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Design, Development, and Testing of a New Device to Prevent High-Frequency Noise-Induced Damage: The "Dynamic Earplug"

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Abstract: Hearing loss resulting from prolonged exposure to loud noise is known as noise-induced hearing loss (NIHL), and it often affects professionals exposed to occupational sources of high sound levels. Among the professionals chronically exposed to noise, dentists use instrumentation that produces high-frequency noise. In this occupational category, NIHL is estimated to reach a 5% to 20% prevalence of workers. However, dentists and healthcare personnel have no suitable personal protection equipment designed for their needs. The study aims to develop a new individual hearing protection device called the "dynamic earplug", which protects from high-frequency noise and amplifies speech frequencies. Testing with the Fonix 7000 Hearing Aid Test System showed effective filtering of high frequencies (above 4000 Hz) from dental instruments and a speech frequency amplification of up to 13 dB (500 Hz–1000 Hz). In a trial involving 20 subjects during an 8 h work shift, most participants positively evaluated the device's esthetics, ease of insertion, comfort, stability, and noise attenuation while still being able to hear patients' and colleagues' voices. The dynamic earplug shows promise as an efficient and comfortable hearing protection solution for professionals exposed to high-frequency noise.

Keywords: noise-induced hearing loss; personal protection equipment; earplug; high frequency

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1. Introduction

Hearing loss (HL) from prolonged noise exposure is known as noise-induced hearing loss (NIHL). It results from multifactorial damage to auditory structures following exposure to occupational, environmental, or recreational sources of loud sound. The duration and severity of NIHL depend on the extent and location of cellular damage, which correlates with the intensity and time of the sound stimulus. Globally, disabling HL attributed to occupational noise is estimated to affect approximately 16% of adults, ranging from 7 to 21% across various geographic regions [1].

Among the various professionals chronically exposed to noise, dental practitioners experience constant exposure to high-frequency (ranging from 4000 Hz to 12,000 Hz) and high-intensity (65 dBA–85 dBA) noise [2–6]. In this occupational category, NIHL is estimated to reach a prevalence ranging from 5% to 20% of workers [7–9]. However, dentists are not the only dental professionals who suffer from this disorder, as they are not the only ones working in such an environment. Dental technicians, prosthodontists, dental hygienists, and chairside assistants are also exposed and may need protection. Chronic exposure to noisy sources can lead to short- and long-term consequences, such as difficulty in communication, annoyance, interference in conversation, and difficulty concentrating [4–7,10,11]. The dental instruments and equipment most used by dentists that emit high-frequency noise are high-speed turbines, aspirators, and ultrasonic scalers. Typically, these dental instruments produce high-intensity noise between 65 dBA and 85 dBA with an average frequency ranging from 4000 Hz to 12,000 Hz [2,3,12]. Even though the levels of exposure of modern dental equipment are generally within the limits set by the National Institute for Occupational Safety and Health (NIOSH), which recommends limiting noise exposure to 85 dBA at 40 h per week [13], studies reported that the noise levels of dental equipment may still provoke NIHL [4–8]. Indeed, continuous exposure to more than 100 dB for more than 8 h increases the risk of permanent HL from 94.5% to 99.5% [5,14]. Prolonged and uninterrupted exposure to noise may impact the professional performance of clinicians, affecting communication with patients and colleagues and potential interruptions in their work. Moreover, long exposure to such noise may result in permanent hearing damage, such as sensorineural NIHL, and the development of tinnitus. Additionally, the enduring consequences of this long-term exposure include reduced concentration and memory capacity and decreased sleep quality. However, there are also short-term consequences that need to be taken into account, such as headache, nausea, fatigue, hypertension, irritability, and tinnitus [15]. In particular, tinnitus is believed to be highly prevalent in the dental clinician's community, yet only a few studies have evaluated the real prevalence of this condition among them. Among these, a study conducted in South Africa showed a prevalence of 31.85% [16], and similarly, a study conducted in the USA found a prevalence of 31% [7]. A slightly higher prevalence was found in the United Arab Emirates (UAE), which was reported to be 37% [17].

