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Impacts of hazardous noise levels on hearing loss and tinnitus in dental professionals

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Abstract

Background Hazardous noise exposure is an important health concern in many workplaces and is one of the most common work-related injuries in the United States. Dental professionals are frequently exposed to high levels of occupational noise in their daily work environment. This noise is generated by various dental handpieces such as drills, suctions, and ultrasonic scalers. Prolonged exposure to such noise levels is known to have adverse effects on hearing health. Despite the prevalence of occupational noise in dentistry, there is a paucity of research specifically examining the prevalence of hearing loss and tinnitus in dental professionals.

Methods To evaluate the prevalence of hearing loss and tinnitus, data were collected from 60 dental professionals, including participant demographics and audiometric thresholds. Thresholds were compared to the age- and sex-based reference ranges from the International Standards Organization (ISO 7029:2017).

Results Results showed that 15–25% of males and 13–18% of females had hearing thresholds that exceeded 95th percentile limits based on the ISO normative age- and sex-distributions. Tinnitus was reported in 40% of the participants.

Conclusion This study is the first to examine the characteristics and prevalence of auditory dysfunctions in dental professionals compared to the ISO normative age and sex distributions of hearing status. Findings from this study highlight the need for increasing the awareness of occupational noise hazards among dental professionals and the importance of routine audiological monitoring.

Keywords Noise-induced hearing loss (NIHL), Tinnitus, Dental professionals, Noise exposure, Occupational noise

Introduction

Occupational hazards in healthcare are multifaceted, encompassing physical, chemical, biological, and ergonomic risks [1]. Noise-induced hearing loss is the most common work-related injury in the United States, with approximately 22 million workers exposed to hazardous noise levels each year. The audiological implications of prolonged noise exposure are often underestimated, particularly in professions such as dentistry, where practitioners routinely operate handpieces that emit high-frequency sounds. Exposure to such noise levels throughout one's career is known to have adverse effects on hearing health.

The dental environment is characterized by the constant whirring of handpieces, ultrasonic scalers, and other instruments integral to diagnostic and therapeutic procedures. According to the National Institute for Occupational Safety and Health Administration (NIOSH), the recommended exposure limit (REL) is 85

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dBA averaged over an 8-hour workday [2]. Additionally, every three-decibel increase in the sound intensity would warrant a reduction in number of hours allowed by half (i.e., 88 dBA for 4 h, 91 dBA for 2 h, etc.). Those exposed to noise levels at or above the limit would be at risk of developing significant hearing loss and other auditory dysfunctions. Many factors determine the adverse auditory impacts of noise exposure, including distance from the noise source, duration of exposure, noise intensity, as well as individual susceptibility based on genetic factors and overall health [3].

Previous studies documented noise levels from dental instruments and revealed that the levels produced by the handpieces could be dangerously loud when compared to the 85 dBA for the 8-hour limit recommended by NIOSH. A study conducted by Damascus University reported that a micro motor handpiece cutting on acrylic can reach 92.2 dBA, and a turbine cutting on tooth can reach 91.2 dBA [4]. Barek et al. (1999) examined the sound intensities generated by different dental handpieces. Results showed that the Micro-Mega handpiece generated a maximum of 95 dB SPL in the audible range and 112 dB SPL at 50,000 Hz. The Siemens and KaVo handpieces generated 101 dB SPL and 115 dB SPL sounds in the ultrasonic frequency range, respectively [5]. Another study revealed noise levels ranging from 98 to 102 dB SPL for a high-speed handpiece and 92–98 dB SPL for an ultrasonic scalar [6]. Overall, dental handpieces generate noises at dangerously loud ranges and pose the risk of hazardous noise exposure in dental professionals.

Several studies examined hearing thresholds and tinnitus in dental professionals and identified evidence of noise-induced hearing loss. An early study comparing hearing thresholds of 137 dentists and 80 physicians noted elevated thresholds in the dentists at 4000 Hz and 6000 Hz, which is a characteristic of noise-induced hearing loss [7]. Willershausen and colleagues reported that dentists are at a higher risk for hearing loss when compared to academic professionals, with statistically significant differences in hearing thresholds at 3000 Hz and 4000 Hz [8]. When comparing dental hygienists who often used ultrasonic scalers to those who rarely use them, the high-usage group had significantly worse thresholds at 3000 Hz [9]. Additionally, dental professionals who routinely use high-speed handpieces have more hearing loss when compared to dental students and dental professionals who do not use such handpieces [6].

