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Dental drill noise reduction using a commercially available device

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Abstract

Aim: The noise in a dental surgery is concerning to both patients and staff, it is a major cause of dental phobia in patients and potential hearing loss in clinical staff. High-frequency noise generated by dental handpieces is considered to be the worst of the many noises in a dental clinic. Methods to reduce this noise have been proposed and either passive or active noise reduction headphones are often suggested. However, in a dental surgery environment, the need for good verbal communication with the patient needs to be maintained. As a result, this paper aims to evaluate one proprietary anti-noise device considered suitable for this specific purpose.

Methods: Lab-based experiments were set up and carried out to evaluate *QuietOn*, using GRAS 43AG-1 Ear & Cheek Simulator to mimic a section of the human head and ear for representing the acoustic characteristics of an actual ear. Two types of dental drill noise recordings, one for electric motor driven and another one for air turbine driven were played back through high-definition speakers. Sound data captured by the simulator are then visualised and plotted using MATLAB for analysis.

Main findings: QuietOn is especially effective at low frequencies (< 1kHz). However, when dealing with high-frequency noise such as that from the dental handpieces it performs in the same way as other passive noise insulation devices as it is relying on the foam tips.

Conclusions: Further development of active or passive noise cancellation earplugs is still needed to target dental handpiece noise whilst maintaining verbal communication.

Keywords: Passive noise reduction, Dental drill noise, High-frequency noise,

Introduction

Dental drills, also known as dental handpieces, produce a characteristic high frequency, narrow-band noise that is uncomfortable for patients and is also known to be harmful to dentists under prolonged exposure [1-7]. The dental handpiece noise is generated by rotating components at high speed. Electric and air turbine-driven are two main types of dental handpieces commonly used in dental surgery. Electric handpieces have speeds of around 200,000 revolutions per minute (rpm), meaning the peak noise generated by mechanical resonance will be around 3.3 kHz. Air turbine-driven handpieces normally operate at a speed range of 250,000 to 450,000 rpm, corresponding to 4.2 to 7.5 kHz. Therefore the target frequency range for dental handpiece attenuation should be between 3.3 to 7.5 kHz.

There are other unpleasant noises in dental surgery including the suction apparatus and the ultrasonic cleaning tool which can also be harmful [8, 9]. However, dental handpiece noise is frequently cited by patients as an unpleasant and anxiety-inducing noise and can result in patients avoiding treatment for oral disease leading to further pathology and increased disease and cost of treatment. Dental handpiece noise has scored highest on the Modified Dental Anxiety Scale (MDAS) [10]. A study conducted in Hong Kong [12] has shown that more than 76% of the participants, even those who come from a dental practice background, would prefer a lower volume of dental handpiece noise.

From previous work in this field, three main noise control methods available, namely Passive Noise Control (PNC), Adaptive Filtering (AF) and Active Noise Control (ANC) [12] were considered here.

PNC is a simple approach to noise attenuation by blocking the acoustic pathway from a noise source to the ear canal. This is typically effective above about 1 kHz, attenuating by up to 20 dB but as it does not selectively reduce noise peaks then they can still be perceived [13].

Adaptive filtering (AF) of dental handpiece noise focuses on removing the unwanted noise from the electrical signal driving earphones and has been proven to be effective in a 30dB reduction of specific signal peak frequencies up to around 10 kHz [13]. However, as electrical handpieces have an internal gearbox that generates two noise peaks of a fixed ratio, these can both be tackled by the AF [14]. In addition, AF allows reproducetion of human speech from the filtered electronic signal, which can be unnatural to hear.

Active Noise Control (ANC) or “anti-noise”, uses similar technologies as AF, but focuses on reversing the unwanted noise played back in the ear out of phase at the same frequency and amplitude to cancel the original acoustic noise. ANC technologies are generally limited to frequencies below 1 kHz such as talking, street sound, traffic and engine noise [15] which will be largely ineffective against dental surgery noise. Producing anti-noise in the acoustic domain is also technically challenging for frequencies above 1 kHz as the ‘zone of quiet’ is inversely proportional to the peak frequency to be reduced [16]. A recent study by Kim et al. [17] concluded that *QuietOn* (Finland) had the best characteristics of the four commercially available devices tested but was still unsuitable overall and further development was needed.

