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Original Article

Assessing the Effectiveness of Virtual Reality vs. Nitrous Oxide in Managing Anxiety and Pain in Pediatric Dental Procedures

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Abstract

Objective: The aim of this study was to compare virtual reality (VR) and nitrous oxide for dental anxiety and pain during a dental procedure in children.

Materials and Methods: This study examined two groups. Group 1 received dental treatment using nitrous oxide. Group 2 received dental treatment while watching a video through a virtual reality headset. Both groups received restorative treatment, including intraoral anesthetic injections, to perform dental restorations, crowns, and/or the extraction of teeth. The participants were asked to rate their pain with the Wong-Baker Faces scale before and after the procedure. After administering local anesthesia, the provider gave the participant a FLACC score. The investigator completed the Houpt Crying and Movement Scale after the procedure. Virtual Reality (VR) may serve as an effective behavior management tool for pediatric dentists by providing distraction and alleviating discomfort during dental procedures. This approach could be a way to enhance the clinical experience for young patients. Additionally, VR may be a valuable alternative when nitrous oxide is contraindicated or unavailable.

Results: Houpt, FLACC, and FACES scores did not demonstrate a statistically significant difference between virtual reality distraction and nitrous oxide in patient reaction to anesthesia, procedure, and post-operative discomfort. The number of participants who claimed they "had fun" during their procedure was statistically higher with VR, demonstrating a p-value of <0.0001.

Conclusion: Virtual reality may be a viable non-pharmacologic behavior management alternative to nitrous oxide.

Keywords: Behavior guidance, children, dental anxiety, nitrous oxide, virtual reality

Introduction

Dental fear and anxiety can significantly limit children's access to dental care. Various triggers, such as the sights and sounds of a dental office, can cause anxiety.[1] To reduce this, dentists have several strategies, including basic behavior management techniques, nitrous oxide, and sedation.[2] Recently, virtual reality (VR) technology has become a promising tool for managing dental anxiety and perceived pain.

Several studies have examined various forms of audiovisual anxiolysis and analgesia through distraction.[3–23] These electronic distractions have ranged from televisions and headphones to pioneering virtual reality systems. VR has been examined not only in dental set-

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tings [3–12,20,21] but also in other medical fields that involve anxiety-inducing or painful procedures, such as burn trauma, chemotherapy, and phlebotomy.[13–19]

Research dating back to 2000 shows that VR can reduce pain more effectively than audio-visual stimuli like video games.[22] For example, when exploring dentistry specifically, a 2001 study claimed that virtual reality is attention-grabbing and allows patients to tolerate painful procedures.[21] Further studies, including one by Atzori in 2018, have shown that modern VR technology can lower "worst pain" and "pain unpleasantness" scores, which children report more enjoyable experiences during dental procedures.[20] In 2019, Rao conducted a study where children using VR during a procedure showed reduced pain and anxiety. Both authors suggested that VR could feasibly be used in dental practice.[3,20]

Standardized systems for measuring behavior and pain perception, such as the FLACC, Wong-Baker FACES, and Houpt Behavior scales, have been validated and are useful in studies demonstrating pain and distress.[24–28]

To our knowledge, this is one of the first randomized controlled trials to directly compare virtual reality distraction with nitrous oxide sedation in pediatric dental procedures, providing novel insights into the comparative effectiveness of these two behavior management strategies.

This study aims to compare the effectiveness of VR and nitrous oxide in relieving dental anxiety and pain during dental procedures.

Materials and Methods

Study Design and Population

This study (IRB#) was an IRB-approved, randomized, controlled, interventional therapy using virtual reality goggles as a method of distraction. The trial adhered to the CONSORT reporting guidelines for randomized controlled trials.

Trial Design: This was a parallel group, randomized controlled trial with a 1:1 allocation ratio comparing standard treatment with nitrous oxide (control) versus distraction therapy (intervention).

Participants: Fifty-three pediatric Dental patients (27 in the control group, 26 in the treatment group) were recruited from the pediatric dental clinic at a tertiary medical center. Data on the type of behavior displayed and the child's responses to standardized questions were collected during and after the procedure.

