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Original Article

Effects of Dental Sound Insulation System on Stress and Dental Fear Reduction in Pediatric Patients

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Abstract

This study aimed to assess the effectiveness of dental sound insulation in alleviating stress and fear during dental scaling in pediatric patients. It also examined the influence of a noise-canceling application on dentist-patient communication and convenience of dental procedures. This study included 60 children and adolescents aged 7 - 16 years between April 2022 and March 2023. All participants underwent dental plaque control using an ultrasonic scaler on the maxilla first, followed by plaque control on the mandible. Dental sound insulation with active noise canceling was randomly applied to either the maxilla or mandible. Findings revealed that the stress index was significantly reduced when the application was used, with a score of 5.85 compared to 8.43 without it ($p < 0.0001$). Similarly, the dental fear score was significantly reduced to 1.17 with the application, as opposed to 2.97 without it ($p < 0.0001$). The dental sound insulation did not affect the communication between dentists and patients or the convenience of treatment. This study demonstrated that active noise canceling during pediatric dental care significantly reduced stress and fear, suggesting that it could be a valuable behavior guidance tool, particularly for children who find dental visits challenging. [J Korean Acad Pediatr Dent 2024;51(4):380-391]

Keywords

Dental noise, Stress index, Dental fear, Active noise canceling, Dental sound insulation application

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Introduction

In pediatric dentistry, dental anxiety and fear are recognized as factors that induce negative behaviors in children and lead to the avoidance of dental vis-

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its[1,2]. The prevalence of dental anxiety in pediatric dental clinics is approximately 20%[3], with higher rates observed in preschoolers and schoolchildren than in adolescents[4]. Various traditional techniques, such as tell-show-do, modeling, systematic desensitization, and positive reinforcement, have been used to manage children with dental anxiety[5].

Recently, efforts have been made to apply new methods to manage dental anxiety or fear that are driven by technological advancements. For example, patients demonstrate reduced wrist-raising movements when wearing eyeglasses during dental treatment or when exposed to three-dimensional videos[6]. This indicates a reduction in dental anxiety by effectively diverting attention away from dental sounds and views, thus serving as a form of distraction for pediatric patients[7]. The use of technologies such as audio and audiovisual distractions appears to result in no contraindications, as they are widely accepted by almost all pediatric patients and are easily implementable and safe in clinical settings[8].

However, distraction methods do not block the stimulus itself but rather divert patient attention elsewhere. Stimuli that can trigger dental anxiety include the smell of dental materials, the sight of needles or dental drills, waiting in the reception area, and noise produced in the dental environment. Among these, dental noise poses a significant challenge to pediatric dental treatment. The sounds produced by dental handpieces, ultrasonic scalers, and suction can cause discomfort and fear in children, resulting in reduced cooperation and compromised treatment outcomes[9].

Active noise-canceling (ANC) technology can be applied to dental treatments to mitigate dental noise stimulation. ANC is based on the principle of superposition and operates by intentionally synthesizing acoustic waves to create destructive interference patterns, thereby eliminating primary noise (unwanted noise)[10]. An anti-noise with a matching amplitude but opposite phase to the primary noise is produced, and this is then combined with the primary noise to effectively cancel both noises[11].

Various initiatives have been pursued to implement ANC in dentistry[12-14]. However, most studies have focused on investigating the effects of ANC on preventing hearing loss among dental staff[15] or have primarily focused on adult models[16], with limited attention given to exploring its direct impact on pediatric patients who are particularly vulnerable to dental noise. Therefore, this study aimed to investigate if a dental sound insulation system is effective in alleviating stress and dental fear in pediatric dental treatment (scaling) and to emphasize the need for advancements in the application of ANC as a behavior guidance technique in pediatric dentistry.

Materials and Methods

1. Protocol registration and reporting

The clinical protocol was reviewed and approved by the Institutional Review Board of Yonsei University Dental Hospital (2-2021-0119) and was performed in accordance with the Consolidated Standards of Reporting Trials 2010 guidelines.

2. Patient enrollment

A randomized study involving 60 participants was performed between April 2022 and March 2023 at Yonsei University Dental Hospital, Seoul, Republic of Korea. Written informed consent was obtained from the parents of all participants prior to the clinical trial.

1) The inclusion criteria were as follows:

(1) Patients aged 7 - 16 years with good general health.

(2) Patients who underwent dental treatment cooperatively (Frankl Behavior Rating Scale score of 3 or 4).

