ORIGINAL RESEARCH

Assessing the effect of virtual reality gamification on anxiety and pain management during extraction of MIH-affected lower first permanent molars in pediatric patients

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Abstract

Dental anxiety can be triggered by previous negative experiences, fear of pain, or loss of control, leading to avoidance of dental treatments and worsening oral health. To alleviate anxiety, various pharmacological and non-pharmacological measures are applied, including distraction as a cognitive-behavioral approach. One innovative method of distraction is gamification, which involves the use of Virtual Reality (VR) to redirect patients' focus to something relaxing instead of the treatment itself. The aim of this research was to evaluate the effectiveness of gamified virtual reality in reducing anxiety and pain during the extraction of molar-incisal hypomineralization (MIH) affected lower first molars under local anaesthesia. In prospective study, gamified virtual reality was applied during the extraction of lower first molars in 56 subjects using the split-mouth method. Through VR goggles, patients were immersed in a virtual video game world to distract them from the dental procedure. The results showed a significant reduction in pain levels during anaesthesia and tooth extraction in subjects using VR. Additionally, these patients had lower heart rate values during the intervention compared to the standard procedure. Most subjects expressed satisfaction with the VR experience, stating that VR technology helped alleviate their fear of the procedure and diverted their thoughts from the treatment itself. This research highlights the potential of gamified virtual reality in reducing anxiety and improving patient experience during the extraction of of MIH affected lower first molars.

Keywords

Virtual reality; Distraction; Gamification; Tooth extraction; MIH

1. Introduction

Dental anxiety is a complex emotional reaction that many individuals experience during dental visits. This fear can be triggered by various factors, including past negative experiences, fear of pain, a sense of loss of control, or simply the anticipation of discomfort during treatments [1]. Some patients may feel anxiety at the mere thought of visiting the dentist or undergoing a specific procedure, and this anxiety is especially pronounced in children who are about to undergo tooth extraction. Symptoms of anxiety in a dental setting may include increased heart rate, sweating, panic and nausea. These symptoms further complicate dental procedures, making them more uncomfortable for both the patient and the dentist [2, 3].

Managing dental anxiety can involve numerous pharmacological and non-pharmacological measures [4, 5]. Inhalation sedation with nitrous oxide, is a commonly used method for managing dental anxiety and pain in pediatric patients during tooth extractions. It is often regarded as the pre-ferred choice due to its safety, ease of use and effectiveness in reducing anxiety and discomfort, particularly for children undergoing potentially stressful procedures like tooth extractions [6, 7]. In addition to pharmacological methods, one non-pharmacological approach is distraction, a cognitive-behavioral technique aimed at reducing pain perception by redirecting the patient's attention to something non-painful [8–10].

This approach allows patients to mentally distance themselves from the procedure and focus on something that relaxes or entertains them, rather than on stressful or unpleasant thoughts. The distraction method is most commonly implemented through Virtual Reality (VR) technology, which helps patients focus on enjoyable experiences instead of distressing thoughts. While this technology is generally more effective than other digital distractions, research on its impact in reducing dental anxiety yields mixed results; some meta-analyses report positive effects, while others show no significant changes, particularly during local anesthesia [11, 12].

In addition to virtual environments, VR content designed to interact with users, known as gamification, is now being implemented. This approach involves introducing games, challenges, rewards and competitions into treatments through specialized applications and equipment, making it particularly appealing to younger patients [13, 14].

Molar-incisal hypomineralization (MIH) is a dental condition where the enamel is not properly mineralized, resulting in weak areas on molars and incisors. This can lead to aesthetic issues, heightened sensitivity, and a higher risk of cavities. Various factors may contribute to MIH, including genetic influences, systemic illnesses that occur during tooth development, infections, or nutritional deficiencies [15]. The classification of MIH divides this condition into four grades, ranging from mild to severe, based on the extent of enamel damage and functional impact [16]. Severe forms often require tooth extraction, which can be complicated due to the weakened structure, potentially increasing discomfort during the procedure [17].