Inclusion Criteria

- ASA 1 or 2, male or female pediatric dental patients aged 4–12 years.
- Participants who require a restorative procedure that includes the injection of local anesthesia.

Exclusion Criteria

- Participants who could not tolerate the use of a headset, local anesthesia, or nitrous oxide.
- Participants who had hypersensitivity to audio-visual devices that can lead to seizures.

Recruitment and Consent

Participants were enrolled consecutively from the clinic population. Written informed consent was obtained from parents, and assent was obtained from all children aged 7 years and above before study initiation.

Randomization and Allocation

On the day of the appointment, the participant was randomly assigned to either of the following groups by flipping a coin:

1) a control group (treatment using nitrous oxide), or
2) a treatment group (treatment using VR goggles).

Allocation concealment was ensured by performing randomization immediately before the procedure.

Blinding

Due to the nature of the intervention, participants and providers could not be blinded to a group assignment. However, outcome assessment (behavior scoring and post-procedure scales) was conducted by the investigator trained in standardized evaluation to minimize bias.

Interventions

1. **Control Group:** Treatment with Nitrous Oxide.
2. **Treatment group:** Treatment using Oculus Quest 2 VR Goggles. The Oculus Quest 2 is a virtual reality headset designed to give users an immersive experience while watching content or playing games. The headset is strapped to the user's head so that an LCD screen dominates the user's field of vision, blocking all other visual distractions. Built-in audio also projects from the headset. Participants viewed a 45-minute cartoon with an immersive audiovisual distraction during the dental procedure.

Outcomes

Primary Outcome: Self-reported pain using the Wong Baker FACES scale (baseline and post-procedure).[29]

Table 1. Demographics and procedures performed

	Nitrous oxide (N=27)		VR goggle (N=26)		Total (N=53)		p
	n	%	n	%	n	%	
Age at diagnosis (years), mean (SD)	7.70 (1.81)		8.73 (1.66)		8.21 (1.80)		0.037[1]
Sex							0.318[2]
Female	13	48.1	9	34.6	22	41.5	
Male	14	51.9	17	65.4	31	58.5	
Indirect Pulp Cap	2	7.4	1	3.8	3	5.7	0.575[2]
Space maintainer	1	3.7	0	0.0	1	1.9	0.322[2]
Pulpotomy	1	3.7	1	3.7	0	0.0	0.322[2]
Prophy	0	0.0	1	3.8	1	1.9	0.304[2]
Removal of distal shoe	0	0.0	1	3.8	1	1.9	0.304[2]
SDF	1	3.7	0	0.0	1	3.8	0.304[2]
Restorations	19	70.4	15	57.7	34	64.2	0.336[2]
Extraction	12	44.4	10	38.5	22	41.5	0.659[2]
Sealants/PRR	9	33.3	12	46.2	21	39.6	0.340[2]
Stainless Steel Crown	10	37.0	6	23.1	16	30.2	0.268[2]

[1]: Two sample t-test, [2]: Chi-Square p-value

Secondary Outcome

- After administering local anesthesia, the provider gave the participant a FLACC score.[30]
- At the end of the procedure, the participants rated their experience using the Wong-Baker FACES scale, and a survey was given to the participants to be completed.
- The investigator completed the Houpt Crying and Movement Scale[31] after the procedure was completed.

Sample Size Calculation

A prior power analysis on Wong Baker Faces scale was performed to determine the sample size required for this study. The calculation was based on an anticipated effect size of 0.5, a significance level of 0.05, and 5 degrees of freedom for a chi-square test. The analysis indicated that a sample size of 52 participants (26 per group) would provide 80% power to detect the hypothesized effect size. To ensure adequate statistical power, a minimum of 53 participants were included in the study, with 26 participants allocated to the VR goggle group and 26 participants to the nitrous oxide group.

Statistical Analysis

Comparisons were performed using a Chi-square test for categorical variables and two-sample t-test or Wilcoxon rank sum test for numerical (normally and non-normally distributed, respectively). The data distribution was evaluated using the Shapiro-Wilk test and histograms. All tests were 2-sided, and p values <0.05 were considered statistically significant. Statistical analysis was conducted using SAS® Enterprise Guide 8.2 (SAS Institute Inc., Cary, NC, USA).