(3) Patients with poor oral hygiene requiring dental plaque control and tooth brushing instructions.

2) The exclusion criteria were as follows:

(1) Patients with congenital hearing loss.

(2) Patients diagnosed with acquired hearing loss.

(3) Patients using hearing aids.

(4) Patients with mental disorders

3. Devices and applications

The equipment required for the dental sound insulation system included an Mpow H21 headphone (Mpow Technology Co., Ltd., Mong Kok, Hong Kong) with ANC functionality, a tablet PC muPAD K10 (FORYOUDIGITAL Co., Ltd., Goyang, Republic of Korea), and a Mamen WMIC-5G Pro wireless microphone (Shenzhen Kuaimen Photographic Equipment Co., Ltd., Haiwang, China) that was used to transmit the dentist's voice to the patient (Fig. 1A, 1B). An application called Healingsound version 1.0 (Healingsound Co., Ltd., Seoul, Republic of Korea) was used to selectively block dental noise. Through this application, even when the patient wore ANC headphones, the dentist's voice could be distinguished from dental noise, and only the dentist's voice was transmitted to the patient's headphones through the microphone (Fig. 1C).

The equipment used to collect the physiological response data of the participants was a Polar Verity Sense sensor (Polar Electro Oy, Kempele, Finland) to measure the heart rate (Fig. 2A). The collected heart rate data were used to calculate the pulse-pulse interval (PPi), one of the heart rate variability (HRV) metrics, using the polar sensor logger application (Polar Electro Oy, Fig. 2B). The PPi was then converted into a stress index using the Kubios HRV Standard program (Kubios Oy, Kuopio, Finland, Fig. 2C).

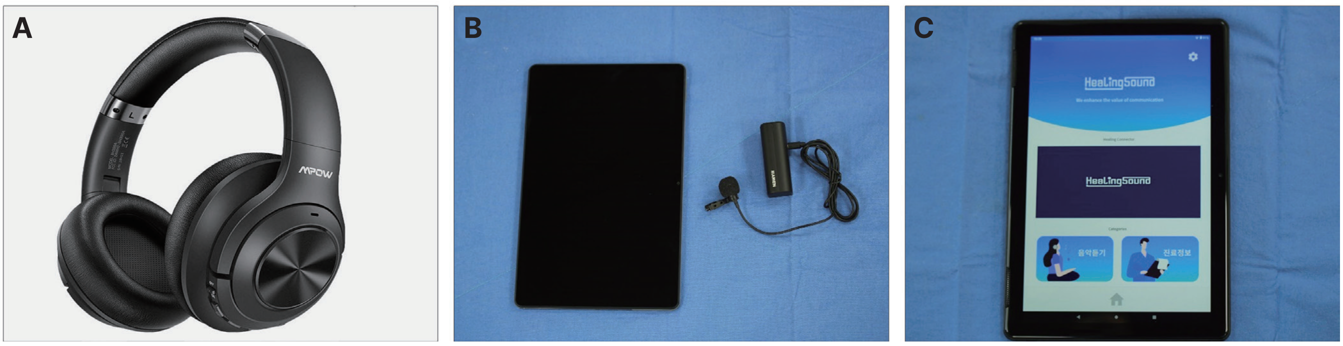

Fig. 1. Devices used in this study. (A) Active noise canceling headphone (MPOW H21), (B) Tablet PC (muPAD K10) and wireless microphone (MAMEN WMIC-5G Pro), (C) Dental noise insulation application (Healingsound).