The aim of this study was to evaluate the effectiveness of gamified virtual reality in reducing anxiety and pain during the extraction of lower first molars with MIH under local anaesthesia.

2. Materials and methods

A prospective study included 56 participants under the age of 10, with and an indication for the extraction of both lower first molars due MIH grade 4. Exclusion criteria for the study encompassed individuals with systemic disease, special needs, patients with a history of epileptic seizures or episodes of dizziness, as well as patients suffering from claustrophobia. Ethical approval for this research was obtained from the Ethical Committee of Faculty of Medical Sciences, University of Kragujevac (no. 01-14788/2022).

2.1 Research protocol

The extraction of lower molars was conducted in two randomized phases, with a four-week interval (split-mouth design study). The randomization list was created based on a list of random numbers and was used for randomization. In the extraction of one tooth, the procedure was performed according to the standard protocol (Non VR Phase). All clinical procedures were performed by one clinician, while the dental assistant measured the pulse values. For the tooth on the opposite side, the entire extraction procedure (including the application of local anesthesia) was conducted using a gamification model with VR goggles (VR Gamification Phase) (Fig. 1).

The study employed the Pico 4 all-in-one VR goggles with wireless streaming capability and precise controllers, weighing only 295 grams, with an elegant design and a high-resolution 4K screen with audio. Prior to the procedure, the patient was familiarized with the VR game—Realm of Dream (exploring a magical VR world that does not require sudden movements from the user, using VR controllers as a magical tool for manipulating water) (Fig. 2).

Pain-free work was ensured in both phases of the study

using local anaesthesia (LA) for Inferior alveolar nerve block (IANB), we used 2% lidocaine with adrenaline (40 mg + 0.025 mg) 2 mL anesthetic solution (Lidokain-hlorid Galenika 2%, Galenika AD, Belgrade, Serbia).

2.2 Measurements

We used the Wong-Baker Face Scale to assess pain, which allows patients to visually describe their level of pain [18]. This scale consists of six faces with different expressions, ranging from a face showing no pain to a face representing the worst possible pain. This method of assessment is particularly useful for children. Pain was recorded during the administration of anaesthesia and during the tooth extraction procedure.

Additionally, heart rate was monitored to assess the patient's physiological response to stress and pain during the procedure. Heart rate was recorded during anaesthesia administration and during the procedure using a smartwatch that allows continuous heart rate tracking (Samsung Galaxy Watch). This type of measurement provides additional information on how the patient responds to pain and stress, enabling the dentist to adjust their approach according to the patient's physiological response.

After the extraction procedure with VR application, patients filled out a modified satisfaction questionnaire [19]. Responses were classified based on a 5-point Likert scale: 1 = strongly disagree, 2 = disagree, 3 = neutral, 4 = agree, and 5 = strongly agree. The post-clinical questionnaire included questions related to reduction of fear of anaesthesia and extraction, effectiveness of VR in diverting attention from the procedure, experience of discomfort during the procedure, enjoyment of the VR experience, and the potential of VR in overcoming fear of other procedures.

2.3 Statistical analysis

The total sample size required to detect an effect size of 0.24 in a repeated measures analysis of variance for the Face pain scale, with a significance level of 0.05 and a statistical power of 0.9, is 48 patients. The effect size was derived based on the assumed ratio of explained to residual variance of 0.05 to 0.9. The sample size calculation was performed using the G-power 3.1.6 software (University of Düsseldorf, Dusseldorf, NRW, Germany).

For the testing of statistical hypotheses, we used the t-test for dependent samples, the Wilcoxon test, and the Mann-Whitney test. The correlation between age and the level of pain or heart rate values was assessed using Spearman's or Pearson's correlation coefficient. The correlation between the variables was estimated using Spearman's correlation coefficient. Statistical hypotheses were tested at a level of statistical significance of 0.05. All data was processed in R software environment (R Core Team, 2019).