In a dental surgery environment, verbal communication between dental staff and the patients is vital to enable successful treatment, especially for phobic patients [16, 18-19]. It is therefore desirable to protect the patient and dentist from this noise whilst allowing two-way verbal communication which is essential to best practice patient care. Commercially available ANC products will attenuate low-frequency speech whilst PNC will block all sounds at high frequencies. Neither of these two technologies can suppress dental handpiece noise whilst maintaining speech sound.

This present study was designed to test the *QuietOn* device in a previously established test environment [16] to evaluate its effectiveness in dental handpiece noise suppression while allowing two-way communication.

Methods

QuietOn has a compact design similar to Apple Airpods. However, it has neither an On/Off button nor the capability to connect to mobile devices to play other types of sounds such as music. The device tested comes with three sets of comply foam tips of the same size. A photograph of *QuietOn* earplugs and comply foam tips is shown in Figure 1a.

Figure 1 QuietOn earplug and comply foam tips

According to the operational manual *QuietOn* is ready to use the moment the user takes them out of the charging box and put them back after use. The user can simply plug them into the ears and get on with the other activities. Since the shape of the earplug is quite unique fitting instructions were referred to and Figure 1b shows *QuietOn* being worn by an adult male. One subjective perception from the authors is that the earplug is easy to put on by referring to the instructions but difficult to find the desired position, i.e. position that offers the best noise cancelling performance. In other words, the earplug only works when it is pushed against the ear canal and seals it, similar to a conventional pair of PNC earplugs. This suggests that different fits can affect its performance on noise suppression. Therefore, two types of fit (tight and normal) were investigated in the experiments.

A calibrated GRAS 43AG-1 Ear & Cheek Simulator (ECS) [20] was used to mimic a section of a human head and ear canal for representing the acoustic characteristics of an actual ear. It contains GRAS RA0045, an externally polarised ear simulator according to IEC 60318-4, which works effectively below 10 kHz [21]. Typical transfer impedance for the RA0045 can be found in Appendix 2, which shows that within the frequency range of interest (3 to 8 kHz), the ear simulator is acceptable for this application. The ECS uses a GRAS 40AG 1/2" externally polarised pressure microphone [22] according to IEC 61094-4. The typical frequency response shown in Appendix 3, shows that the microphone is suitable for up to 20 kHz. Figure 2a shows the GRAS 43AG-1 ear and cheek simulator with a GRAS KB0065 Large Right KEMAR Pinna [23]. A normal fit is achieved by gently pushing the foam tip against the artificial ear without deflecting its shape too much. In order words, a normal fit can be understood as a comfortable fit that users are most likely to achieve when actually wearing the earplugs. A tight fit is achieved by forcing the foam tip halfway into the artificial ear, deforming it considerably to create a much better air-tight seal. This aims to create an ideal environment for testing. An indication of the amount of foam pushed into the artificial ear is presented in Figure 2b.