Statistical Methods

Due to the limited sample size, multivariate analyses were not performed. Comparisons were limited to group-level descriptive statistics and univariate tests.

The statistician was not blinded to group allocation; however, all outcomes were predefined and evaluated using validated behavioral and pain assessment tools to minimize potential bias.

Results

Fifty-three patients were recruited to participate in the study. Table 1 presents the demographic and procedural characteristics of patients who underwent dental procedures using nitrous oxide sedation (N=27) or VR goggles (N=26). The mean age at diagnosis differed between groups, with patients in the nitrous oxide group being younger on average (7.70±1.81 years) compared to those in the VR group (8.73±1.66 years). The gender distribution was similar between groups (p=0.318), with males comprising 51.9% of the nitrous oxide group and 65.4% of the VR group.

The distribution of dental procedures performed was similar between the two groups, with no statistically sig-

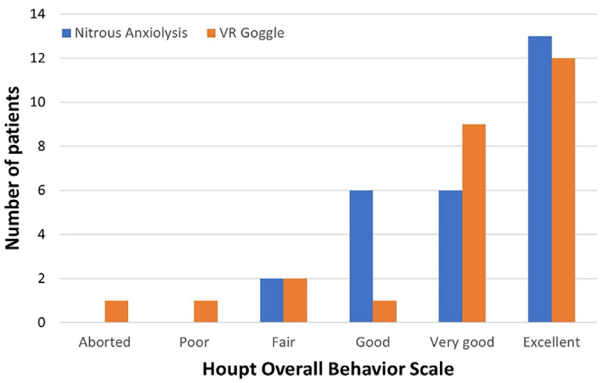

Figure 1. Distribution of Houpt behavior score listed by treatment group

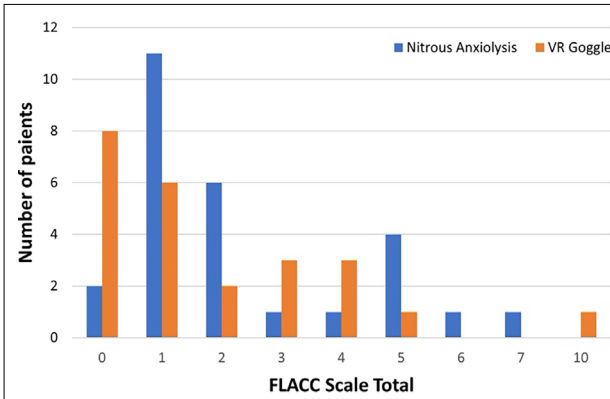

Figure 2. Distribution of total FLACC scale listed by treatment group

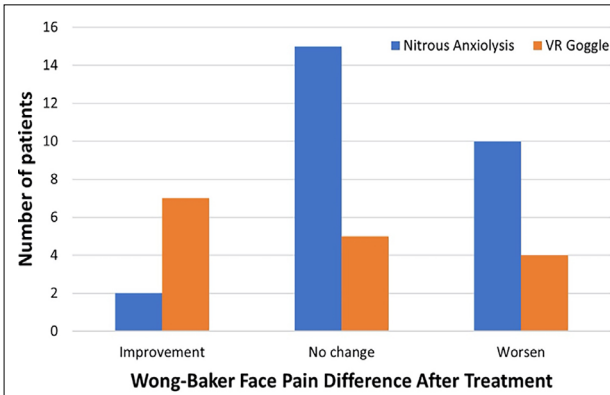

Figure 3. Distribution of Wong-Baker face pain change listed by treatment group. *No significant difference (p=0.069)

nificant difference observed for indirect pulp cap (IPC), pulpotomy, prophylaxis, silver diamine fluoride (SDF) application, extractions, sealants, or stainless-steel crowns (p>0.05 for all). Composite Restorations were the most common procedure, performed in 64.2% of all patients, followed by extractions (41.5%). The number of procedures per patient also did not differ significantly between groups (p=0.437), with most patients undergoing one (41.5%) or two (34%) procedures. We found no statistically significant difference in the Houpt behavior scores between the VR and nitrous oxide groups (p=0.359). Due to the limited sample size, a Houpt score lower than 4 was categorized as poor behavior, and a score of 4 or above was classified as good behavior. A slightly higher rate of good behavior was noticed in the nitrous oxide group (92.6% vs 84.6%). Although the differences were insignificant, Houpt scores (Fig. 1) for movement were similar between the two groups, behavior scores for crying were slightly better among the VR group, and the nitrous oxide group had somewhat better overall behavior.