3. Results

The study included a total of 56 patients, with 30 boys and 26 girls. The average age was 7.6 ± 1.9 years.

Participants with VR had significantly lower pain scores during anaesthesia ($p < 0.001$) and during the extraction pro-
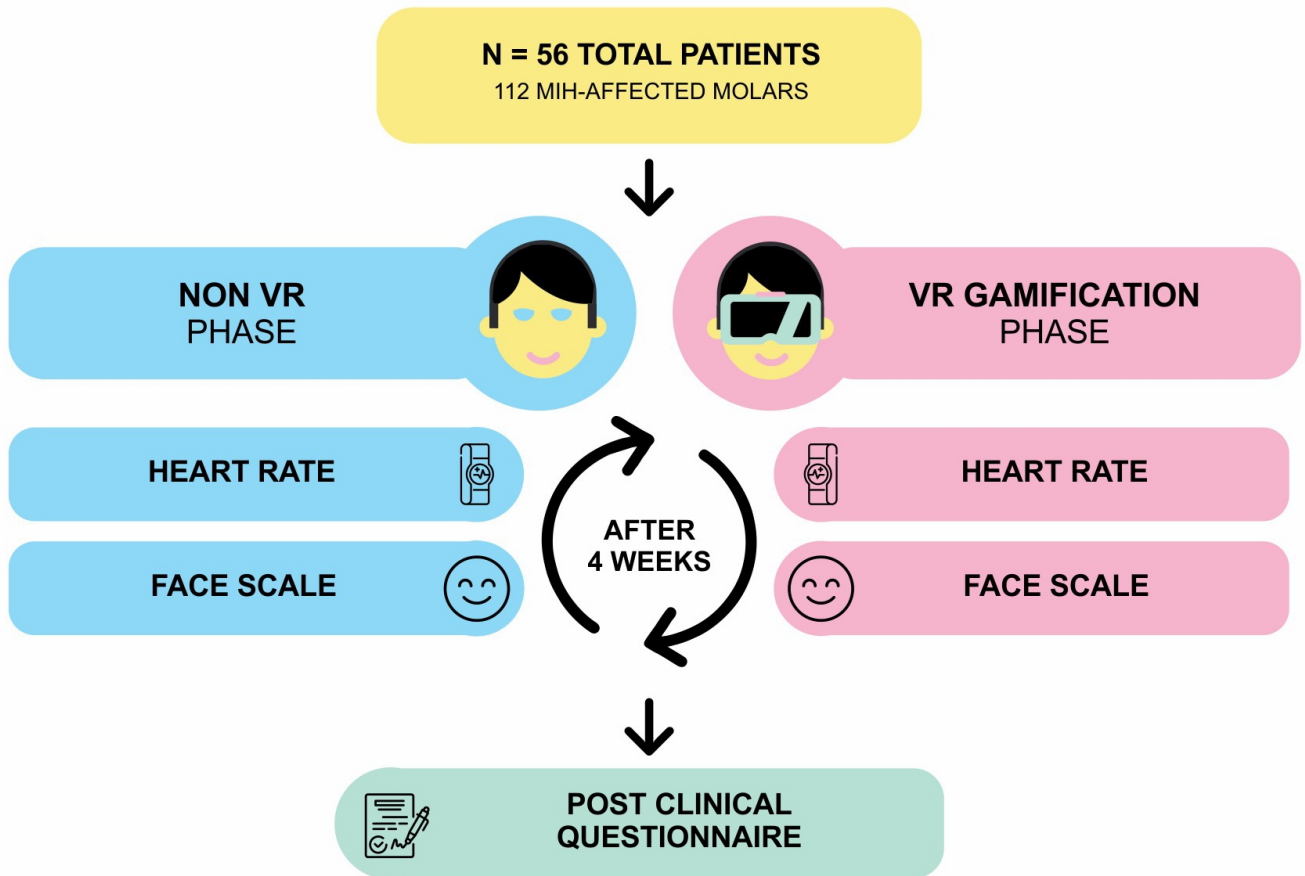
N = 56 TOTAL PATIENTS
112 MIH-AFFECTED MOLARS