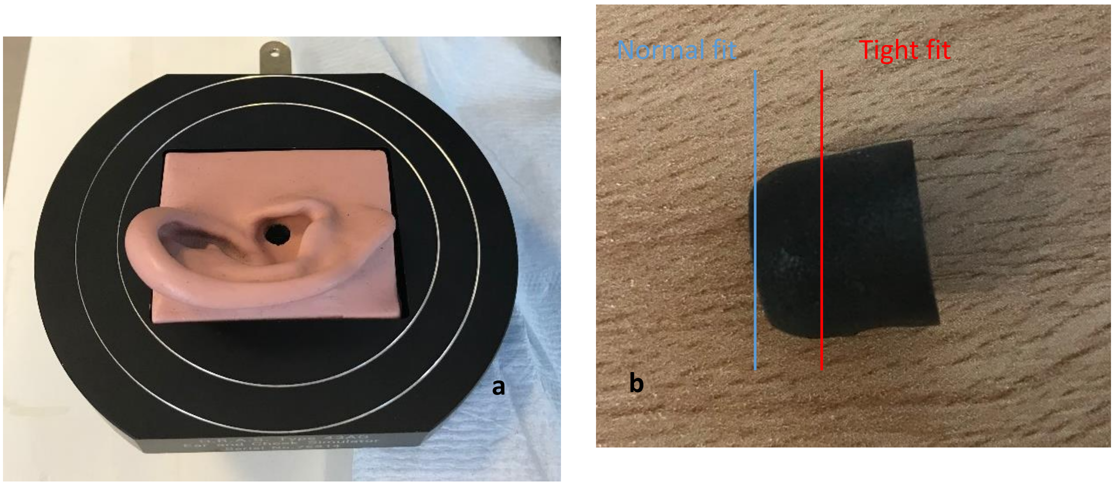


Figure 2 G.R.A.S large right ear and comply foam tip with two fit settings

The experiment setup is shown in Figure 3. The ECS is powered by GRAS 12AD which is also the hardware interface between the ECS and a PC. A high-performance Behringer MS16 16-Watt monitor speaker was used at a constant volume setting to playback sound recordings representing the sound source. Each type of dental handpiece sound recording was played simultaneously with a speech recording. All digitised audio recordings were 24-bit audio, with a sampling rate of 48 kHz and a duration of 10s. The speaker has a frequency response over the 80 Hz to 20 kHz range [24] that is again suitable for this study. To mimic a dental surgery environment, the nominal distance from the ear to the dental drill and the dentist is estimated as 150mm horizontally and 50mm vertically.