A FLACC score was given by the provider after the administration of local anesthesia. The mean FLACC score given to patients who received treatment with nitrous oxide was 2.3 (±1.9), while the mean FLACC score given to patients who received treatment with VR was 2.0 (±2.3). These findings are detailed in Figure 2. The mean difference in FLACC score between the VR and nitrous oxide group was 0.3 (95% Confidence interval: -0.9–1.5, p=0.526).

Pre-operative and post-operative pain scales were recorded using the Wong-Baker FACES scale (Fig. 3). An improvement in pain rating after the procedure was more likely to be noticed among the nitrous oxide group (26.9% vs 7.4%), and the VR group was more likely to have a worse pain rating after the procedure (37% vs 15.4%). These differences in Wong-Baker FACES pain scores were not statistically significant (p=0.069).

Although the nitrous oxide group showed a numerically higher proportion of patients reporting post-procedure pain improvement compared to VR group, the difference did not reach statistical significance (p=0.069). These results suggest a potential trend that warrants further study but should be interpreted with caution given the limited sample size.

When asked if the patient had fun after the procedure, the patients responded more in the affirmative with VR than with nitrous oxide (87% vs 19%, p<0.0001).

Discussion

Nitrous oxide, commonly known as laughing gas, has been widely used in dentistry for decades because of its calming and pain-relieving properties. It provides a quick onset of sedation, is easily adjusted, and has a fast recov-

ery time, making it a popular choice for managing dental anxiety in children. Its safety profile is well-documented, and it helps ensure patient cooperation during procedures, which is especially important in pediatric dentistry. On the other hand, virtual reality (VR) offers a new, non-drug approach that has gained interest for its ability to distract and immerse young patients during dental treatments. VR can significantly lower perceived pain and anxiety by shifting the child's focus away from the procedure, creating an engaging and soothing environment. Unlike nitrous oxide, VR is a non-pharmacological modality that removes concerns about drug interactions or side effects. Comparing nitrous oxide and virtual reality in children is important for several reasons.

First, it helps identify which method provides better control of anxiety and pain, leading to a better patient experience and improved cooperation.

Second, it provides insights into the safety profiles, cost-effectiveness, and practicality of implementing these interventions in clinical settings. Third, understanding the differential effects can guide clinicians in selecting personalized management strategies tailored to each patient's needs, preferences, and medical considerations.

Furthermore, this comparison can contribute to the development of integrated approaches that combine pharmacological and non-pharmacological techniques, potentially enhancing overall efficacy. As research advances, establishing evidence-based guidelines for using nitrous oxide and virtual reality can optimize pediatric dental care, reduce dental fear, and promote better oral health outcomes in children. Therefore, a comprehensive comparison of these two modalities is essential for advancing pediatric dental practice and improving patient-centered care.

A recent meta-analysis reviewed and summarized studies on the effectiveness of virtual reality distraction up to 2018. The analysis found that "no differences were observed in anxiety levels during the administration of local anesthesia, use of rubber dam, removal of caries and restorative procedures" and concluded that "the use of virtual reality glasses is an effective tool for improving behavior and reducing pain perception during the dental treatment of children."[32] However, these studies compared the use of VR to dental treatment without the use of any specific form of anxiolysis.

The author aimed to determine if using a virtual reality headset for distraction could serve as a viable alternative to nitrous oxide for managing anxiety and pain in pediatric patients. The results demonstrated no statistically significant difference between VR and nitrous oxide behavior scores. This outcome suggests that VR can be used as a behavior management tool for children in the dental office.

Our findings are consistent with previous reports showing that VR reduces pediatric dental anxiety and pain,[3,20,32] though most prior studies compared VR to no intervention rather than to nitrous oxide. By directly contrasting the VR with an established standard, our trial expands on the literature and provides evidence for VR as a potential alternative. Considering these results, dental providers must evaluate whether VR distraction will benefit their patients after considering the advantages and limitations of both VR and nitrous oxide.

