	Group I (EMD) Mean $\pm$ SD	Median (IQR)	Group II (Binaural) Mean $\pm$ SD	Median (IQR)	p (MWU)
T1 – Baseline	3.56 $\pm$ 0.70	3.0 (1.0)	4.08 $\pm$ 0.80	4.0 (2.0)	0.023*
T2 – Post-intervention	2.08 $\pm$ 0.63	2.0 (0.0)	1.52 $\pm$ 0.64	1.0 (1.0)	0.004**
T3 – Post-LA	2.84 $\pm$ 1.01	3.0 (1.0)	2.64 $\pm$ 0.97	3.0 (1.0)	0.604
T4 – Post-extraction	2.24 $\pm$ 0.99	2.0 (1.0)	1.56 $\pm$ 0.75	1.0 (1.0)	0.012*

MWU = Mann-Whitney U (two-tailed). IQR = Interquartile Range. ** $p<0.01$; * $p<0.05$

Graph 1. Intra-group comparison of median Facial Image Scale (FIS) scores across four procedural time points in Group I (EMD) and Group II (Binaural Beats).





Graph 2. Inter-group comparison of median anxiety scores (FIS) across four time points

3.3 Objective measure of Physiological Anxiety

Pulse rate values are presented in Table 2 and illustrated in Graph 4. No significant inter-group differences were observed at T1 ($p=0.418$), T2 ($p=0.361$), or T3 ($p=0.600$). At T4, binaural beats showed a significantly lower mean pulse rate (92.60 ± 8.97 vs 100.08 ± 12.30 bpm; $p=0.020$), indicating faster post-procedural physiological recovery.

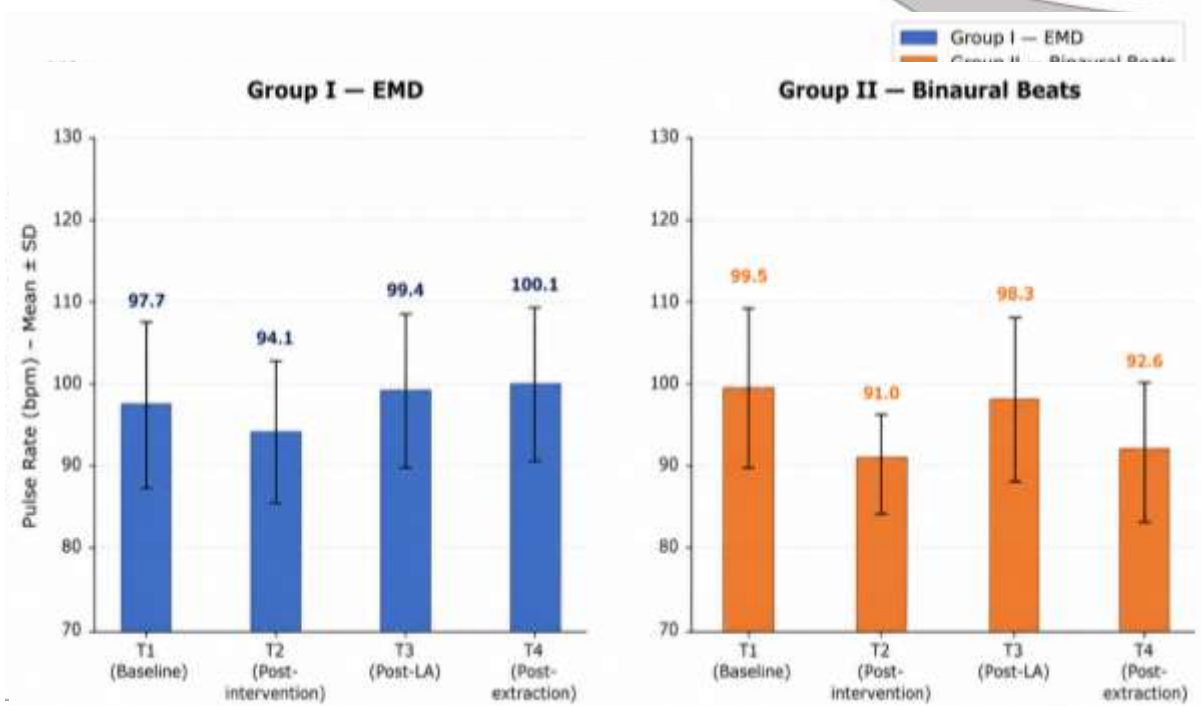
3.4 Intra-group Analysis – Friedman Test

The Friedman test revealed highly significant within-group changes in both anxiety scores (Graph 1) and pulse rates across all four time points in both groups (all $p < 0.001$; Graph 3). The markedly higher chi-square in the binaural beats group for anxiety measure ($\chi^2=59.082$ vs 34.831) suggests a greater magnitude of change, consistent with its superior inter-group performance.