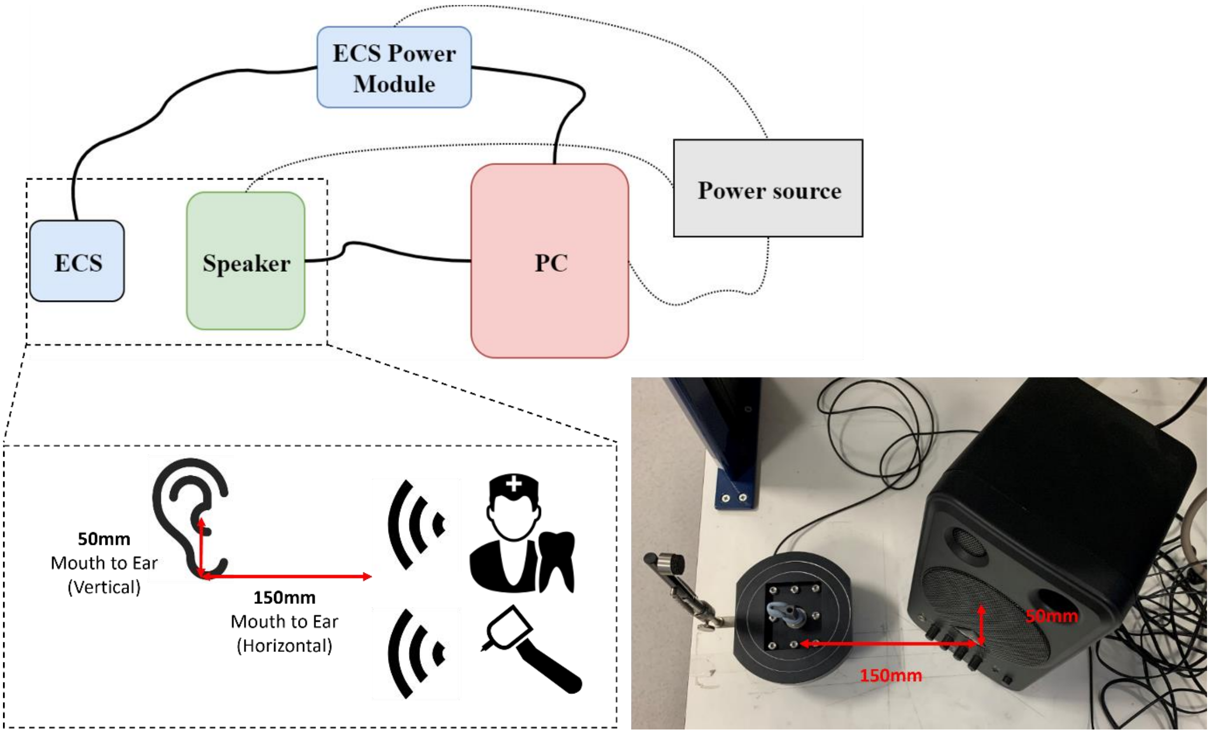


Figure 3 Experiment set-up for QuietOn

A Windows PC was used to capture the sound data transmitted through the ECS. MATLAB applications were developed to enable data recording and analysis. Frequency domain techniques are widely applied to perform audio signal analysis as they are able to analyse individual frequency components of a signal [25], amongst which Welch method is used in this study due to its popularity. Welch's power spectrum density (PSD) analysis is enabled by the MATLAB Signal Process ToolBox. A window size of 2048 and 1024 overlapped samples were used to produce a PSD plot. The frequency spectrum for the PSD plot was selected to be 16 kHz as above this the threshold of human hearing starts to increase rapidly [26].

Results

PSD analysis for the two types of handpiece noise and two types of fits using *QuietOn* are presented in Figure 4**Error! Reference source not found.** and Figure 5. In these plots, three sound profiles are plotted: the original handpiece noise with speech without wearing QuietOn (black), wearing QuietOn with tight fit (red dash-dot) and wearing QuietOn with normal fit (blue dot). The power of the signal at specific frequencies as indicated by the vertical axis, is a relative measure as commonly used in the Welch method, where a higher value indicates a more powerful noise.

