https://doi.org/10.1016/j.apacoust.2019.107164

Title

The perceptual and behavioral influence on dental professionals from the noise in their workplace

Author names and affiliations

Kuen Wai Ma[a], Cheuk Ming Mak[b, *], Hai Ming Wong[a, **]

[a] *Faculty of Dentistry, The University of Hong Kong, Pok Fu Lam, Hong Kong Island, Hong Kong*

[b] *Department of Building Services Engineering, The Hong Kong Polytechnic University, Hung Hom, Kowloon, Hong Kong*

* Corresponding author. Tel.: 2766 5856; fax: +852 2765 7198; E-mail address: cheuk-ming.mak@polyu.edu.hk (C.M. Mak); address: Department of Building Services Engineering, The Hong Kong Polytechnic University, Hung Hom, Kowloon, Hong Kong.

** Corresponding author. Tel.: +852 2859 0261; fax: +852 2559 3803; E-mail address: wonghmg@hku.hk (H.M. Wong); address: Paediatric Dentistry and Orthodontics, 2/F Prince Philp Dental Hospital, 34 Hospital Road, Hong Kong.

Abstract

A long-term exposure to the high-frequency dental noise is a potential hazard to the health of dental professionals and the quality of oral health service provisions. This study aims to thoroughly investigate the influence of an acoustic environment on the perceptions and behaviors of dental professionals. A multidimensional sound quality assessment that comprises the objective measurements of the acoustic and psychoacoustic metrics in different statistical levels and a self-administrated questionnaire was conducted in the Prince Philip Dental Hospital of Hong Kong. The results indicate that the dental professionals' noise sensitivity and job-performance drops are mainly affected by loudness of noise. Moreover, two types of health risk perceptions, loudness-related and sharpness-related, were found to be associated with a health state of dental professionals. Also, a higher chance of having health-mediated avoidance was found for the dental professionals who had a worse health state and worked in a noisier workplace. These findings provide new knowledge on the development of a health-supportive acoustic environment.

Keywords: acoustic environment, behavior influence, dental workplace, perceptual influence, psychoacoustics

1. Introduction

The awareness of the negative influence of acoustic environment on occupants has increased because numerous health impacts were found to be induced by environmental noise exposure [1, 2]. Many people spend almost one-third of a day on working. Uncontrolled occupational noise [3, 4] in a workplace is a potential hazard [5, 6] to the health of occupants. In a dental workplace, the use of dental equipment such as clinical instruments and laboratory machines [7, 8] will create a high-energy and high-frequency [9] noise. Therefore, dental professionals unavoidably perceive the dental equipment noise during their daily practices [10]. Most of the current dental noise studies [8, 11-13] relied on the objective measurements of time-equivalent continuous A-weighted sound pressure levels (L_{Aeq}) owing to the international regulation (L_{Aeq} < 80 dBA) of the 8-hour daily occupational noise exposure [3]. However, the study of the systematic review of the human perceptual dimensions of sounds [14] pointed out that the temporal and spectral content of sound as well as the sound energy content will affect the human perceptions of sounds. It raised the concern about whether L_{Aeq} is adequate to describe the acoustical influence of the noise in a dental workplace. According to the international standard ISO 12913 [15], a complete sound quality assessment should cover the objecitve measurements of both acoustic and psychoacoustic metrics. Total loudness (*N*) is a psychoacoustic metric to estimate the human loudness sensation of sound, considering the transmission characteristics of the human middle ear structure [16] and the relationships between physical stimuli and perceptual judgments [17]. As just mentioned, the noise in a dental workplace is high-frequency noise. Sharpness (*S*), as a psychoacoustic metric to estimate the human sharpness sensation about the skewness of the energy distribution toward high-frequency components [18], might play an important role in the sound quality assessment of a dental workplace. In addition, to measure statistical noise levels is another common approach in acoustics studies to describe the acoustical influence of industrial noise [19] and outdoor road traffic noise [20]. For instance, L_{A10} is an acoustic parameter of the noise level exceeded for the 10% of the elapsed time. The acoustical influence from the significant noise (L_{A10}) and from the background noise (L_{A90}) in the surroundings can then be distinguished with the help of the parameters in different statistical noise levels. The ambient noise, which encompasses all significant noise and background noise, can also be represented by the parameter L_{A50}. Hence, the sound quality assessment of this study that combined the psychoacoustic measurements with the statistical noise level measurements was a novel and multidimensional approach to investigate the acoustical influence of dental noise on the working environment.