One of the initial signs of changes in the auditory system is the presence of tinnitus, the perception of sound without an external source [10]. Tinnitus is closely associated with prolonged noise exposure [11]. Tinnitus in dental professionals has been explored in a few studies globally. A survey of South African dentists found that 31.85% experienced tinnitus [12]. Another survey of dental professionals in the United Arab Emirates found that 37% of the dental professionals reported tinnitus after working in a dental office [13]. Togoo et al. (2023) investigated the impact of noise on tinnitus among dental students, interns, and practitioners and revealed that 29% complained of tinnitus [14]. Moreover, the prevalence of tinnitus in dental professionals in Oklahoma exceeded national averages in every age group [15, 16]. Overall, dentists are 50% more likely to experience tinnitus when compared to the general population [17].

The American Dental Association (ADA) reported that the average dentist in the United States has a career of approximately 35 years, with some practicing well into their 70s and 80s. Sensory abilities, including hearing, decline with age. Hearing loss typically begins in the fourth decade of life and progresses throughout a person's lifetime [18]. Although many studies documented the effects of occupational noise on dentists' hearing, there are no known reports that compare their hearing thresholds to age- and sex-based reference ranges. The present study aims to identify the risk of hearing loss and tinnitus among dental professionals and compare their hearing thresholds with these reference ranges.

Materials and methods

Participants

The data presented in this study contains both retrospective audiological data obtained as part of routine clinical care as well as data from recruited dental professionals. We included data from 60 dental professionals, with an equal number of males and females. Inclusion criteria included dental professionals (dentists and dental hygienists) who have been practicing for at least one year to account for adequate exposure to occupational noise and are still practicing clinically. Exclusion criteria included those with a history of chronic ear disease, ear surgery, ear trauma, known use of ototoxic medications, or hearing loss identified before working in the dental profession. These criteria were established to ensure a more homogeneous sample. This study was conducted in accordance with the Declaration of Helsinki and was approved by the Institutional Review Board at the University of the Pacific under the approval number IRB2022-209. Informed consent was obtained from all participants before their involvement in the study.

Case history and demographics form

All participants completed a standard audiologic case history form [Appendix A]. Basic demographic information was collected from all participants, including gender, age, years of experience, and dental specialty. Otologic history was also collected, including information about tinnitus, otalgia, family history of hearing loss, balance disorders, known use of ototoxic medication, and temporomandibular joint disorders. Participants who reported experiencing tinnitus were asked to complete the Tinnitus Handicap Inventory (THI) [19].

Audiometric assessments

All audiometric assessments were completed according to the standard audiologic evaluation procedures at the University of the Pacific Hearing and Balance Center in San Francisco. The audiologic test battery was conducted in accordance with the clinical guidelines from the American Speech-Language-Hearing Association (ASHA) and included speech and pure-tone audiometry and middle ear function measures [20–22]. Following an otoscopic examination of the external ear, hearing evaluation was performed for pure tone thresholds for air conduction from 250 Hz to 8000 Hz and bone conduction from 250 Hz to 4000 Hz. Air-conduction and bone-conduction thresholds were obtained using the modified Hughson-Westlake method [23] and hearing loss severity was categorized using the standard classification system [24]. Word recognition scores were obtained monaurally in each ear using NU-6 lists and the percentage of words repeated correctly by the participant was reported as their word recognition score [21]. Speech and pure tone audiometry were conducted using the GSI AudioStar Pro (Grason-Stadler Inc., Eden Prairie, MN, USA) or the Madsen Astera 2 (Natus Medical Incorporated, Middleton, WI, USA) clinical audiometers in a double-walled sound-treated room meeting the American National Standards Institute (ANSI) criteria (ANSI S3.1-1999 (R2003)). Tympanometry was performed using the GSI Tympstar Pro (Grason-Stadler Inc., Eden Prairie, MN, USA) to evaluate the status of the middle ear system.

Data and statistical analysis

Descriptive statistics were computed using Microsoft Excel, version 16.6, and GraphPad Prism, version 9.3.1. Descriptive statistics were used to examine the prevalence of tinnitus and identify hearing thresholds that exceeded clinical norms and the 95th percentile age- and sex-based reference ranges from the International Standards Organization (ISO 7029:2017) [25]. Student's *t*-test was performed to compare group means for male and female four-frequency pure tone average (4F-PTA), which is the average of the thresholds for 500, 1000, 2000, and 4000 Hz. Two-way ANOVA was performed to examine interactions between hearing thresholds at various frequencies versus lateralization (left or right ear) or sex. A z-test was used to compare the proportions of males and females with hearing loss, defined as a 4F-PTA greater than 20 dB HL. Assessment of the strength of association between years of experience and 4F-PTA was performed using the Pearson correlation coefficient. Lastly, Chi-square test was utilized to analyze the relationship between the number of ears with thresholds that exceed the 95th percentile age- and sex-based reference ranges for each frequency between males and females. An α-level of 0.05 was chosen for statistical significance.