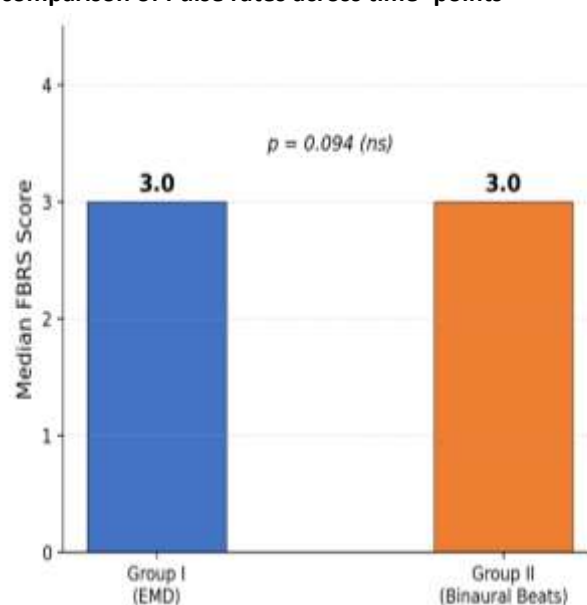
Table 2. Descriptive Statistics and Inter-group Comparison – Pulse Rate (bpm)

Time Point	Group I (EMD) Mean $\pm$ SD	Range	Group II (Binaural) Mean $\pm$ SD	Range	p (MWU)
T1 – Baseline	97.68 $\pm$ 11.12	76–127	99.48 $\pm$ 9.95	81–119	0.418 ns
T2 – Post-intervention	94.08 $\pm$ 10.53	74–126	91.04 $\pm$ 7.56	80–110	0.361 ns
T3 – Post-LA	99.44 $\pm$ 11.25	80–130	98.28 $\pm$ 11.32	83–127	0.600 ns
T4 – Post-extraction	100.08 $\pm$ 12.30	75–133	92.60 $\pm$ 8.97	78–115	0.020*

MWU = Mann-Whitney U (two-tailed). * $p < 0.05$; ns = not significant.



Graph 3. Intra-group comparison of Pulse rates across time- points



Graph 4. Inter-group comparison of mean Pulse rates

3.5 Secondary Outcome – Frankl Behaviour Rating Scale (FBRs)

Both groups demonstrated equivalent cooperative behavior after extraction, with a median FBRs of 3.0 (positive/cooperative) in both groups ($p=0.094$, Table 6, Graph 5). This confirms that both interventions were effective in ensuring clinically acceptable child cooperation, irrespective of differences in subjective anxiety and pulse rate.

Table 6. Inter-group Comparison – Frankl Behaviour Rating Scale (FBRs)

Outcome	Group I – EMD	Group II – Binaural	p- value
FBRs Median	3.0	3.0	0.094

Graph 5. Median Frankl Behaviour Rating Scale (FBRS) scores during extraction for both groups. No statistically significant inter-group difference was observed ($p=0.094$).

4. DISCUSSION

To the best of our knowledge, this study is the first randomized comparative clinical study to directly compare Eye Movement Desensitization and binaural beats for the management of pre-procedural dental anxiety in children undergoing primary tooth extraction under local anesthesia. The key finding is that while both interventions are effective, binaural beats demonstrated a statistically superior and more sustained anxiolytic effect, along with faster post-procedural physiological recovery.

Both groups exhibited significant reductions in median FIS scores from baseline to the post-intervention point (T1 to T2), with the binaural beats group achieving a median reduction from 4.0 to 1.0 and the EMD group from 3.0 to 2.0, confirming that a brief 5-minute non-pharmacological intervention can meaningfully attenuate pre-procedural dental anxiety. The larger chi-square value for the binaural beats group suggests a greater overall magnitude of change, potentially reflecting a more consistent and calming neurophysiological in children.

The mechanism underlying EMD is attributed to bilateral stimulation of the oculomotor system, which engages working memory through taxing visuospatial resources, thereby reducing the vividness and emotional loading of anxiety-eliciting thoughts which is analogous to memory reprocessing that occurs during REM sleep¹¹. Kalra et al. (2023) found Eye Movement Desensitisation and Reprocessing (EMDR) significantly reduced Visual Facial anxiety Scale scores in children undergoing extraction compared to routine behavior management¹¹, consistent with our finding of significant reductions in the EMD Group. Tirupathi et al. (2019) similarly reported that 78.9% of children in the EMD group had comfortable pain scores during LA, compared to only 12.2% in the control group¹². Rathore et al. (2024) found that EMDR therapy significantly reduced pain compared to the Tender Love and Care approach, particularly after LA administration and extraction¹⁶. They also reported that children who received EMDR also needed less post-extraction analgesic use and reported a notably better overall dental experience ($P < 0.0001$), suggesting EMDR could be a useful adjunct behavior management technique in pediatric dentistry.