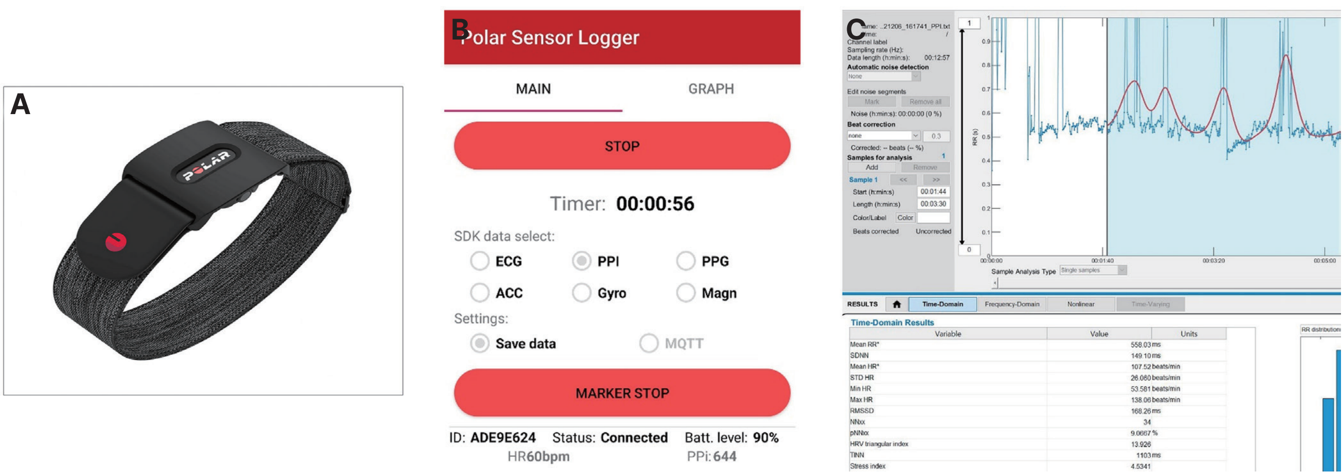

Fig. 2. The device, application, and software used to calculate the stress index. (A) Heart rate sensor (Polar Verity Sense), (B) Heart rate and pulse-pulse interval recording application (Polar sensor logger), (C) Software that converts pulse-pulse interval to stress index (Kubios HRV Standard).

4. Clinical procedures

Plaque control was performed using an ultrasonic scaler on the maxilla, followed by the mandible in all patients. One arch was treated with sound insulation, while the other was not. The order of the ANC was determined using a coin toss. Patients who initially received ANC underwent plaque control of the maxillary teeth while wearing headphones and then received plaque control of the mandibular teeth without wearing headphones. Conversely, patients who received ANC later underwent plaque control of the maxillary teeth without wearing headphones and then underwent plaque control of the mandibular teeth while wearing headphones. Following treatment of the maxillary teeth, the patients were provided a 5-minute rest interval before proceeding with treatment of the mandibular teeth. During the treatment, the dentist attempted to communicate with the patient by using the following sentences: “Please open your mouth,” “Try breathing through your nose,” and “I will remove saliva.”

Before starting the treatment, the participants wore a Polar Verity Sense sensor on their upper arms to measure the stress index during the treatment. It was also measured when not receiving treatment, in order to establish a baseline. To eliminate visual effects, all the patients were treated with a dental drape (Fig. 3). As the behavior guidance and clinical skills of the operator could influence the participants’ stress and fear levels, a single pediatric dentistry resident conducted all clinical trials for consistency. Following treatment, they were asked to complete a questionnaire regarding dental fear, communication between dentists and patients, and the convenience of dental treatment using a visual analysis scale (VAS).

Fig. 3. The participant ready for treatment with all devices on.

5. Questionnaire survey

A questionnaire was given after all treatments were completed, and all participants received the same questionnaire regardless of the ANC order. The questions were divided into the following two categories.

1) VAS assesses dental fear, communication between dentists and patients, and convenience of dental treatment. These scores were measured separately under two conditions: when ANC was used and when it was not used. The included items such as:
   (1) How would you rate the level of fear experienced?
   (2) How would you rate the smoothness of communication with the dentist?
   (3) How would you rate the convenience of receiving the treatment?
2) A 5-point Likert scale asking regarding the necessity of the ANC system during dental treatment, with items such as:
   (1) Are you afraid of dental sounds?
   (2) Need to protect ears from dental noise?
   (3) Does ANC help during treatment?
   (4) Will you use ANC in the future?

6. Variables indicating the effects of the dental sound insulation application

The effects of dental sound insulation application were evaluated based on changes in stress and fear. For convenience, the use of dental sound insulation is denoted as “with ANC” and its removal as “without ANC”. The effects of ANC were expressed as a reduction in the stress index and fear score based on the presence or absence of ANC, as demonstrated below.

1) Stress Reduction Effects

   : ΔStress Index (SI)

   : $SI_{(without\ ANC)} - SI_{(with\ ANC)}$

2) Fear Reduction Effects

: ΔFear Score

: $\text{Fear}_{(\text{without ANC})} - \text{Fear}_{(\text{with ANC})}$

7. Statistical analysis

All statistical analyses were performed using SPSS (Statistical Package for Social Sciences) version 26.0 (IBM Corporation, Armonk, NY, USA), and statistical significance was set at $p < 0.05$. All variables were confirmed to be normally distributed using the Shapiro-Wilk test.