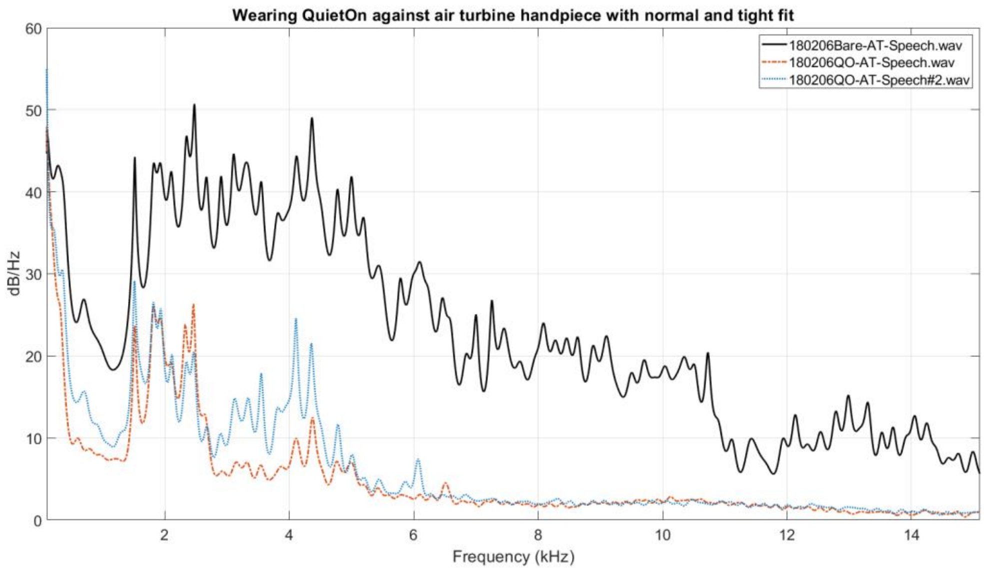


Figure 4 QuietOn performance on Air Turbine handpiece and speech with two fits

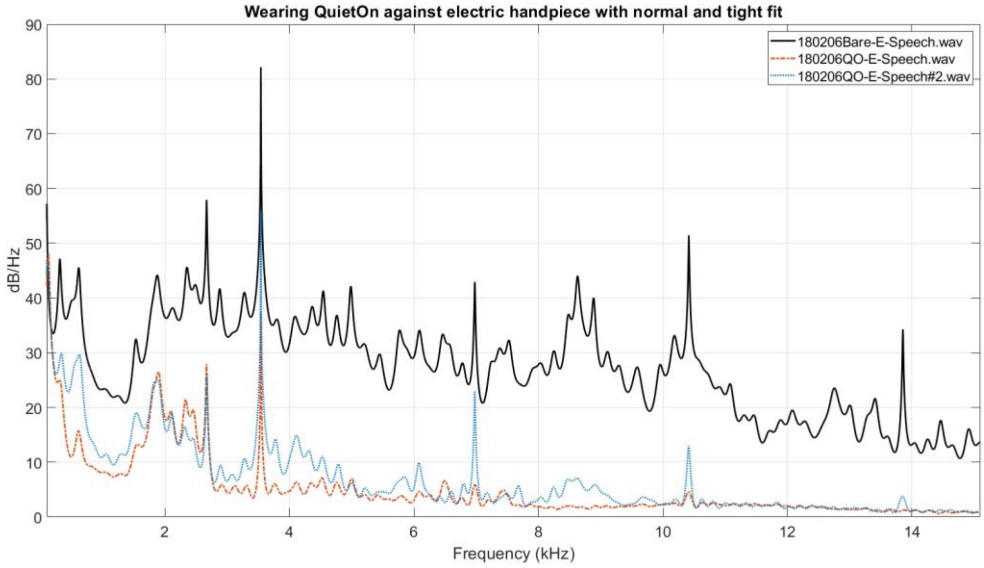


Figure 5 QuietOn performance on Electric handpiece and speech with two fits

From the figures it is obvious that frequency characteristics of electric handpiece and air turbine-driven are distinct. Air-turbine-driven handpiece has several noise peaks due to speed changes when contacting with teeth. Main peaks occurs approximately between 2 and 5 kHz. Electric handpiece on the other hand, is more consistent due its geared mechanical tramission. It has a main noise peak at 3.3 kHz, corresponding to its constant speed of 200,000 rpm.

When comparing both fits with the original noise (black), a significant reduction in noise power can be observed when *QuietOn* is worn. This is indicated by a large drop of response profiles. This suggests that when *QuietOn* is used together with comply foam tips, handpiece noise can be suppressed to a significant amount. From both figures it can be observed that different fits indeed have an effect on the noise attenunation performance, with tight fit being more effective. This is reflected on a lower response profile (red dash-dot) compared to normal fit (blue dot), especially when noise frequency is lower than 1 kHz and higher than 3 kHz. Interestingly both fits performance almost identical around 2 kHz.

With normal fit using *QuietOn*, noise attenuation performance starts to weaken beyond 3 kHz. Worth noticing that the only changing configuration being the type of fit during the experiments. When the foam tip is not fully sealed peaky noise with higher frequencies managed to pass through, indicated by the remaining noise peaks (blue dot) shown in both figures.

The results show that within the frequency range 0 to approx. 1.5 kHz, *QuietOn* is able to suppress the noise down by at least 10 dB, even with normal fit. In frequency range 3 to 6 kHz, *QuietOn* was able bring the noise level down, mostly likely by using foam tip, but 'peakyness' of the handpiece noise remained. Beyond 6 kHz the earplug acts as a good passive insulation and essentially prevents all sound passing through to the ear.

Discussion

The present study set out to test the *QuietOn* device using our previous experimental set-up used in previous studies [16]. These initial tests have indicated that *QuietOn* is just like other common noise cancellation earphone/headphones that are only capable of suppressing low frequency noises. This is in agreement with the recent work by Kim et al. [17]. According to the *QuietOn* website (see Figure 6**Error! Reference source not found.**), the device indeed claimed to focus on suppressing the noise below 1 kHz and will just function as a passive insulation for higher frequencies.

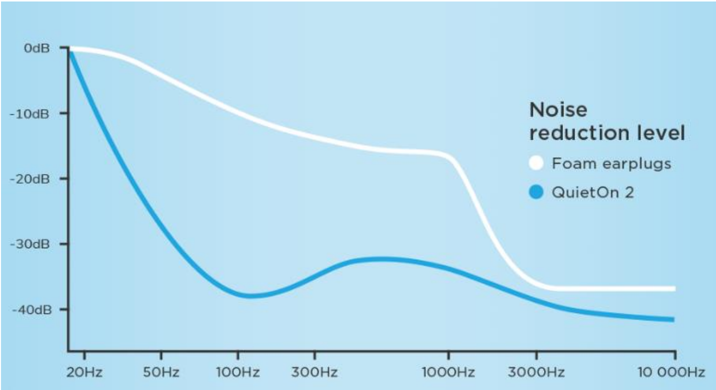


Figure 6 QuietOn claimed noise suppression performance spectrum [27]