Although the presence of NIHL among dentists is well documented, many are still unaware of the immediate and long-term effects that chronic noise exposure can cause on the auditory system, and preventive measures are not widely promoted and used. Dentists are often reluctant to use these ear protection devices as they are perceived as annoying and as severely limiting to clinical activity as they reduce the ability to communicate with patients and assistants [4].

Various strategies are employed to limit noise exposure in the workplace to prevent occupational NIHL. These strategies include engineering controls, such as reducing noise at the source or implementing noise barriers and dampening systems, and administrative controls by scheduling changes to limit the duration of noise exposure and implementing quiet zones. When noise levels cannot be reduced to acceptable standards, personal protection equipment (PPE) becomes crucial [18]. Hearing PPE can be divided into two groups: those that attenuate airborne noise (headphones and inserts or earplugs) and those that also attenuate sound transmission through bone conduction, enveloping all or part of the head of the exposed individual, such as acoustic helmets or headsets. Currently, the most commonly used hearing protection means are as follows:

- Passive earmuffs: These consist of ear cups that fit around or cover the ear and apply pressure to the head. They are particularly used on construction sites and in manufacturing plants.
- Active earmuffs: These are headphones that automatically adjust protection based on sound levels. These devices can reproduce external sounds at a lower level in the ear

while providing attenuation for higher level sounds through a gain function. These PPEs are used especially in the military field, at shooting ranges, and in aviation.

- Earplugs: These devices are designed to be inserted into the external auditory canal. They are available in various shapes and materials, offering a range of options to suit individual preferences. In order to protect their hearing from prolonged exposure to high decibel levels while still being able to hear the music and communicate, musicians and concert staff frequently use earplugs.
- Acoustic helmets or headsets: These are rigid devices that cover a significant part of the head and external ear, reducing sound propagation through bone conduction as well. They are used in mining, heavy industry, and construction.

While common hearing protection devices provide good protection, they can completely isolate the user from the surrounding environment, increasing workplace risks related to the perception of acoustic signals and hindering effective and comfortable communication with colleagues. Currently, no commercially available hearing PPE is specifically designed for dentists and healthcare personnel, but earplugs and/or headphones inserted in the pinna may be used. However, the PPE attenuates all sounds indiscriminately, affecting typical speech frequencies. This, of course, can generate difficulties in communication with patients and staff members, so these devices are often abandoned [8]. Electronic headphones with controlled attenuation are commercially available, featuring adjustable amplification for speech frequencies (i.e., 500 Hz–2000 Hz) and an electronic system for limiting impulsive noises to 82 dBA. However, integrating the electronic regulation mechanism increases the device's costs (around EUR 500–1000). It is essential to note the absence of regulatory mandates obligating workers in this category to wear hearing PPE; instead, the decision remains discretionary for individuals. The high costs associated with these devices may potentially dissuade prospective buyers from acquiring them.

The study aims to design and develop a new individual hearing protection device called the "dynamic earplug", which protects from high-frequency noise and amplifies speech frequencies. Moreover, we aim to test this prototype in the context of healthcare personnel routinely working in a dental office who are chronically exposed to high-frequency noise sources.

2. Materials and Methods

2.1. Working Principle

The resonance effect is a phenomenon where a system naturally oscillates or vibrates at its resonant frequency, significantly amplifying its response. On the contrary, antiresonance occurs when a system exhibits a decrease in response at a specific frequency. The resonance–antiresonance principle offers a practical approach for achieving the selective amplification and attenuation of a particular frequency range. Indeed, a resonant filter or circuit can be designed to amplify specific frequencies while attenuating frequencies outside that range. Among the different possible solutions, resonance tubes can be used as mechanical filters, achieving a similar effect through acoustic resonance. In this study, we used a closed-end resonance tube with one end open and one closed. Modifying the tube's length makes it possible to tune it to resonate at frequencies within the desired range. Also, the tube's diameter can impact the resonance's quality and efficiency: a larger diameter tube generally allows for greater air volume and can result in more robust resonant responses, while a smaller diameter tube may exhibit higher frequencies and have a narrower resonance bandwidth [19].