Changes in the stress index were analyzed using repeated-measures analysis of variance (ANOVA) and compared among baseline, with ANC, and without ANC. A paired-sample t-test was used to analyze differences in dental fear, communication, and convenience, depending on the presence or absence of ANC. Pearson's correlation analysis was performed to determine the variables that correlated with the effectiveness of ANC.

Results

Among the 60 children, 29 were male and 31 were female. The mean patient age was 10.32 ± 2.18 years. The average number of dental visits in the previous year was 3.47 ± 1.26. General characteristics related to the sex and age distribution of the study participants and the number of dental visits in the past year are presented in Table 1.

Table 1. General characteristics of the study participants

Characteristics	n	%
Sex		
Male	29	48.3
Female	31	51.7
Age (years)		
7 - 9	23	38.3
10 - 12	28	46.7
≥ 13	9	15.0
Dental visits		
1 - 2	18	30.0
3 - 4	23	38.3
≥ 5	19	31.7
Total	60	100.0

In the survey, six patients (10%) responded that they were afraid of dental sounds, and 26 patients (43%) stated that they needed to protect their ears from dental noise (yes or absolutely yes). Furthermore, thirty-nine patients (65%) responded that the dental sound insulation system was helpful during treatment, and 38 patients (63%) stated that they would use it in the future (Fig. 4).

When the ANC system was not used, the communication score between the dentist and patient was 7.82. When the ANC system was used, the score decreased slightly to 7.57; however, no significant difference was observed ($p = 0.522$). When the ANC system was not used, the convenience score for dental treatment was 7.22. When the ANC system was used, the score increased slightly to 7.70, but the difference was not significant ($p = 0.161$, Fig. 5).

The baseline stress index, measured without treatment was 3.73. During dental treatment, the stress index increased significantly ($p < 0.0001$). When the ANC was not applied, the stress index was 8.43, and when it was applied, the stress index was 5.85. The stress index also differed significantly depending on whether ANC was used ($p < 0.0001$). When treated without ANC, the fear score was 2.97, and this decreased to 1.17 when treated with ANC, representing a significant result ($p < 0.0001$, Fig. 6).

The stress index without ANC was significantly and positively correlated with stress reduction ($p < 0.0001$, $R = 0.753$, Fig. 7A). Similarly, the fear score without ANC exhibited a significant positive correlation with the fear reduction effect ($p < 0.0001$, $R = 0.792$, Fig. 7B). The number of dental visits and patient age were not correlated with stress or fear reduction (Table 2, Fig. 8).

Discussion

A recent study investigating dental noise observed that applying ANC during scaling in adults reduced the discomfort and pain caused by noise[16]. In contrast to previous studies that focused on adults, this study aimed to provide objective data regarding the effectiveness of ANC in children. Additionally, this study sought to determine the conditions necessary for ANC to effectively

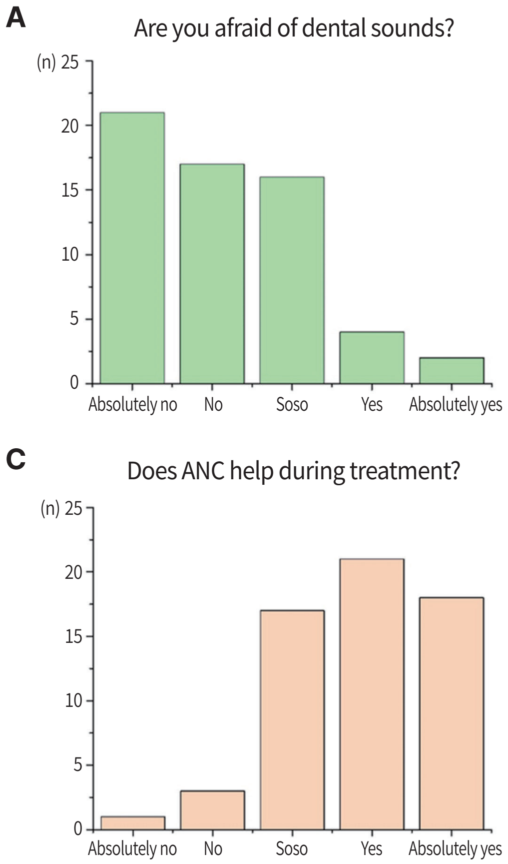

Fig. 4. Responses regarding the necessity of dental insulation applications. The x-axis shows the answers, and the y-axis shows the number of persons. The following questions were asked: (A) "Are you afraid of dental sounds?", (B) "Need to protect ears from dental noise?", (C) "Does ANC help during treatment?", (D) "Will you use ANC in the future?".
ANC: Active noise canceling.