With a demand in maintaining verbal communication in dental surgery, it is necessary to understand the speech characteristics. Commonly used English speech phonemes feature in a banana-shaped cluster on a frequency audiogram, which is often referred to as the 'speech banana', shown in Figure 7. The majority of phonemes are within the frequency range of 250 Hz to 2 kHz, except for 'f', 's' and 'th' which are around 5 kHz. In order to maintain the delivery of these phonemes, sounds with 250 to 2 kHz must not be attenuated too much to allow effective verbal communication. However, from the experiment results and what is claimed on *QuietOn* website, speech frequencies with this range got suppressed significantly. Based on this, the authors are in agreement with Kim et al [17] that while *QuietOn* can reduce some dental surgery background noise it would not meet the requirements of suppressing drill noise while enabling verbal communication from dentist and dental nurse to the patient.

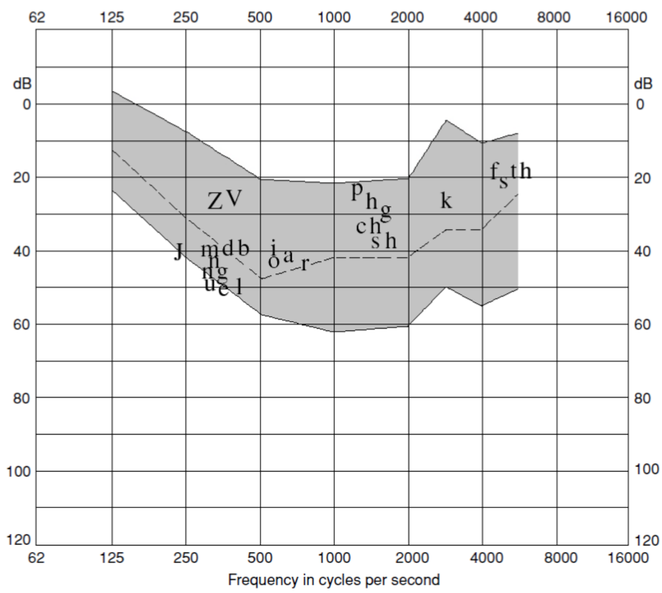


Figure 7 The "speech banana" audiogram (Adapted from [28])

The results shown in this study plus four commercially avaible ANC devices tested in a recent study done by Kim et al[17] and found that the *QuiteOn* device had the better characteristics amongst all, there is still a clear need for a device that is able to target dental handpiece noise reduce the anxiety-inducing effect of dental drill noise for patients whilst maintaining verbal communication. In addition to dental handpiece noise reduction, there may also be a need to reduce this background noise for staff working in a dental surgery environment.

Conclusion

Dental handpiece noise in a dental surgery is serious issue affecting successful treatment as well as wellbeing. Therefore it is reasonable that individuals consider using commercially available devices in an attempt to reduce unwanted dental handpiece noise. In this study a series of of tests were carried out on a commercially available anti-noise earplug, *QuietOn* that has been proven to be the best amongst four devices in a recent study. The results show that *QuietOn can* provide noise suppression in general but has very limited benefit for dental surgery noise, especially that it cannot maintain the verbal commnucation frequencies. Further development is needed to provide reduction in the undesirable noises in the dental surgery to improve patient welfare. It may also have benefits in reducing loss of hearing for the dental team.

References

1. Forman-Franco B, Abramson AL, Stein T. High-speed drill noise and hearing: audiometric survey of 70 dentists. J Am Dent 326 Assoc 1978; 97: 479-82.

2. Coles RR, Hoare NW. Noise-induced hearing loss and the dentist. Br Dent J 1985; 159: 209-18.

3. Lehto TU, Laurikainen ET, Aitasalo KJ, et al. Hearing of dentists in the long run: a 15-year 317 follow-up study. Community Dent Oral Epidemiol 1989; 17: 207-11.