In the application proposed in this study, the dimensions of the tube's parameters also need to meet the typical characteristics of an earplug: the diameter cannot be too small, or it could be obstructed by cerumen, and the dimensions of the earplug can influence the length.

2.2. Device Design and Fabrication

The "dynamic earplug" is an ear protector designed to have a central part that is universal and closely resembles a real ear canal and concha and ear tips which can be used to customize it. This design allows for a highly comfortable ear protector that fits the ear better than standard ones, typically with simple shapes like cylinders or cones. Furthermore, the device has a hole that runs through the ear protector's entire length, allowing controlled sound passage from the outside to the inside of the ear. The hole is designed to attenuate harmful sounds and, at the same time, amplify essential sounds, such as human voices.

For this specific application, the hole diameter was chosen to filter out high frequencies (4000 Hz–6000 Hz), typically produced by dental instrumentation, and amplify speech frequencies (500 Hz–1000 Hz).

The dynamic earplug was realized using a Resin Digital Light Processing (DLP) 3D printer (EnvisionTEC Perfactory) and made of acrylic resin, available in various colors. The ear tips used are made of silicone or neoprene. The earplug viewed from two opposite angles and worn by a subject is shown in Figure 1.

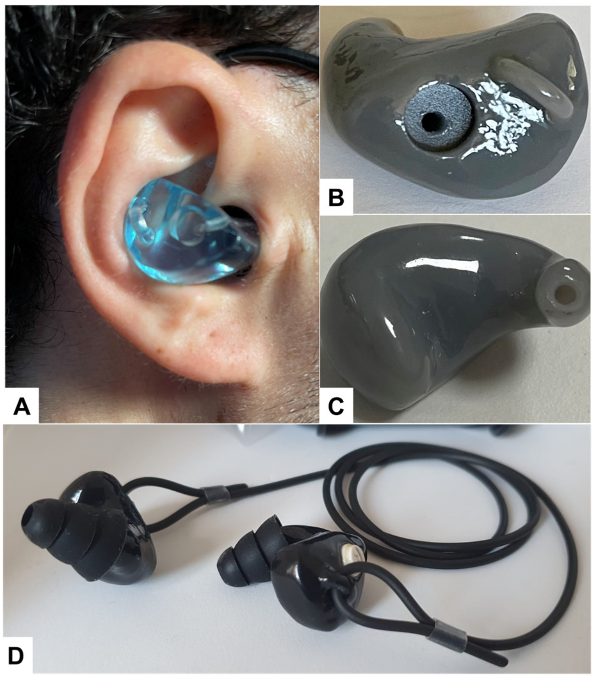

Figure 1. (**A**): Dynamic earplug worn by a subject; (**B**): anterior view of the dynamic earplug; (**C**): posterior view of the dynamic earplug (without ear tip); (**D**): dynamic earplugs with ear tips.

2.3. Population

From January to May 2023, we recruited dentists and technical staff who, in everyday clinical practice, are chronically exposed to noise generated from high-frequency dental instruments averaging 4000 Hz–6000 Hz. The inclusion and exclusion criteria are listed in Table 1.

Table 1. Inclusion and exclusion criteria.

Inclusion	Exclusion
- Dentists and associated healthcare personnel aged >18 years old who, in everyday clinical practice, are chronically exposed to high-frequency noise sources (4000 Hz–6000 Hz). - Normal on otoscopic inspection. - Hearing sensitivity less than 15 dB bilaterally.	- Hearing threshold greater than 15 dB bilaterally for frequencies between 250 Hz and 4000 Hz. - Previous history of ear infection or trauma. - Pathologies affecting the pontocerebellar angle. - Pregnant or lactating women. - History of previous otologic surgery.

2.4. Experimental Protocol

At the beginning of the study, each participant underwent an ENT examination with otoscopy and liminal tonal audiometry, and the following information was recorded:

- profession (e.g., dentist, prosthodontist, dental technician, dental hygienist, dental assistant);
- years of professional activity;
- number of hours of average daily exposure;
- regular use of hearing PPE in clinical practice.