Binaural beats operate through neural entrainment via the frequency-following response (FFR), wherein cortical activity synchronizes with the perceived binaural frequency, promoting a shift from anxious high-beta brainwave activity toward relaxed alpha states (8–12 Hz)^{13,14}. Bhusari et al. (2023) demonstrated that both monaural and binaural beats significantly reduced anxiety scores and pulse rates compared to controls during restorative treatment¹³. Rathie et al. (2024) found that binaural beat audio significantly reduced pulse rate and improved SpO2 during dental procedures¹⁴. We also noticed a similar trend of decreased pulse rate and FIS scores.

The universal anxiety spike at T3 (post-LA administration) in both groups, with equivalent median FIS scores of 3.0 (IQR 1.0) and no significant inter-group difference ($p=0.604$), is a clinically important observation. This represents an acute needle prick transiently overrides the pre-conditioning effects of either intervention. This finding validates the accuracy of the data collection and diminished effect of both interventions during an acute stressful procedure.

The universal anxiety and pulse-rate rebound we observed at T3, overriding the pre-conditioning effect of either intervention, aligns with evidence that LA administration provokes a characteristic, injection-specific cardiovascular response (Sharma et al., 2019)¹⁷ and that pre-procedural distraction does not always blunt the physiological response at the moment of needle insertion. Felemban et al. (2021)¹⁸ similarly found heart rate during LA injection is significantly higher in a VR-distraction group than controls. Notably, Rathore et al.'s (2024)¹⁶ EMDR trial did find significantly lower pain specifically at the LA-administration timepoint compared to control.

At T4 (post-extraction), the superior anxiolytic and physiological performance of binaural beats is particularly noteworthy. The binaural beats group achieved a median FIS of 1.0 (IQR 1.0) compared to 2.0 (IQR 1.0) in the EMD group ($p=0.012$), indicating that children in the binaural beats group self-reported minimal residual anxiety. Concurrently, the significantly lower post-extraction mean pulse rate in the binaural beats group (92.60 ± 8.97 vs 100.08 ± 12.30 bpm; $p=0.020$) suggests more rapid return of autonomic nervous system activity to a rest state. This may reflect sustained cortical entrainment effects persisting beyond the active listening period. Faster post-procedural physiological recovery has practical implications regarding chair time, patient comfort, and the child's overall dental experience.

The absence of a significant difference in FBRS scores ($p=0.094$) despite significant differences in FIS and pulse rate is an interesting dissociation. Both groups achieved a median FBRS of 3.0, indicating positive cooperative behavior. This suggests that even a moderate level of subjective anxiety does not necessarily translate into observable behavioral non-cooperation when appropriate behavior guidance is employed.

Shekhar et al. (2022)¹⁹ similarly found no inter-group behavioural differences despite within-group anxiety reductions. This pattern suggests that FBRS, a relatively coarse observer-rated scale, may be less sensitive than continuous physiological or self-report measures.

Üstün et al. (2025)²⁰ reported the converse dissociation, in which distraction improved behaviour without significantly reducing anxiety.

The superior T2 performance of binaural beats is arguably more impressive given that this group began at a higher baseline anxiety. Future studies should employ stratified randomization by baseline anxiety level, and incorporate salivary cortisol or skin conductance measures for comprehensive neuroendocrine anxiety quantification.^{21,22}

The simplicity and low cost of both techniques make them immediately implementable in routine pediatric dental practice. Binaural beats require only stereo headphones and a smartphone, while EMD requires no equipment beyond operator training. Both may be combined or deployed contextually based on child characteristics and operator proficiency, which needs further investigation.

5. CONCLUSION

Within the limitations of this study, the following conclusions are drawn:

1. Both Eye Movement Desensitization and binaural beats are valid, highly effective non-pharmacological behavior management techniques that produce significant and clinically meaningful reductions in dental anxiety and physiological stress in pediatric patients undergoing primary tooth extraction under local anesthesia.
2. Binaural beats demonstrated a statistically superior anxiolytic effect and faster autonomic recovery, confirming their clinical utility for procedure completion. It may be considered as the preferred first-line non-pharmacological intervention for pediatric dental extractions requiring local anesthesia,

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