4. Forman-Franco B Merrell HB, Claggett K. Noise pollution and hearing loss in the dental office. Dent Assist J 1992; 61: 6-9.

5. Szymanska J. Work-related noise hazards in the dental surgery. Ann Agric Environ Med 2000; 7: 67-70.

6. Alabdulwahhab BM, Alduraiby RI, Ahmed MA, et al. Hearing loss and its association with occupational noise exposure among Saudi dentists: a cross-sectional study. BDJ Open 2016; 2: 16006

7. Al-Rawi NH, Al Nuaimi AS, Sadiqi A, et al. Occupational noise-induced hearing loss among dental professionals. Quintessence Int 2019; 50: 245-50.

8. Wilson JD, Darby ML, Tolle SL, et al. Effects of occupational ultrasonic noise exposure on hearing of dental hygienists: a pilot study. J Dent Hyg 2002; 76: 262-9.

9. Kwon B, Lee J-h, Kim S, et al. The assessment of noise in the pediatric dental clinics. Journal of The Korean Academy of Pediatric Dentistry 2012; 39:2 67-72.

10. Humphris G, Crawford J, Hill K, et al. UK Population Norms for the Modified Dental Anxiety Scale with Percentile Calculator: Adult Dental Health Survey 2009 Results. BMC Oral Health 2013; 13:29.

11. Wong H, Mak CM, Xu YF. A Four-Part Setting on Examining the Anxiety-Provoking Capacity of the Sound of Dental Equipment. Noise and Health 2011; 13:55:385–91.

12. Kaymak E, Atherton M, Rotter K, et al. Dental Drill Noise Reduction Using a Combination of Active Noise Control, Passive Noise Control and Adaptive Filtering. In *Inter-Noise 2007*, Istanbul, Turkey 29-31 Aug 2007, pp.110-18.

13. Rotter K, Atherton M, Kaymak E, et al. Noise reduction of dental drill noise, In *Mechatronics 2008*, Limerick, Ireland, 23-25 June 2008, pp.1-5.

14. Jiang P, Atherton M. A multi-objective approach for improving real-time audio peak reduction and speech clarity in a dental drill noise reduction device. The Journal of Engineering 2021;7, pp.380-393.

15. Kaymak E, Atherton M, Rotter K, et al. Active Noise Control at High Frequencies. In *13th International Congress on Sound and Vibration*, Vienna, Austria, 2-6 July 2006, pp.275-281.

16. Kaymak E, Atherton M, Rotter K, et al. Active noise control on high frequency narrow band dental drill noise: preliminary results. In *14th International Congress on Sound & Vibration*, Cairns, Australia, 9-12 July 2007, pp.26.

17. Kim I-H, Cho H, Song JS, et al. Assessment of Real-Time Active Noise Control Devices in Dental Treatment Conditions. Int. J. Environ. Res. Public Health 2022; 19(15): 9417, https://doi.org/10.3390/ijerph19159417

18. Freeman R. Communicating Effectively: Some Practical Suggestions. British Dental Journal 1999; 187(5): 240–44. https://doi.org/10.1038/sj.bdj.4800251a.

19. Rogers JL. Factors Affecting Noise Levels of High-Speed Handpieces. MSc Thesis, Uniformed Services University of the Health Sciences, USA, 2012.

20. GRAS. GRAS 43AG Ear & Cheek Simulator. https://www.gras.dk/products/ear-simulator-kit/product/737-43ag (2018, accessed 16 July 2022)

21. GRAS. Instruction Manual GRAS 60318-4 Ear Simulators. GRAS. DK. 2019

22. GRAS. GRAS 40AG 1/2" Ext. Polarized Pressure Microphone. https://www.gras.dk/products/measurement-microphone-cartridge/externally-polarized-cartridges-200-v/product/167-40ag (2018, accessed 16 July 2022)

23. GRAS. GRAS KB0065 Large Right KEMAR Pinna for 43AG, 45BB and 45BC. https://www.gras.dk/products/accessories/for-artificial-ears-and-mouths/product/436-kb0065 (2018, accessed 16 July 2022)

24. Behringer. “User Manual: MONITOR SPEAKERS MS16.”. Behringer.

25. Souden M, Benesty J, Affes S. On Optimal Frequency-Domain Multichannel Linear Filtering for Noise Reduction. IEEE Transactions on Audio, Speech and Language Processing 2010; 18 (2): 260–76. https://doi.org/10.1109/TASL.2009.2025790.