Then, each participant received the dynamic earplug for an entire work shift (minimum 8 h).

At the end of the work shift, they were asked to complete a questionnaire, as reported in the literature [20]. The questionnaire is divided into three parts: the first regarding the device's characteristics, the second the device's usefulness, and the last the critical aspects and benefits of the device. The questions asked of the subjects are reported in Table 2. Before completing the questionnaire, the questions were explained to the included subjects. In particular, concerning the question related to the hearing of patient's and colleagues' voices (questions 2.3 and 2.4), it was explained that they have to understand what they were saying and not just hear the sound of the voice. Also, regarding the perception of muffled ears (question 1.2) and pain (question 1.5), it was specified that "Excellent" indicated the absence of these sensations.

Table 2. Questionnaire submitted to participants.

Part 1. *Device Characteristics*					
1.1 Quality of hearing during instrument use	☐ Poor	☐ Fair	☐ Good	☐ Very Good	☐ Excellent
1.2 Perception of muffled ear	☐ Poor	☐ Fair	☐ Good	☐ Very Good	☐ Excellent
1.3 Stability within the ear canal	☐ Poor	☐ Fair	☐ Good	☐ Very Good	☐ Excellent
1.4 Comfort during use	☐ Poor	☐ Fair	☐ Good	☐ Very Good	☐ Excellent
1.5 Perception of pain during use	☐ Poor	☐ Fair	☐ Good	☐ Very Good	☐ Excellent
1.6 Esthetic judgment of the device	☐ Poor	☐ Fair	☐ Good	☐ Very Good	☐ Excellent
1.7 Ease of insertion of the device into the external ear canal	☐ Poor	☐ Fair	☐ Good	☐ Very Good	☐ Excellent
Part 2. *The usefulness of the device*					
2.1 Would you recommend it to other coworkers?	☐ YES		☐ NO		
2.2 Would you use it while working?	☐ YES		☐ NO		
2.3 Can you hear the voices of coworkers?	☐ YES		☐ NO		
2.4 Can you hear patients' voices?	☐ YES		☐ NO		
Part 3. *Any critical aspects and benefits regarding the use of the device*					

2.5. Statistical Analysis

Data collected from each test have been expressed as a percentage of agreement. The correlation between the results of the first part of the questionnaire and the years of experience and time of noise exposure was calculated by Pearson's correlation coefficient, while the correlation between part 2 of the questionnaire and the years of experience and time of noise exposure was calculated with the Point-Biserial correlation since the responses are binary. A p-value < 0.05 was considered statistically significant. Data were analyzed and plotted using MATLAB® by MathWorks.

3. Results

The Fonix 7000 Hearing Aid Test System was used with a 2 cc coupler to test the performance of the dynamic earplug. The result is shown in Figure 2. The no earplug line was normalized using a 60 dB SPL composite sound source, according to the IEC 118-7 standard; the closed earplug was measured by blocking the dynamic earplug hole with surgical silicone. Using a 60 dB SPL composite sound source, the closed earplug showed an attenuation greater than 15 dB for all frequencies, while the dynamic earplug allowed for the amplification of frequencies between 500 Hz and 1000 Hz from 4 dB to 13 dB and predominantly pulled down frequencies of 4000 Hz–6000 Hz.