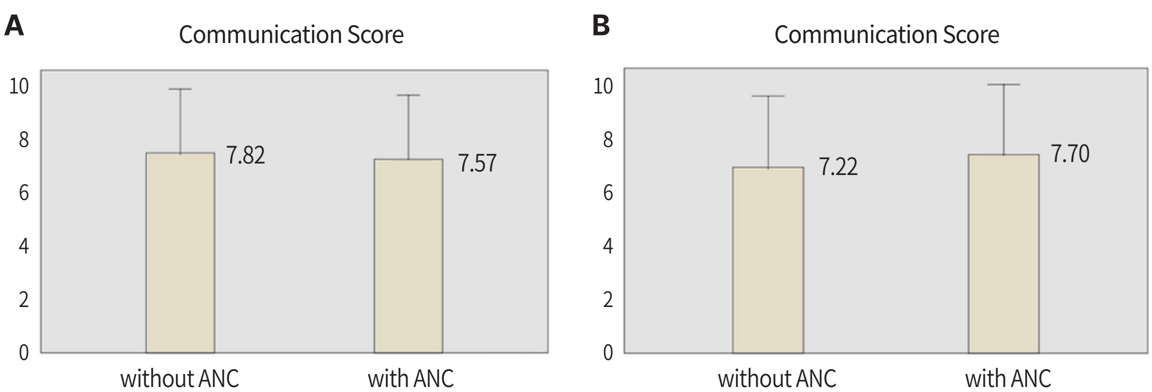

Fig. 5. Comparison of communication and convenience scores between the without ANC and with ANC groups. (A) The communication score decreased slightly from 7.82 (without ANC) to 7.57 (with ANC) but exhibited no significant difference (p = 0.522), (B) The convenience score increased slightly from 7.22 (without ANC) to 7.70 (with ANC) but exhibited no significant difference (p = 0.161).
p value from paired sample t-test.
Error bars: mean ± standard deviation.
ANC: Active noise canceling.

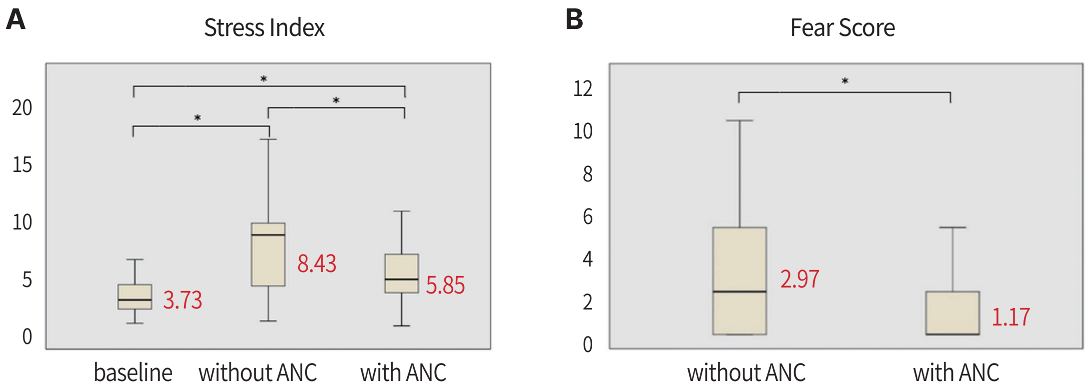

Fig. 6. Boxplot of stress index and fear score. (A) Stress index increased from 3.73 (baseline) to 8.43 (without ANC). Stress reduced from 8.43 to 5.85 when ANC was applied. The stress index was higher during treatment than at baseline, regardless of whether the patients were using ANC. All stress index values exhibited statistically significant differences ($p < 0.0001$), (B) The fear score decreased from 2.97 (without ANC) to 1.17 (with ANC) during treatment. There was also a significant difference in patient fear scores according to the presence or absence of ANC ($p < 0.0001$).
*$p < 0.05$, p values from repeated measures analysis of variance (A).
*$p < 0.05$, p values from the paired sample t-test (B).
ANC: Active noise canceling.