Table 1 Participant demographics

	Sample Size (n)	Age Range (yrs)	Mean (yrs)	SD (yrs)
Male	30	33–80	62.8	13.9
Female	30	30–80	55.5	11.8
Total	**60**	**30–80**	**56.0**	**17.0**

Age Range	Male	Female
≤ 40	3	3
41–50	3	4
51–60	7	13
61–70	5	7
71–80	12	3

Results

Demographics

Data from 60 dental professionals, equal in number of males and females, were analyzed. Table 1 shows the age and gender distribution for the study population. The mean age for males was 62.8 years old (SD = 13.9), 95% CI [57.57 to 67.89], with an age range of 33 to 80. The mean age for females was 56.0 years old (SD = 17.0), 95% CI [51.05 to 59.88], with an age range of 30 to 80. Majority of the females (43%) were between the ages of 51 to 60 years old, while the majority of males (40%) were between the ages of 71 to 80 years old.

Table 2 describes the participant sample, including their dental specialty and years of practice. Our participants spanned a wide range of specialties but primarily identified as general practitioners (44% in males and 70% in females). The other categories included technicians and professionals with specialty areas in orofacial pain, dental sleep medicine, and geriatrics. The majority of participants had 36 to 40 years of experience with an average of 27.5 years for females (SD = 10.89) and 37.8 years for males (SD = 13.7).

Audiometric results

Behavioral audiometric evaluations were completed on all participants. Word recognition testing was completed on all female participants and 29 of the 30 male participants. Word recognition scores were within normal limits (≥88%) for all female participants and were within normal limits for 12% (7/58) of the ears for the male participants. Tympanometry was within normal limits bilaterally for all participants suggesting normal middle ear function.

Averaged audiometry thresholds for each frequency and for each ear in both females and males are shown. On average, thresholds were within clinically normal

Table 2 Practice specialty of our study participants and their years of experience

		Male	Female
Dental Specialty	General Practice	13 (44%)	21 (70%)
	Endodontist	2 (7%)	0 (0%)
	Orthodontist	4 (13%)	0 (0%)
	Periodontist	1 (3%)	1 (3%)
	Prosthodontist	3 (10%)	1 (3%)
	Pediatrics	0 (0%)	3 (10%)
	Oral and Maxillofacial Surgeon	4 (13%)	0 (0%)
	Oral Hygienist	1 (3%)	2 (7%)
	Other	2 (7%)	2 (7%)
Years of Practice	< 10	2 (7%)	1 (3%)
	10–15	1 (3%)	4 (13%)
	16–20	1 (3%)	2 (7%)
	21–25	2 (7%)	9 (30%)
	26–30	2 (7%)	4 (13%)
	31–35	4 (13%)	0 (0%)
	36–40	5 (15%)	8 (27%)
	41–45	2 (7%)	1 (3%)
	46–50	7 (23%)	1 (3%)
	50+	4 (13%)	0 (0%)

range (≤20 dB HL) for all frequencies in both ears except for 6000 Hz and 8000 Hz in females (Fig. 1A). In males, average thresholds were within clinically normal range for only 250 Hz, 500 Hz, and 1000 Hz, sloping to a mild to moderate sensorineural hearing loss from 2000 Hz to 8000 Hz (Fig. 1B). Hearing thresholds were not statistically significant when comparing left versus right ear in both males (two-way ANOVA, F (1, 464)=0.0.054, p=0.815), 95% CI [-3.40 to 4.32], and females (two-way ANOVA, F (1, 464)=0.3723, p=0.542), 95% CI [-1.57 to 2.99]. However, males exhibited more hearing loss when compared to females in the higher frequencies (two-way ANOVA, F (7, 944)=10.97, $p<0.0001$; $p=0.0005$ for 2000 Hz, 95% CI [-21.60 to -4.06]; $p<0.0001$ for 3000 Hz, 95% CI [-29.19 to -11.65]; $p<0.0001$ for 4000 Hz, 95% CI [-34.02 to -16.48]; $p<0.0001$ for 6000 Hz, 95% CI [-34.52 to -16.98], and $p<0.0001$ for 8000 Hz, 95% CI [-35.52 to -17.98]).

Hearing status in each ear was analyzed using a four-frequency air conduction threshold pure tone average (4F-PTA) of 500, 1000, 2000, and 4000 Hz. Clinically normal hearing is defined as a 4 F-PTA of ≤20 dB HL in both ears and was documented in 32 participants, 22 females (73%) and 10 (33%) males. When examining individual ears (n=60 for both males and females), 61% (37/60) of the male, while only 25% (15/60) of the female ears showed hearing loss. There is a statistically significant difference in the prevalence of hearing loss between male and female dental professionals (Fig. 1C, z=4.05, $p<0.001$, 95% CI [0.19 to 0.54]). On average, males had a 4 F-PTA of 25.5±21.5 dB HL, and females had a 4 F-PTA of 14.2±10.8 dB HL. This difference is statistically significant (Fig. 1D, Student's t-test, t (58)=3.462, p=0.001, 95% CI [4.83 to 18.08]). Additionally, we revealed a positive correlation between years of experience and 4F-PTA (Fig. 1E, males: r=0.4976, p=0.005, 95% CI [0.18 to 0.95]; females: r=0.2909, p=0.1189, 95% CI [-0.07 to 0.55])