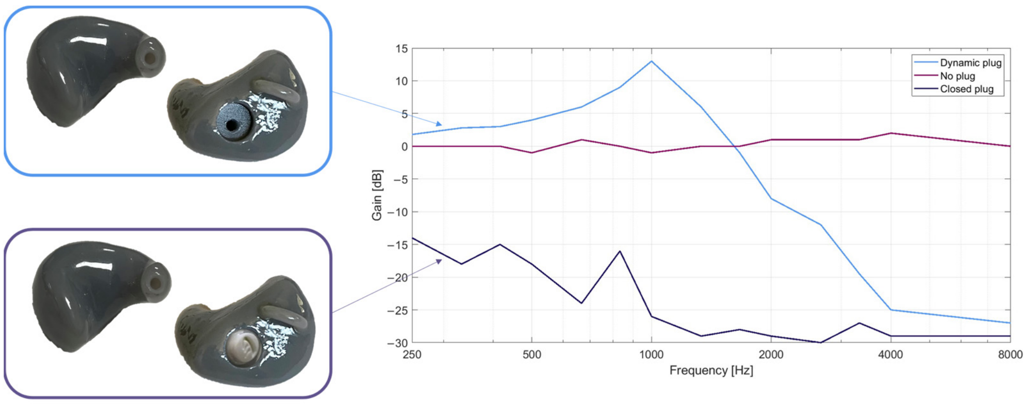

Figure 2. The response curve of the dynamic earplug closed earplug and when no earplug was inserted.

Experimental Results

At the end of our selection process, we included 20 subjects (12 males and 8 females), aged (mean ± standard deviation) 47.5 ± 14.4 years old and with 17.4 ± 14.0 years of practice. The study population comprised thirteen dentists, three dental hygienists, and four chairside assistants. The chronic noise exposure recorded was 8.1 ± 1.7 h. Among the included subjects, 90% (n = 18) reported not using hearing protection devices every day.

The questionnaire results were reported in Table 3 as mean ± standard deviation of the scores and in Figures 3 and 4 as percentages of agreement. The third part of the questionnaire allows subjects to comment on their experience. Among those who would not recommend the earplugs to coworkers or use them while working, two mentioned experiencing a muffled ear sensation, two stated that the dimensions need to be reduced, one noted difficulty in adjusting their speaking volume with the earplugs inserted, and one reported that the earplugs tend to disengage from the ear. The remaining participants did not provide any comments.

Table 3. Results of Part 1 of the questionnaire.

	Mean ± Standard Deviation
1.1 Quality of hearing during instrument use	2.40 ± 1.10
1.2 Perception of muffled ear	3.10 ± 1.17
1.3 Stability within the ear canal	2.50 ± 1.36
1.4 Comfort during use	2.45 ± 1.10
1.5 Perception of pain during use	1.60 ± 0.75
1.6 Esthetic judgment of the device	2.40 ± 1.35
1.7 Ease of insertion of the device into the external ear canal	2.15 ± 1.18

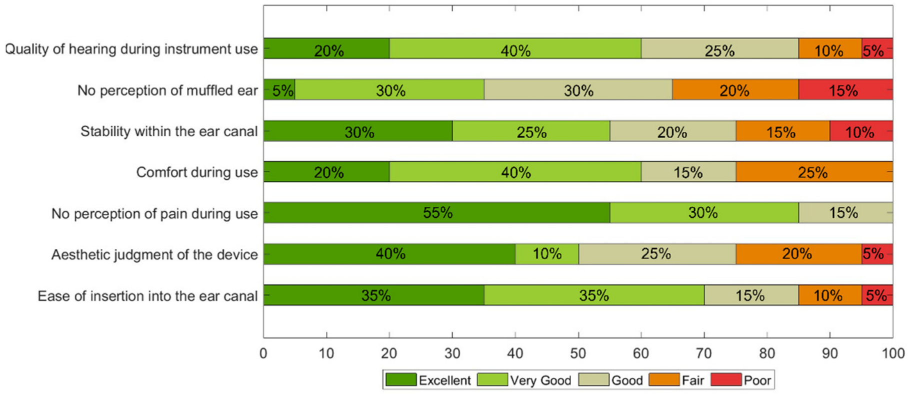

Figure 3. Questionnaire Part 1: device characteristics.