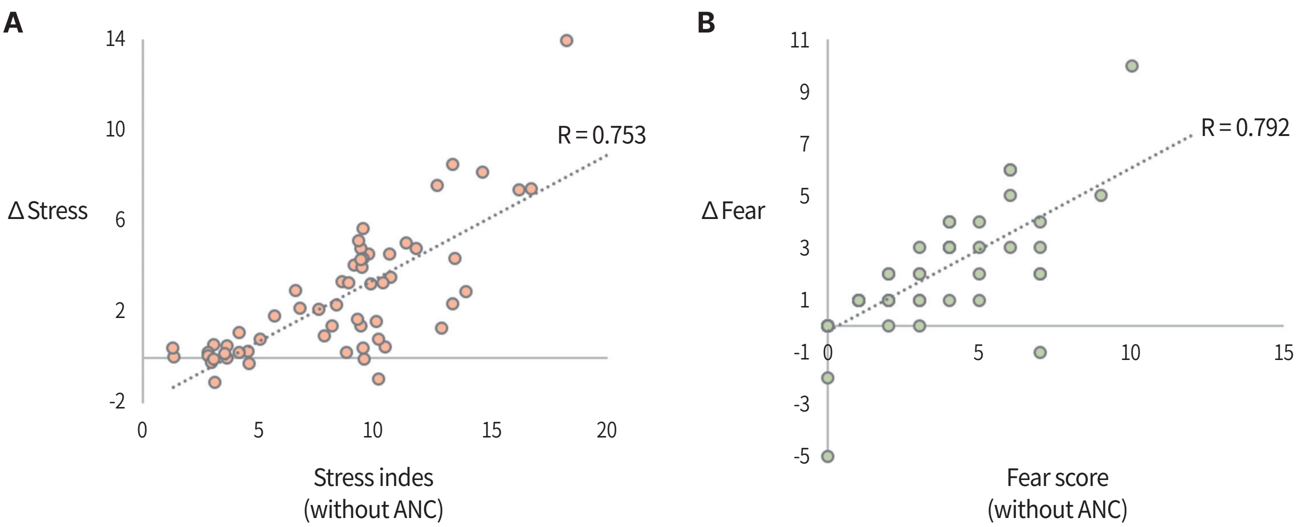

Fig. 7. Scatter plot of stress and fear reduction effects according to dental stress and fear level. (A) Patients with a high stress index (without ANC) exhibit a good stress reduction effect ($p < 0.0001$, R = 0.753), (B) Patients with a high fear score (without ANC) exhibit a good fear reduction effect ($p < 0.0001$, R = 0.792).
$p < 0.01$, p values from Pearson's correlation test.
R: Pearson's correlation coefficient.
ANC: Active noise canceling.