Given that the mean age of our population was 56–63 years old, an age range where individuals are experiencing age-related hearing loss, further analysis was conducted to determine how many participants had hearing thresholds that exceeded the normal range for their age. This analysis compared each participant's thresholds with the 95th percentile age- and sex-based reference ranges from the International Standards Organization (ISO 7029:2017) cohort of otologically normal persons [25] for each frequency. The results showed a general trend that more males (Fig. 2A) had elevated hearing thresholds compared to the age- and sex-based normative ranges when compared to females (Fig. 2B) across all frequencies as well as the 4F-PTA. However, the difference was not statistically significant (Chi-square test of independence: χ^2 (7)=4.459, p=0.725) (Table 3).

Self-report of tinnitus

Figure 3 shows participants' self-report of tinnitus. Twenty-four out of 60 (40%) participants reported experiencing tinnitus. Ten (42%) reported intermittent tinnitus while 14 (58%) complained of constant tinnitus. However, based on the THI, none of the participants reported that their tinnitus was bothersome. Moreover, there was no statistically significant difference between

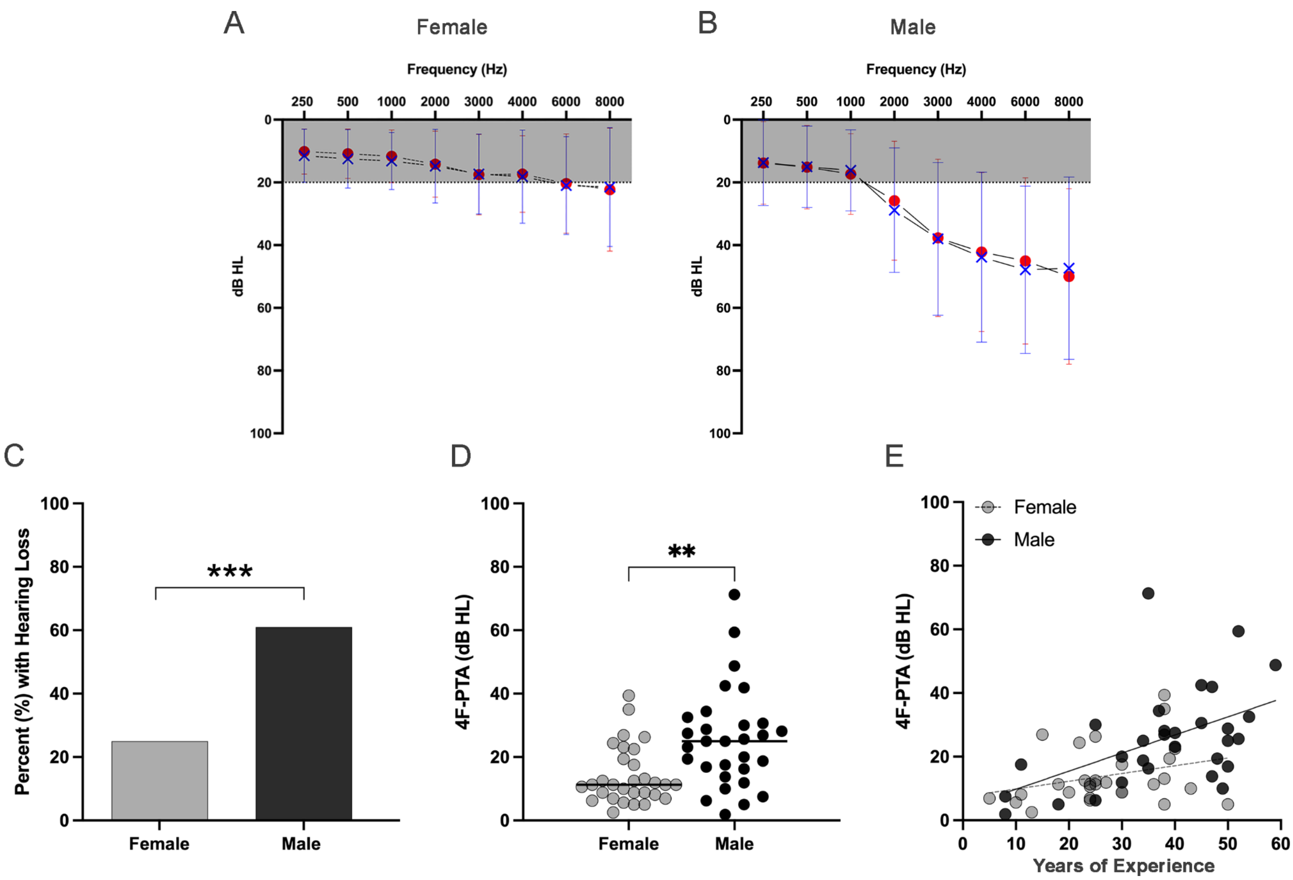

Fig. 1 Mean audiometric thresholds for study participants. Red circles represent the right ear and blue X's represent the left ear. (**A**) Dotted line represents the male participants (left) and (**B**) solid line represents the female participants (right). The horizontal dotted line at 20 dB HL identifies the upper limit for normal clinical hearing determination. Bars = standard deviation. (**C**) Percentage of male and female participants with a clinically defined hearing loss (4F-PTA of greater than 20 dB HL). 61% (37/60) of the male and 25% (15/60) of the female ears showed a clinically defined hearing loss. (**D**) Comparison of 4F-PTA for males and females. Each dot represents the average of the left and right ear for each participant. (**E**) Correlation analysis reveals a positive correlation between the years of experience and 4 F-PTA (males: $r = 0.4976$, $p = 0.005$; females: $r = 0.2909$, $p = 0.1189$). ** $p < 0.01$, *** $p < 0.001$