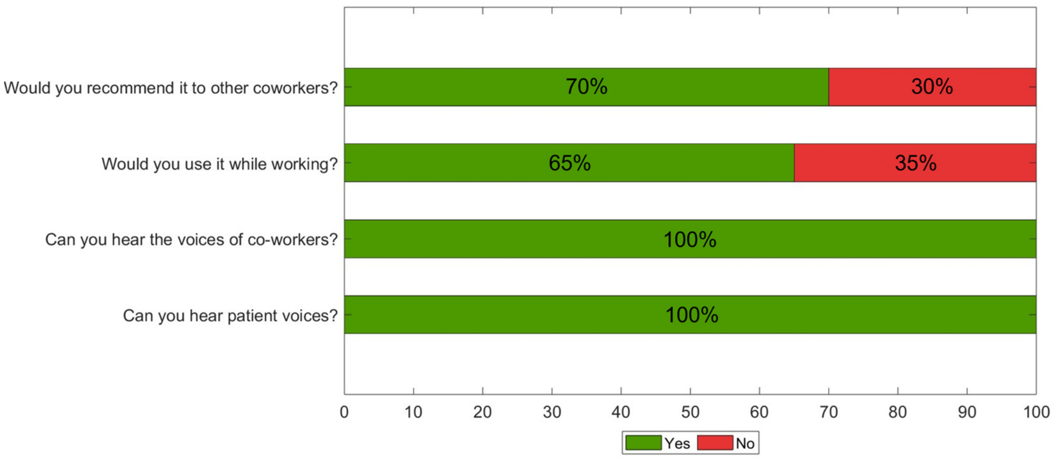

Figure 4. Questionnaire Part 2: usefulness of the device.

Conversely, other participants noted that the overall ergonomics were satisfactory and reported a 50% reduction in mechanical sounds. Finally, one subject mentioned that the earplugs tend to disengage from the ear only when the operator's head is in certain positions, suggesting that this might have been due to improper placement.

Lastly, the correlation between the results of the first part of the questionnaire and the years of experience and time of noise exposure was calculated. The results are shown in Table 4; however, no correlation was found, except for a significant correlation between the device's esthetic judgment and the noise exposure time (r = 0.451, $p = 0.046$). No correction for multiple comparisons was applied since all the comparisons, except for one, were already non-significant before applying any correction for multiple testing. Therefore, the adjustment for multiple comparisons would not change the overall conclusions drawn.

Table 4. Pearson Correlation between Part 1 of the questionnaire and the years of experience and between Part 1 of the questionnaire and the time of noise exposure during the work shift.

	Years of Experience		Time of Noise Exposure	
	r	***p*-Value**	**r**	***p*-Value**
1.1 Quality of hearing during instrument use	−0.117	0.624	0.347	0.134
1.2 Perception of muffled ear	−0.290	0.215	0.335	0.149
1.3 Stability within the ear canal	0.223	0.346	0.229	0.330
1.4 Comfort during use	0.330	0.158	0.255	0.278
1.5 Perception of pain during use	0.094	0.693	0.148	0.534
1.6 Esthetic judgment of the device	0.097	0.684	0.451	0.046 *
1.7 Ease of insertion of the device into the external ear canal	−0.069	0.772	0.329	0.157

* Statistically significant.

The correlation between the second part of the questionnaire and the years of experience and the hours of exposure is reported for the questions related to the use and recommendation. The questions related to hearing the colleagues' and patients' voices led to all positive answers, so it was impossible to calculate the correlation. No correlation was found between these variables (Table 5).

Table 5. Point-Biserial Correlation between Part 2 of the questionnaire and the years of experience and between Part 2 of the questionnaire and the time of noise exposure during the work shift.

	Years of Experience		Time of Noise Exposure	
	r_{pb}	***p*-Value**	r_{pb}	***p*-Value**
2.1 Would you recommend it to other coworkers?	−0.32492	0.16218	0.23015	0.32897
2.2 Would you use it while working?	−0.34847	0.13214	0.22447	0.34138