NON VR PHASE

VR GAMIFICATION PHASE

HEART RATE

HEART RATE

FACE SCALE

FACE SCALE

AFTER 4 WEEKS

POST CLINICAL QUESTIONNAIRE

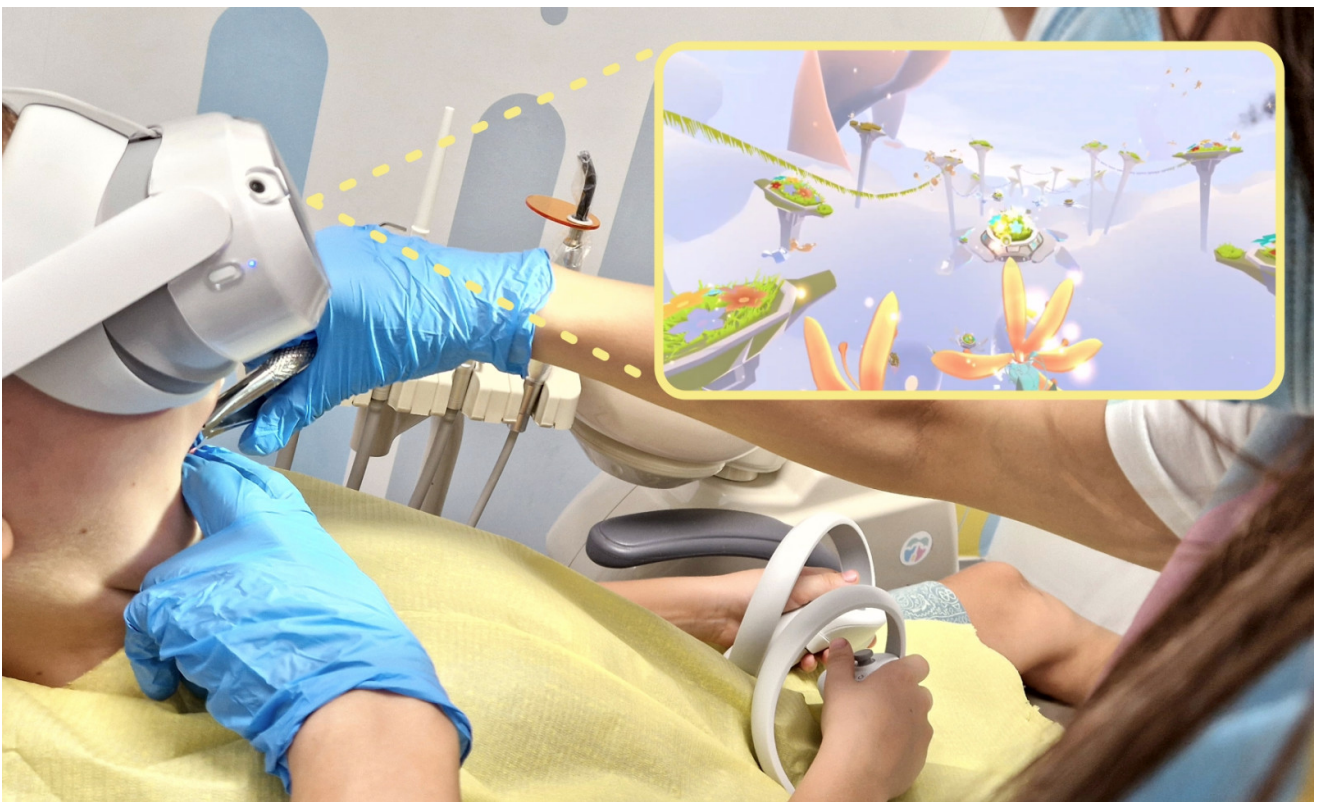**F I G U R E 1. Research protocol.** VR: Virtual Reality.