Some advantages of using VR include its ability to distract children and reduce "the unpleasantness and distress that arises during dental restorative procedures."[10] The goggles also prevented the child from seeing intimidating objects such as the dental syringe or dental instruments. Furthermore, to view the VR content, the child needed to keep their head in an optimal position; otherwise, the screen would not be visible. Participants also reported having more fun during the procedure,[20] which could enhance patient satisfaction and retention.

Conversely, virtual reality technology is new and can be challenging to use if the user is not familiar with the technology. On occasion, patients needed repeated commands since they were distracted. If a patient became disengaged or began to cry, tears or closed eyes made VR less effective. Additionally, while there is a possibility that a child could experience an adverse reaction to the VR headset, like headaches or nausea, a 2020 meta-analysis investigating the use of VR in dentistry found no evidence of this in any literature that they compared.[32]

Nitrous oxide has a long history of use and extensive research supporting its benefits, safety, and effectiveness.[33] It can be easily titrated for the individual. If a patient becomes distressed, the nitrous oxide concentration can be increased, and anxiolysis may be achieved after allowing sufficient time for the child to inhale the gas.

However, even with nitrous oxide, basic behavior management techniques are still necessary, for example, the use of distraction. Some children may not tolerate nitrous oxide or may have medical conditions that prevent its use, requiring alternative treatment modalities.

Limitations and weaknesses

This study has potential limitations and weaknesses:

1. Participants underwent various dental procedures, which prevented standardization across the treatments. Some procedures may be more difficult to tolerate than others. For example, a pulpotomy might be more difficult to tolerate than an occlusal composite restoration. If a child receiving an "easier" treatment was assigned to the VR group and a child undergoing a "difficult" treatment was assigned to the nitrous group, the results could be skewed. To mitigate this bias, participants were randomized using a coin toss. Future studies with larger sample sizes are needed to confirm these findings.
2. The statistician was not blind to group allocation; however, all outcomes were pre-defined and evaluated using validated behavior and pain assessment tools to minimize potential bias.
3. While VR offers an engaging, non-pharmacological approach, its limitations include potential intolerance to the headset, occasional distraction from provider instructions, and a reliance on equipment. Conversely, nitrous oxide has a strong safety record and predictable anxiolytics effects, but requires monitoring, carries pharmacological risks, and may not be suitable for all patients.

The results of this study offer valuable insight into virtual reality's usefulness in the dental setting. Most other studies on the topic were designed to evaluate VR's effectiveness in reducing pain and anxiety and its dental application;[4–9] however, few have compared it to existing anxiolytic and analgesic techniques. Although nitrous oxide represents a pharmacologic anxiolytic and VR is distraction based, both serve the same clinical purposes: To reduce anxiety and facilitate cooperation. Our findings suggest that the VR offers a non-pharmacologic alternative with comparable clinical outcomes, particularly in cases where nitrous oxide is contraindicated or declined.

Further research is needed to assess VR's usefulness in the dental setting. One approach could be to have participants experience nitrous oxide and VR on separate occasions to compare their effectiveness. Additionally, comparing VR as a distraction tool to television screens would be beneficial, as it is a common method already employed by many pediatric dentists.

Conclusion

The findings indicate that VR can be as effective as nitrous oxide in managing patient behavior, with no statistically significant differences observed in behavioral responses or perceived pain levels between patients using VR and those receiving nitrous oxide.

Notably, patients reported experiencing greater enjoyment and engagement with the VR experience compared to nitrous oxide, highlighting its potential to enhance patient comfort and cooperation.

These results suggest that VR technology could serve as a viable alternative to traditional sedation methods, offering a distraction technique that may improve the overall dental experience for pediatric patients.

However, further research is necessary to fully understand the scope of VR's effectiveness, optimal application strategies, and long-term benefits within the dental setting. Continued investigation will help establish standardized protocols and determine the practicality of integrating VR into routine dental practice, ultimately aiming to improve patient outcomes and satisfaction.

Disclosures

Ethics Committee Approval: The study was approved by the Geisinger Ethics Committee (no: 2021-0138, date: 10/21/2021).

Informed Consent: Informed consent was obtained from all participants.

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