4. Discussion

Numerous nations mandate that workplaces in all economic sectors adhere to rules aimed at limiting exposure to harmful noise levels and putting in place programs to preserve hearing. Although controlling the source of exposure is the best way to lower risks from workplace hazards, the most popular approach in use today is the distribution of hearing PPE [21]. The primary frequencies involved in NIHL are mainly the high frequencies (4000 Hz–6000 Hz), which are processed by nerve endings located in the basal turn of the cochlea, following the cochlea's tonotopic organization [22,23]. Due to its tonotopic organization, the basis of the cochlea is typically involved in decoding high frequencies. The hair cell of the basal turn of the cochlea is more sensitive to noxa pathogens than the apex [24]. Lesions that occur in the inner ear due to noise exposure can be divided into two main categories: mechanical and metabolic. The earliest mechanical lesions observed following noise exposure include the rupture of the bridges connecting the stereocilia of the hair cells, their reorganization through the repair mechanisms of the ciliary bundles, and the disconnection followed by the restoration of contact between the stereocilia and the tectorial membrane. This varying susceptibility is believed to be due to mechanical reasons: on one hand, there is greater stress imposed on the cilia by the oscillations of the tectorial membrane near the first row; on the other hand, there is a lower tolerance of the ciliary bundles of the outer hair cells in this region because they are shorter. Metabolic lesions, on the other hand, depend on different mechanisms, particularly ionic, ischemic, excitotoxic, and oxidative. Basal outer hair cells are also more susceptible to free radical damage because of the lower level of glutathione [23]. For this reason, it is important to protect the hearing from these high frequencies.

Among all the working categories, dental workers are at high risk of exposure. Although modern dental equipment generally adheres to the noise limits set by the NIOSH [13], studies have indicated that dental equipment noise levels can still cause noise-induced HL, leading to an estimated prevalence of up to 20% [4–9,25–27]. In the literature, several studies have assessed the effect of NIHL in the field of dentistry. In particular, a recent study conducted on 114 dental students observed that 80% of the students experienced auditory discomfort, while 10% exhibited hearing loss [5]. Also, Al-Rawi et al. [28] and Ma et al. [15] demonstrated a positive correlation between the duration of service and the degree of auditory alterations. Theodoroff and Folmer [4] compared dental clinicians exposed to noise with a group of dental professionals who do not use high-speed handpieces and a group composed of dental students. The audiometric results for the noise-exposed group revealed a sloping high-frequency hearing loss. On the contrary, the group of workers with minimal noise exposure had hearing thresholds within the normal hearing range; however, their thresholds were poorer than the last group. Lastly, a recent study [8] compared the audiometry results of two groups of dentists: the first one was asked to use the ultrasonic scaler without wearing any protection, while the second one used a hearing protection device. They demonstrated that the noise produced by the ultrasonic scalers can negatively impact the hearing acuity, with an increase in the pure tone audiometry and the acoustic reflex threshold and a reduced otoacoustic emission value. Indeed, the use of protection devices was effective in reducing the immediate temporary threshold shift. Also, hearing protection devices can reduce the risk of non-auditory effects of high-frequency noise, such as fatigue, nausea, headaches, irritation, tinnitus, and hypertension [11,15].

Commonly employed hearing PPE includes passive earmuffs, which consist of rigid cups internally lined with sound-absorbing material to enhance sound attenuation; ear inserts designed for insertion into the external auditory canal; and acoustic helmets or headsets, which are rigid devices that effectively reduce sound transmission through bone. However, these types of PPE attenuate all frequencies equally, including those essential for comprehending spoken language. According to a recent systematic review and meta-analysis [29], three studies showed that wearing hearing PPE did not improve speech perception ability [30–32]. The authors tested two passive and two active hearing PPEs commonly used in the military field [30], namely the MineEars electronic hearing protector and the Bilsom model 847, which is a conventional passive-attenuation earmuff [31], and two types of insert hearing PPEs commonly used in industry, namely a user-molded foam earplug and a pre-molded triple flange earplug [32]. On the other hand, three studies found that wearing hearing PPE could improve speech perception performance [33–35]. Active noise reduction PPE significantly improved speech recognition performance, particularly for hearing-impaired users [33]. Passive noise reduction PPE, on the other hand, has a low noise reduction rating but has demonstrated increased speech intelligibility in the presence of background noise [35]. Manning et al. tested the military communication headsets and reported on the benefits of bone-conduction PPE [34]. Using both air- and bone-conduction PPEs, they performed speech recognition tasks in noisy environments for tinnitus patients, hearing-impaired users, and listeners with normal hearing. According to the authors, in every group, bone-conduction hearing protection performed better than air-conduction protection [34]. Consequently, the uniform attenuation may lead to challenges in perceiving conversations, verbal messages, and warning signals, potentially resulting in users abandoning these protective devices. To address this issue, specialized electronic headphones with controlled attenuation are available on the market. These headphones allow users to adjust the amplification of speech frequencies (500 Hz–2000 Hz) while effectively limiting impulsive noises to 82 dBA. However, the electronic tuning system increases the cost of the device and limits its deployment. Notably, there are no hearing protection devices specifically designed for dental workers that effectively address these issues.