F I G U R E 2. The tooth extraction phase with VR goggles featuring framed VR content that the patient sees during the procedure.

cedure ($p = 0.039$) (Table 1). The heart rate values of all participants did not significantly differ before the extraction procedure (during application of LA) ($p = 0.248$), while participants with VR had significantly lower heart rate values during the intervention ($p < 0.001$) (Table 2). Regarding gender, there were no statistically significant differences in the degree of pain during anaesthesia ($p > 0.05$) or during the intervention ($p > 0.05$). Heart rate values did not differ between genders at any measurement point ($p > 0.05$).

There is a statistically significant moderate positive correlation between age and pain level during anaesthesia in the traditional intervention (rho = 0.412; $p = 0.037$) and in VR (rho = 0.395; $p = 0.046$). Younger participants experienced higher levels of pain in both cases. There is a statistically significant moderate positive correlation between age and pain level during the procedure in VR (rho = 0.456; $p = 0.019$), while in the traditional intervention, there is no correlation (rho = 0.295; $p = 0.144$). There is no statistically significant correlation between age and heart rate values at any measurement point ($p > 0.05$).

More than 65% of participants believe that VR alleviated their fear of anaesthesia or surgery. Over 75% of participants feel that VR diverted their thoughts from the surgery. Over 90% of participants had no discomfort with VR during the intervention, while the rest experienced partial discomfort. Over 80% of participants enjoyed the experience with VR. Over 80% of participants believe that VR can help them overcome fear in other procedures (Table 3). There is no statistically significant correlation between age and all questions, Q1 (rho = -0.335; $p = 0.095$), Q2 (rho = -0.354; $p = 0.076$), Q3 (rho = -0.110; $p = 0.594$), Q4 (rho = -0.251; $p = 0.217$), Q5 (rho = -0.093; $p = 0.653$) and Q6 (rho = 0.060; $p = 0.770$).

4. Discussion

In early childhood, when children are particularly susceptible to forming attitudes toward dental treatments, it is important to create positive experiences. Given that molars affected by MIH are often more complicated to extract, an appropriate approach that includes non-pharmacological methods should enhance the quality of therapy and the overall experience for patients. Based on these considerations, we decided to apply the VR gamification model for the extraction of such teeth, which should be particularly engaging and interactive for children. The results of our study show that the use of VR gamification significantly contributed to reducing the perception of pain among participants during the administration of local anaesthesia and extraction of the first lower molar compared to the traditional procedure without VR. These findings support previous research suggesting that virtual reality technologies can be an effective means of reducing anxiety and pain in patients during dental procedures [13, 19].

Additionally, the use of VR technology led to significantly lower heart rate values among participants during the intervention. This suggests that VR successfully acts not only to reduce the perception of pain but also to reduce the physiological stress associated with dental treatments. Although the exact mechanism of pain reduction caused by VR technology is not yet fully understood, research suggests that reduced activity in parts of the brain responsible for pain recognition and signalling may result from distraction in the virtual environment

T A B L E 1. Pain scale values during anaesthesia administration and tooth extraction.

Face Scale	Non VR median (range)	VR median (range)	p-value
During application of LA	2 (0–8)	0 (0–6)	<0.001*
During extraction	0 (0–8)	0 (0–2)	0.039*

statistically significant. VR: Virtual Reality; LA: local anaesthesia.

T A B L E 2. Heart rate values during application of LA and during tooth extraction.

Heart rate (bpm)	Non VR mean ± sd	VR mean ± sd	p-value
During application of LA	88.5 ± 12.1	87.4 ± 11.1	0.248
During extraction	90.5 ± 12.3	83.1 ± 9.6	<0.001*

statistically significant. VR: Virtual Reality; sd: standard deviation; LA: local anaesthesia.