sex and the frequency of tinnitus (Chi-square test of independence: χ^2 (2, 60) = 1.997, $p = 0.368$).

Discussion

The present study evaluated hearing loss and tinnitus as potential risk factors among dental professionals. The results showed that 25% of female and 61% of male ears have clinically defined hearing loss (4F-PTA of greater than 20 dB HL). More males (67%) have thresholds that exceed the 95th percentile age- and sex-based reference ranges compared to females (27%). 40% of participants report experiencing either intermittent or constant tinnitus. These findings are comparable to previous studies and suggest a compelling occupational noise concern in dental professionals.

This study is the first to compare hearing thresholds of dental professionals to age- and sex-based reference ranges. The significant percentage of elevated hearing thresholds (Table 3) suggests a previously underreported risk of hearing loss for dental professionals. This indicates that noise exposure in the dental profession is more detrimental than previously recognized. Findings from this study also revealed a significant sex difference, with males exhibiting a higher prevalence of hearing loss as compared to females. This is consistent with previous studies where occupational noise exposure is more common in males than females [26–29], even when accounting for noise exposure history [30]. This difference may be attributed to various factors, including biological susceptibility [31] and recreational noise exposure [26].

Several studies have implicated that exposure to high-intensity sounds, leading to noise-induced hearing loss, during aging causes an acceleration and worsening of age-related hearing loss [32–34]. Dental professionals are at a particularly high risk due to frequent exposure to loud dental equipment that can exacerbate the natural age-related auditory decline. Additionally, there are non-auditory consequences of occupational noise exposure, including annoyance [35], cardiovascular disease [36, 37], and cognitive performance [38]. Given that dental