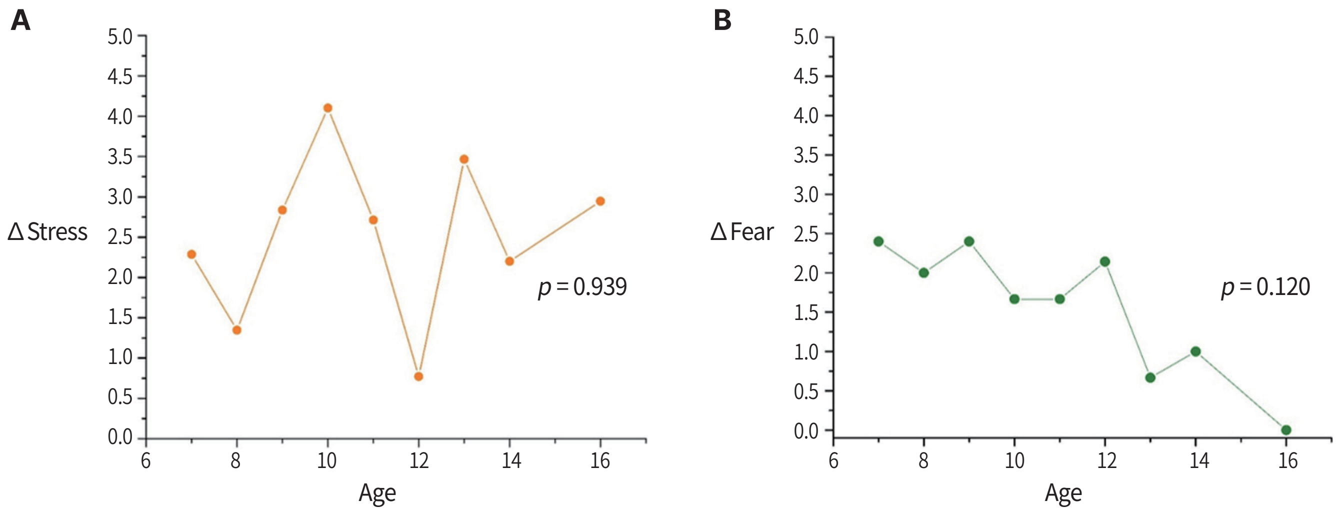

Fig. 8. Changes in the effectiveness of ANC with age. (A) The stress-reducing effect did not exhibit regularity with age (p = 0.939), (B) As age decreased, the effect of reducing fear tended to increase; however, it was not statistically significant (p = 0.120).
p values from Pearson's correlation test.
ANC: Active noise canceling.

Table 2. Correlation coefficients between age, dental visit, stress index 'without ANC', fear score 'without ANC', stress reduction, and fear reduction

	Age	Dental visit	Stress index (without ANC)	Fear score (without ANC)	Stress reduction	Fear reduction
Age						
Dental visit	0.112*					
Stress index (without ANC)	0.335*	0.048				
Fear score (without ANC)	-0.198	-0.105	-0.153			
Stress reduction	0.010	-0.022	0.753*	-0.203		
Fear reduction	-0.187	-0.161	-0.097	0.791*	-0.158	

All values from Pearson's correlation test.
*Correlation is significant at the 0.01 level (2-tailed).
ANC: Active noise canceling.

demonstrate its effects, and to assess if ANC interferes with patient-dentist communication.

Headphones utilizing ANC principles fundamentally comprise a reference microphone that detects the primary noise requiring cancellation, a loudspeaker that generates anti-noise, and an error microphone that assesses the level of noise cancellation[17]. The ANC headphones used in this study employed a multi-reference controller strategy in which the left and right reference microphones were placed in each ear cup, utilizing multiple reference signals to achieve more effective attenuation in various sound environments[18]. These dental headphones differ from existing commercial products in that they primarily block the human voice (1 kHz) and public transportation noise (10 kHz)[12]. Additionally, hybrid ANC technology has been applied[19] that not only focuses on blocking high-frequency noises, specifically at 1, 4, and 8 kHz that are commonly observed in dental environments[20,21], but also blocks ambient noise in the low-frequency range.

In our study, we investigated the effects of ANC in pediatric patients undergoing treatment with an ultrasonic scaler. Ultrasonic scalers pose difficulties to patients due to three factors that include water spray, pain from vibration, and noise[22]. Among these factors, ANC helps to reduce the impact of noise. Although the ANC can cancel air-conducted sounds, it cannot block bone-conducted sounds. Thus, we specifically evaluated the effects of reducing air-conducted noise.

It has been suggested that HRV, which denotes fluctuations in the length of heartbeat intervals[23], can serve as an objective indicator of stress[24,25]. The correlation between HRV and ventromedial prefrontal cortex activity was elucidated using neuroimaging mapping[26]. When HRV variation is low, sympathetic nervous system activation indicates a high stress level, whereas when HRV variation is high, parasympathetic nervous system activation indicates a low stress level[27]. Based on these findings, research utilizing HRV to measure stress index has been conducted. HRV was assessed using the R-R interval (RRi), which denotes the period between two consecutive electrocardiographic R-waves of the QRS complex[23]. PPi represents the period between the peaks of two consecutive volume pulses and typically shares similar values with RRi[28]. For convenience, PPi values measured using a Polar Verity Sense sensor, a type of photoplethysmography, have been used as an alternative parameter for evaluating HRV[29]. The collected PPi values were converted into stress indices using the Kubios HRV program[30,31].

The average age of the 6 participants (10%) who reported feeling fearful of dental sounds was 9.5 years, and this was slightly lower than the overall average age of 10.32 years. More than half of the participants (approximately 65%) reported the ANC application as helpful and expressed their desire to use it in the future. This indicates that even the participants who did not experience a significant fear of dental sounds evaluated the ANC application as beneficial. While most pediatric patients reported that ANC was helpful during treatment and expressed a willingness to use it in future treatments, it is possible that they responded positively to ANC simply because the device was new or novel. However, it is encouraging that negative opinions regarding device use were not predominant.