T A B L E 3. Participants' responses regarding satisfaction with VR technology.

Questions	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
Q1—VR has alleviated my fear of anesthesia?	0.0%	7.7%	26.9%	42.3%	23.1%
Q2—VR has alleviated my fear of tooth extraction?	0.0%	6.2%	16.9%	65.4%	11.5%
Q3—VR diverted my thoughts from the intervention?	5.2%	0.0%	17.8%	30.8%	46.2%
Q4—Did I feel discomfort with VR during application?	53.8%	26.9%	15.4%	3.8%	0.0%
Q5—I enjoyed the experience with VR?	0.0%	2.9%	7.1%	55.2%	34.8%
Q6—Can VR help me overcome fear in other procedures?	0.0%	0.0%	19.2%	38.5%	42.3%

VR: Virtual Reality.

and reduced cognitive resources, which disrupt the processing of neural signals by pain receptors [14].

It is important to note that the VR goggles used in this study were comfortable to wear and allowed children to interact with virtual content through VR controllers, which further engaged patients in the game, making them less likely to focus on their anxiety or discomfort related to the treatment [13]. In addition, the VR experience included sound effects and music that enhanced immersion, creating a more enjoyable and engaging environment for the patients. This audio component, combined with the visual elements of the VR experience, likely contributed to a comprehensive distraction that helped reduce anxiety. Furthermore, gamification, which includes fun, challenging, and rewarding aspects, can trigger positive emotions when a patient achieves success or earns a reward. These positive emotions can neutralize the negative feelings associated with dental stress, helping patients to relax [14]. The weight of the goggles can also be an important factor, as excessively heavy goggles may cause discomfort or pressure on the patient's nose or ears during longer procedures. Additionally, it is crucial that VR goggles have clear and sharp screens so that patients can enjoy a realistic virtual experience. Poor resolution or blurry screens can diminish the therapeutic effect of VR technology and reduce the effectiveness of distraction during procedures [20, 21].

Our results also demonstrate a high level of satisfaction with the use of VR, with most participants not experiencing discomfort during treatment and believing that VR helped reduce the fear of anesthesia and extraction. These findings suggest that VR technology is well accepted by patients and can be useful in overcoming dental anxiety [9, 11, 13, 19]. Although this study did not find a significant correlation between gender, patient age, and discomfort when using VR technology, further research is needed to better understand this relationship. Although this study did not find a significant correlation between gender, patient age, and discomfort when using VR technology, further research is needed to better understand this relationship.

Regarding patient age, our results show a positive correlation between age and pain perception during anesthesia and tooth extraction. Younger participants reported higher levels of pain in both cases, which may be attributed to younger individuals being more sensitive to pain, having higher expectations of pain, or being more likely to indicate greater pain on the Faces Pain Scale. Therefore, it is necessary to take these results with caution.

Despite the study including a single game suitable for the age and interests of the examined population, future steps should focus on developing VR gamified content that can be further customized to individual patient interests and the duration of the intervention. It is also necessary to apply additional tools for pain analysis.

5. Conclusions

Gamified virtual reality represents an effective method of non-pharmacological intervention for reducing anxiety and pain in patients during the extraction of the MIH-affected first lower permanent molar, manifested through pain reduction and lower heart rate values.

AVAILABILITY OF DATA AND MATERIALS

The data presented in this study can be made available on request.

AUTHOR CONTRIBUTIONS

RM—designed the research study, methodology. RM, FD—investigation, resources and data curation. RM, FD, MM, ZA, ISK—writing-original draft preparation, writing-review and editing, performed visualization.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

This study was approved by the Ethical Committee of Faculty of Medical Sciences, University of Kragujevac (01-14788/2022). Additionally, parents had to sign a paper granting permission for their child's participation (including any images).

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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