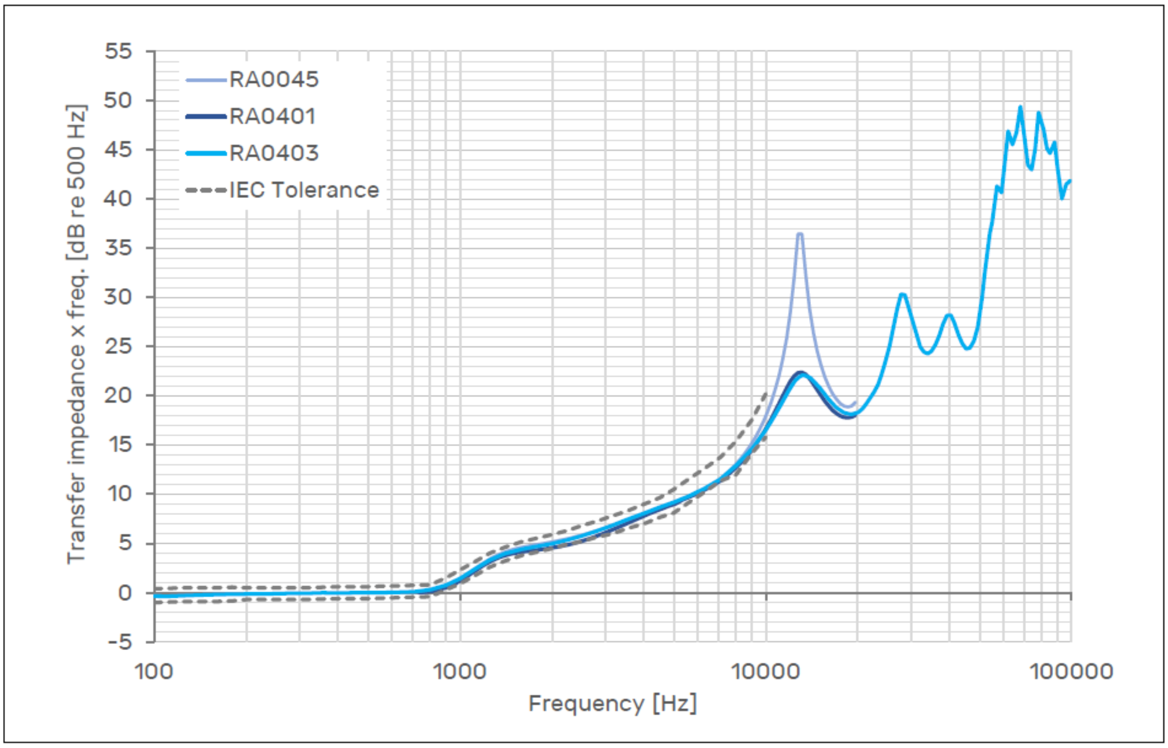
26. Ashihara K. Hearing Thresholds for Pure Tones above 16kHz. The Journal of the Acoustical Society of America 2007; 122 (3): EL52–57. https://doi.org/10.1121/1.2761883.

27. QuietOn. https://www.quietondental.com/ (2022, accessed 16 August 2022)

28. Klangpornkun N, Chutamanee O, Charturong T, et al. Predictions from"speech Banana"and Audiograms: Assessment of Hearing Deficits in Thai Hearing Loss Patients. The Journal of the Acoustical Society of America 2013; 134 (5): 1–11. https://doi.org/10.1121/1.4831179.

1. Appendices

Appendix 2 Typical transfer impendence of GRAS RA0045 Externally Polarized Ear Simulator



Appendix 3 Typical frequency response of GRAS 40AG 1/2" Ext. Polarized Pressure Microphone