The ANC system used in this study was designed to block dental noise while allowing the transmission of a recognized human voice through a microphone to the patient's headphones with the aim of enhancing communication. Communication scores were expected to improve when ANC was applied. However, no significant differences were observed between groups. This may be due to the observation that participants did not perceive significant limitations in communication during routine scaling. Therefore, no substantial differences were observed, even when ANC was applied.

The convenience score increased slightly when the ANC was applied; however, no significant differences were observed. While some participants reported feeling comfortable receiving treatment in a quiet and calm atmosphere with surrounding noise and dental noise blocked by ANC headphones, a minority expressed feeling disturbed by excessive quietness or expressed concerns regarding the headphone wire touching or tangling with their bodies. These factors may have contributed to the lack of comfort provided by the ANC systems.

The stress index was higher when receiving treatment, regardless of ANC, than it was when not receiving treatment. This was an expected outcome, indicating that dental scaling is challenging and induces stress in pediatric patients. However, when ANC was applied during the treatment, the stress index was lower. Although there was a tendency for a relatively short washout time of 5 minutes between ANC application and non-application, we ensured a sufficiently stable state following the first treatment, before commencing the second treatment. Similarly, a lower fear score was observed when ANC was used. Consequently, the use of dental sound insulation systems decreased stress and fear.

Having discovered that stress and fear decreased when ANC was applied during dental scaling, we investigated the conditions under which this reduction was most pronounced. Prior to conducting this study, we expected the effectiveness of ANC to be greater in younger children due to their potential to perceive stimuli more intensely. However, age was not associated with the effectiveness of ANC. No discernible pattern was observed in the stress-reduction effect when the effect of ANC was plotted according to age. Although there was a tendency for a greater reduction in fear with younger age, as observed in the graph, this was not statistically significant (Fig. 8). The frequency of dental visits was also unrelated to the effectiveness of ANC. Therefore, we hypothesized that the effectiveness of ANC would vary depending on the individual temperament of pediatric patients rather than their age or frequency of dental visits.

As represented in a scatter plot, the stress and fear reduction effects were positively correlated with the levels of stress and fear experienced during dental scaling without ANC (Fig. 7). Patients who exhibited a significantly high stress index during dental scaling without ANC exhibited a substantial stress reduction when ANC was applied. Similarly, patients who experienced notably high fear scores without ANC demonstrated significant fear reduction when ANC was implemented. These findings outlined the target population for the application of dental sound insulation systems. They suggested that children who experienced high levels of stress and fear during dental treatment could effectively benefit from ANC, thereby facilitating dental procedures.

This study had several limitations. First, due to variations in the participants' oral hygiene status, we could not control the treatment time uniformly. Participants with heavy dental plaque and calculus may have undergone longer treatment durations, and this may have influenced their stress and fear scores. Second, although the groups were differentiated based on whether ANC was applied first or later, the dental scaling sequence was first standardized to the maxilla (followed by the mandible) rather than being equally divided. If the sequence of maxillary and mandibular scaling had been randomized, it could have helped control for the impact of arch type on stress and fear scores. Third, some younger participants may not have fully understood the questionnaire, thus leading to dentist intervention in explaining the survey content. This may have affected the survey responses. Finally, to collect more accurate data, a wash-out time of over 24 hours should have been implemented between treatments with and without ANC. However, to adhere to the principle of beneficence, which prioritizes patient health promotion during treatment, we set only a short wash-out time. Future studies should focus on the research design to address these limitations. This study only examined the effectiveness of ultrasonic scalers. Demonstrating the effectiveness of dental drills such as high-speed or low-speed handpieces in subsequent studies will broaden the scope of ANC applications. Furthermore, researching and clarifying if dental-specific ANC techniques are more effective than general noise-canceling headphones could lead to greater adoption of this application.

Conclusion

The effectiveness of dental sound insulation for alleviating stress and fear during pediatric dental scaling was evaluated. The application resulted in reduced stress and fear; however, there were no significant differences in communication between the dentist and patient or in the convenience of dental treatment. To the best of our knowledge, this study is the first to assess the use of dental sound insulation in pediatric dental treatment, and determined it to be particularly effective for patients who typically find dental treatment challenging. These findings suggest that dental sound insulation can be used as a behavior guidance method in pediatric clinical practice.

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Conflicts of Interest

The authors have no potential conflicts of interest to disclose.

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