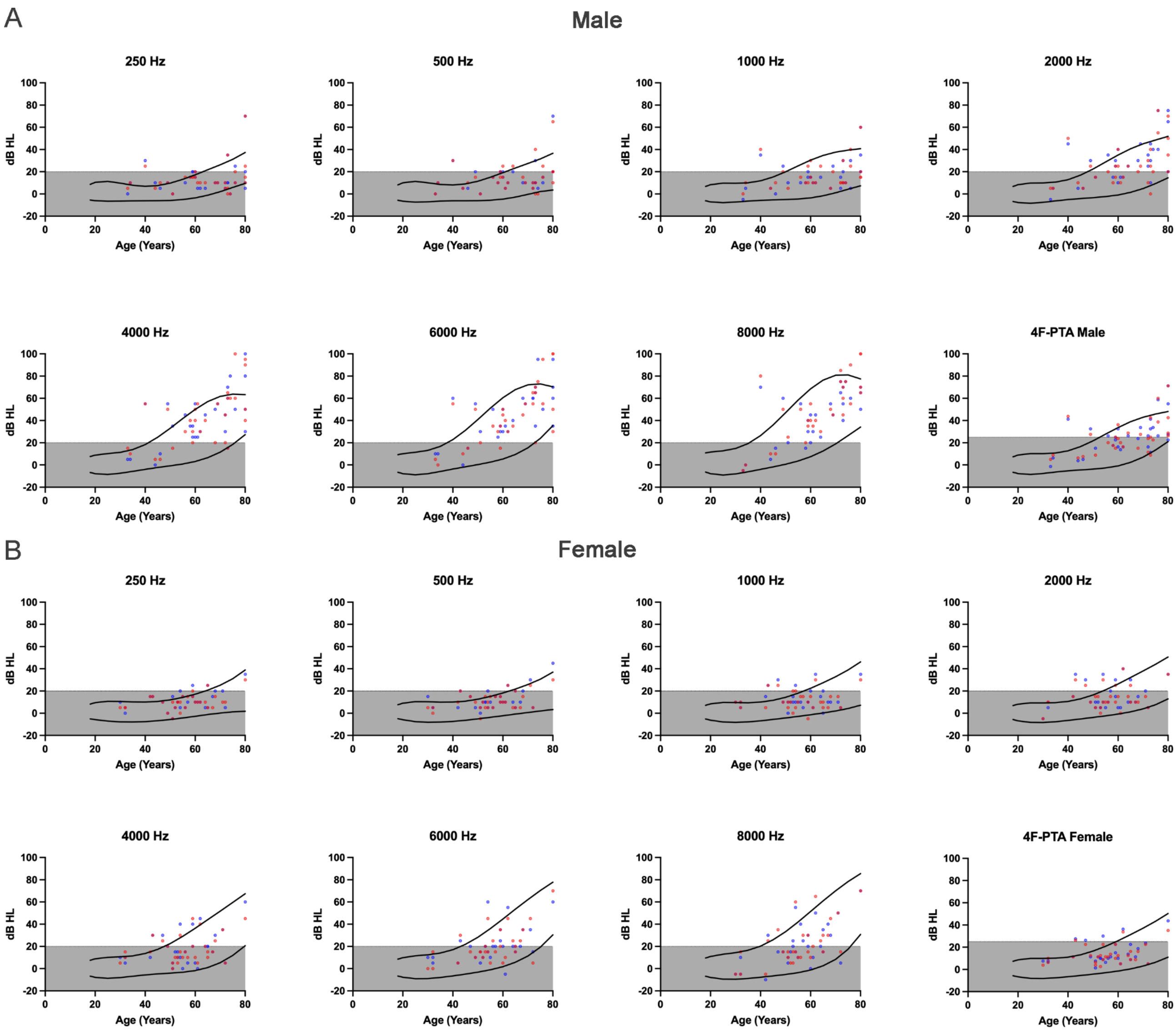

Fig. 2 Audiometric thresholds in dB HL for males and females plotted by age. Curved lines represent the International Organization for Standardization (ISO) normative age-distributions for the 5th percentile (lower black line) and the 95th percentile (upper black line) for each sex, (**A**) males and (**B**) females, and frequency, including the four-frequency pure tone average (4F-PTA). The horizontal dotted line at 20 dB HL identifies clinically normal hearing. Red circles represent the right ear, and blue circles represent the left ear

Table 3 Number and percentage of ears ($n=60$ for males and females) with elevated hearing thresholds when compared to the 95th percentile age- and sex-based reference ranges from the International Standards Organization (ISO 7029:2017)

Frequency	Male	Female
250 Hz	15 (25%)	14 (23%)
500 Hz	13 (22%)	10 (17%)
1000 Hz	5 (8%)	10 (17%)
2000 Hz	13 (22%)	11 (18%)
4000 Hz	16 (27%)	10 (17%)
6000 Hz	11 (18%)	6 (10%)
8000 Hz	10 (17%)	6 (10%)
4F-PTA	10 (17%)	8 (13%)

professionals have long careers well into their 70s and 80s, it is imperative for them to prevent the negative consequences of noise exposure.

Given the risk of hearing loss and tinnitus among dental professionals, several recommendations can be made to mitigate these risks. Firstly, implementing the use of high-quality hearing protection in dental clinics can significantly reduce hazardous noise exposure. Additionally, routine audiologic assessments can help in early detection, prevention, and management of hearing-related issues. Lastly, raising awareness and educating dental professionals on the importance of hearing protection starting in dental schools can empower them to take proactive measures to preserve their hearing health.