In this context, we developed a new hearing protection device called a dynamic earplug. The device was designed to be universal and low-cost, eliminating the need for electronic filters. It selectively reduces harmful high-frequency noise and amplifies speech frequencies using the physical principle of the resonant tube. Indeed, by modifying the tube length, a specific range of frequencies resonates and is amplified while all the other frequencies are attenuated.

The initial assessment evaluated the device's performance using the Fonix 7000 Hearing Aid Test System. It was found that the dynamic earplug effectively filtered out frequencies higher than 4000 Hz, commonly generated by dental instruments, and amplified speech frequencies (500 Hz–1000 Hz) by up to 13 dB. Since modern dental equipment adheres to noise limits, this attenuation can limit the difficulty in communication and concentration caused by prolonged exposure to noise.

After this first analysis, the dynamic earplug was worn by a group of 20 individuals, including dentists, dental hygienists, and chairside assistants. The participants were instructed to wear the device during an approximately 8 h workday and provide feedback through the questionnaires previously presented by Spomer et al. in a similar study [20]. First, neither the years of experience nor the noise exposure duration has influenced the answers to the questions. Moreover, the findings of our study can be compared with the ones found by Spomer et al. [20], who tested four different types of earplugs: the MP 9–15 Music PRO Electronic Earplugs (Etymotic Research, Inc., Elk Grove Village, IL, USA), the ETY Plugs High Fidelity Non-Electronic Earplugs (Etymotic Research, Inc.), the Laser-Lite Earplugs (The Safety Zone, LLC, Cleveland, OH, USA, distributed by Henry Schein), and the DI-15 High-Fidelity Electronic Earplugs (Dental Innovations, LLC, Greenville, SC, USA). Our results from the first section of the questionnaire align with the outcomes reported by Spomer et al. For the second section, all participants included in our study reported the ability to hear patients and coworkers clearly. In comparison, the most effective earplugs among the four tested by Spomer et al. achieved an 86.7% success rate for both questions. Regarding the intention to use the earplugs regularly and recommend them, our earplugs demonstrated superior outcomes to non-electronic earplugs and performed similarly to electronic ones [20].

This pilot study presents some limitations. First, a small number of subjects were included in the study. Additionally, even though a correlation between the answers and the noise exposure time was not found, long-term monitoring would be desirable to assess its effectiveness over time, eliminating possible bias due to first-time experience. Finally, the lack of a control group using a different hearing protection device, or no device, prevents a direct comparison of the efficacy of the dynamic earplug with other options. Also, the objective assessment of speech understanding through speech audiometry will be carried out in future studies. Future studies will address the drawbacks reported by the subjects, like the perception of ear muffling and a better fit and stability during head movements. Furthermore, the device will be tested on a larger sample of subjects with different occupations, comparing it with a control group.

5. Conclusions

The dynamic earplug represents a hearing protection device that selectively filters high-frequency noise and amplifies speech frequencies. Most subjects in the study positively evaluated the esthetics, ease of insertion, comfort, stability, and noise attenuation while using high-frequency dental instrumentation. Further studies on a larger scale will be needed to improve this prototype, confirm these interesting data, and extend its application to other professional groups.

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Data Availability Statement: The data presented in this study are available upon reasonable request from the corresponding author. The data are not publicly available due to privacy and ethical restrictions.

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Conflicts of Interest: The authors declare no conflicts of interest.

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