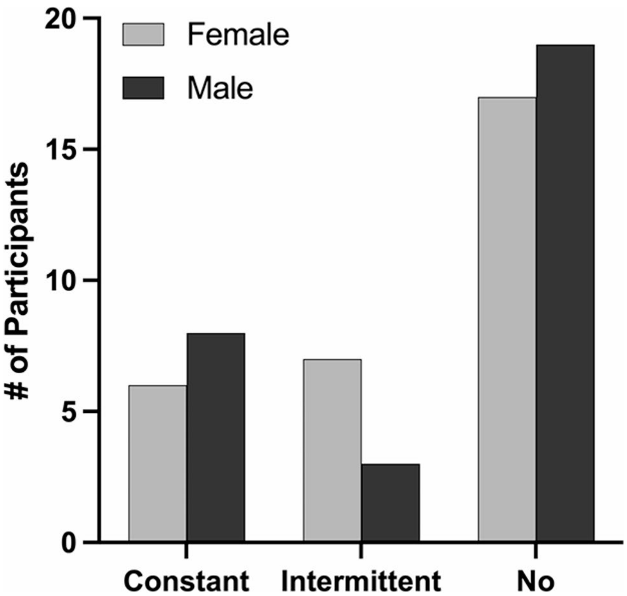

Fig. 3 Prevalence of tinnitus in male and female dental professionals

Conclusion and study limitations

The evaluation of hearing status and tinnitus among dental professionals in this study revealed a significant occupational health concern. The findings underscore the importance of preventive measures and regular auditory monitoring to mitigate the risks associated with prolonged hazardous noise exposure in dental practice. Addressing these risks can enhance the well-being and professional longevity of dental professionals. However, it is important to note that this study is limited by its cross-sectional design, which may not fully capture the long-term effects of noise exposure. Future studies can be executed to longitudinally investigate the impact of dental noises on the hearing acuity of dental students and practitioners since they routinely have lengthy controlled practice sessions with dental handpieces. Additionally, the present study did not account for potential confounding factors such as the practitioner's specialty, age, ethnicity, years of experience, lifestyle habits, genetic factors, work setting, and other relevant variables. These factors should be considered in future research to further expand on the current findings. Furthermore, these confounding factors may affect the generalizability of the results. Future studies should aim to recruit a larger, more diverse sample to explore these aspects in greater depth and enhance the generalizability of the findings.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12995-024-00447-0.

Supplementary Material 1

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Author contributions
Conceptualization: CZ, AY, JH; Investigation: CZ, AY, SR, KS, BS, FN, JH; Methodology: CZ, AY, SR, KS, BS, FN, JH; Data analysis: CZ; Writing – original draft: CZ; Writing – review and editing: CZ, AY, KS, FN, JH.

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Data availability
The data that support the findings of this study are available on request from the corresponding authors, CZ and JH.

Declarations

Ethics approval and consent to participate
This study was conducted in accordance with the Declaration of Helsinki and was approved by the Institutional Review Board at the University of the Pacific, under the approval number IRB2022-209. Informed consent was obtained from all participants prior to their involvement in the study

Consent for publication
All authors provide consent for the publication of this manuscript

Competing interests
The authors declare no competing interests.

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References

1. DiBenedetto DV. Occupational hazards of the health care industry: protecting health care workers. AAOHN J. 1995;43(3):131–7.
2. NIOSH. Criteria for a recommended standard: occupational noise exposure, revised criteria 1998. In.: National Institute for Occupational Safety Health (NIOSH) Cincinnati, OH; 1998.
3. Natarajan N, Batts S, Stankovic KM. Noise-Induced hearing loss. J Clin Med 2023;12(6).
4. Qsaibati ML, Ibrahim O. Noise levels of dental equipment used in dental college of Damascus University. Dent Res J (Isfahan). 2014;11(6):624–30.
5. Barek S, Adam O, Motsch JF. Large band spectral analysis and harmful risks of dental turbines. Clin Oral Investig. 1999;3(1):49–54.
6. Theodoroff SM, Folmer RL. Hearing loss associated with long-term exposure to high-speed dental handpieces. Gen Dent. 2015;63(3):71–6.
7. Zubick HH, Tolentino AT, Boffa J. Hearing loss and the high speed dental handpiece. Am J Public Health. 1980;70(6):633–5.
8. Willershausen B, Callaway A, Wolf TG, Ehlers V, Scholz L, Wolf D, Letzel S. Hearing assessment in dental practitioners and other academic professionals from an urban setting. Head Face Med. 2014;10:1.
9. Wilson JD, Darby ML, Tolle SL, Sever JC Jr. Effects of occupational ultrasonic noise exposure on hearing of dental hygienists: a pilot study. J Dent Hyg. 2002;76(4):262–9.
10. Henry JA, Roberts LE, Caspary DM, Theodoroff SM, Salvi RJ. Underlying mechanisms of tinnitus: review and clinical implications. J Am Acad Audiol. 2014;25(1):5–22. quiz 126.
11. Phoon WH, Lee HS, Chia SE. Tinnitus in noise-exposed workers. Occup Med (Lond). 1993;43(1):35–8.
12. Sidley CG. Prevalence of tinnitus and hearing loss in South African dentists and investigation into possible connections with noise levels and frequencies in the dental environment. Stellenbosch: Stellenbosch University; 2004.

13. Elmehdi HM. Noise levels in UAE dental clinics: Health impact on dental healthcare professionals. J Public Health Front. 2013;2(4):189–92.
14. Alhaider SH, Togoo RA, Hakami RM, Alzamil NS, Alassmi AA, AlShahrani AA, et al. Impact of noise on the hearing and tinnitus among dental students, interns, and dental practitioners: a cross-sectional study. World J Dent. 2023;14(7):581–5.
15. KochKin S, Tyler R, Born J. MarkeTrak VIII: the prevalence of tinnitus in the United States and the self-reported efficacy of various treatments. Hear Rev. 2011;18(12):10–27.
16. Myers J, John AB, Kimball S, Fruits T. Prevalence of tinnitus and noise-induced hearing loss in dentists. Noise Health. 2016;18(85):347–54.
17. Hoffman HJ, Dobie RA, Losonczy KG, Themann CL, Flamme GA. Declining prevalence of hearing loss in US adults aged 20 to 69 years. JAMA Otolaryngol Head Neck Surg. 2017;143(3):274–85.
18. Cruickshanks KJ, Wiley TL, Tweed TS, Klein BE, Klein R, Mares-Perlman JA, Nondahl DM. Prevalence of hearing loss in older adults in Beaver Dam, Wisconsin. The epidemiology of hearing loss study. Am J Epidemiol. 1998;148(9):879–86.
19. Newman CW, Jacobson GP, Spitzer JB. Development of the Tinnitus Handicap Inventory. Arch Otolaryngol Head Neck Surg. 1996;122(2):143–8.
20. Guidelines for manual. Pure-tone threshold audiometry. ASHA. 1978;20 4:297–301.
21. There seems to be no volume number for this paper. Tillman TW, Carhart R. An expanded test for speech discrimination utilizing CNC monosyllabic words. Northwestern University Auditory Test No. 6. SAM-TR-66-55. Tech Rep SAM-TR. 1966:1–12.
22. Tympanometry. J Speech Hear Disorders. 1988;53(4):354–77.
23. Carhart R, Jerger J. Preferred method for clinical determination of pure-tone thresholds. J Speech Hear Disorders. 1959;24:330–45.
24. Basner M, Babisch W, Davis A, Brink M, Clark C, Janssen S, Stansfeld S. Auditory and non-auditory effects of noise on health. Lancet. 2014;383(9925):1325–32.
25. ISO. Acoustics – Statistical Distribution of Hearing Thresholds Related to Age and Gender (ISO 7029:2017). In.: AENOR; 2017.
26. Wang Q, Wang X, Yang L, Han K, Huang Z, Wu H. Sex differences in noise-induced hearing loss: a cross-sectional study in China. Biol Sex Differ. 2021;12(1):24.
27. Lie A, Skogstad M, Johnsen TS, Engdahl B, Tambs K. The prevalence of notched audiograms in a cross-sectional study of 12,055 railway workers. Ear Hear. 2015;36(3):e86–92.
28. Masterson EA, Bushnell PT, Themann CL, Morata TC. Hearing impairment among noise-exposed workers—United States, 2003–2012. MMWR Morb Mortal Wkly Rep. 2016;65:389–94.
29. Helzner EP, Cauley JA, Pratt SR, Wisniewski SR, Zmuda JM, Talbott EO, de Rekeneire N, Harris TB, Rubin SM, Simonsick EM, et al. Race and sex differences in age-related hearing loss: the Health, Aging and Body Composition Study. J Am Geriatr Soc. 2005;53(12):2119–27.
30. Agrawal Y, Platz EA, Niparko JK. Prevalence of hearing loss and differences by demographic characteristics among US adults: data from the National Health and Nutrition Examination Survey, 1999–2004. Arch Intern Med. 2008;168(14):1522–30.
31. McFadden D. Sex differences in the auditory system. Dev Neuropsychol. 1998;14(2–3):261–98.
32. Kujawa SG, Liberman MC. Acceleration of age-related hearing loss by early noise exposure: evidence of a misspent youth. J Neurosci. 2006;26(7):2115–23.
33. Bielefeld EC, Tanaka C, Chen GD, Henderson D. Age-related hearing loss: is it a preventable condition? Hear Res. 2010;264(1–2):98–107.
34. Campo P, Venet T, Rumeau C, Thomas A, Rieger B, Cour C, Cosnier F, Parietti-Winkler C. Impact of noise or styrene exposure on the kinetics of presbycusis. Hear Res. 2011;280(1–2):122–32.
35. Fredriksson S, Li H, Soderberg M, Gyllensten K, Widen S, Persson Waye K. Occupational noise exposure, noise annoyance, hearing-related symptoms, and emotional exhaustion - a participatory-based intervention study in preschool and obstetrics care. Arch Environ Occup Health. 2023;78(7–8):423–34.
36. Li X, Dong Q, Wang B, Song H, Wang S, Zhu B. The influence of occupational noise exposure on Cardiovascular and hearing conditions among Industrial Workers. Sci Rep. 2019;9(1):11524.
37. Yang Y, Zhang E, Zhang J, Chen S, Yu G, Liu X, Peng C, Lavin MF, Du Z, Shao H. Relationship between occupational noise exposure and the risk factors of cardiovascular disease in China: a meta-analysis. Med (Baltim). 2018;97(30):e11720.
38. Vasudevamurthy S, Kumar UA. Effect of occupational noise exposure on Cognition and Suprathreshold Auditory skills in normal-hearing individuals. Am J Audiol. 2022;31(4):1098–115.

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