Apart from the objective measurements, the measurements of subjective responses provide a valuable information about the perceptual and behavior influence on occupants [21]. Noise sensitivity (NS) is indicators of the subjects' ability to sense the environmental noise. The researchers [22] also found that NS was correlated with the subjects' annoyance [23, 24], anxiety [25, 26], and other mood disorders [27, 28]. If the noise exposure continues, a list of health risks such as memory loss [29, 30], stress [31], poor sleep quality [2, 32], headaches [33, 34], nausea [35], and fatigue [36, 37] will be possibly perceived by occupants. Furthermore, drops in job performance and actions against noise are also good indicators of the behavioral influence of noise on occupants. Oral health service provisions require dental professionals to concentrate on their work and to communicate with their teammates. Consequently, the work disturbance [38, 39], communication difficulty, and concentration difficulty [40] from noise on dental professionals should be avoided. This is important to maintain a good quality of oral health care service. More importantly, a preference for noise control works is related to the reactions [41] of occupants to noise. The findings on the relationships between the objective acoustic environment and the subjective influence on dental professionals are essential for future noise management work [42]. Thus, this study aims to comprehensively investigate the acoustical influence of the noise in a dental workplace, the perceptual and behavioral influence on dental professionals, and the human-environment interactions.

2. Materials and methods

2.1. Subjects

The sound quality assessments were conducted for the dental professionals in the Prince Philip Dental Hospital (PPDH). The PPDH is the only dental hospital in Hong Kong and is the only building with the different dental workplaces. The assessments were conducted during the official working hours in a random working day. The dental professionals with self-reported hearing problems were excluded in the study. A written informed consent was obtained from everyone prior to any assessment. An ethics approval of the study was obtained from the Institutional Review Board of the University of Hong Kong/Hospital Authority Hong Kong West Cluster (UW 17-088).

2.2. Sound quality assessment

2.2.1. Objective measurement

The acoustical influence of noise in a dental workplace was measured by the advanced, two-channel, handheld analyzer (Type 2270; Bruel & Kjaer, Naerum, Denmark). The analyzer was horizontally placed at 30 cm away from the ears of dental professionals to avoid affecting their work. The elapsed time of each objective measurement was about 10 minutes. The sound level meter software of the analyzer was designed to assess, monitor, and evaluate the acoustical influence of noise on the sound pressure levels (SPL) such as unweighted SPL (L_z) and A-weighted SPL (L_A). Furthermore, the time-varying 1/3 octave band spectrum of L_z was also recorded by the internal frequency analysis software of the analyzer. The 1/3 octave band spectrum was then converted to the 24 Bark band spectrum in terms of the psychoacoustic metric specific loudness (*N'*), and eventually converted to the psychoacoustic metric *N*. The standardized conversion between L_z and *N* can be found in the internal standard [16]. Moreover, the psychoacoustic metric *S* was computed by applying the critical-band-rate dependent into the 24 Bark band spectrum of *N'*. In brief, the *S* increment means that the energy distribution of noise was skewed towards high-frequency components. The development and the explanation of the metric *S* can be found in the Zwicker's book [18]. The *N* and *S* of the reference sound in 1000 Hz with 60 dB are 60 phons and 1 acum, respectively. Since the acoustic environment of a dental workplace varied from time to time, the noise levels at different time were represented by the time-equivalent level, 10%-, 50%, and 90% percentiles of the metrics. Three parameters L_{A10}, N_{10}, and S_{10} were selected to represent the acoustical influence of significant noise. Six parameters L_{A50}, N_{50}, S_{50}, L_{Aeq}, N_{eq}, and S_{eq} were about the acoustical influence of ambient noise. The last three parameters L_{A90}, N_{90}, and S_{90} were about the acoustical influence of background noise in the workplace.

2.2.2. Subjective measurement

Dental professionals were immediately asked to complete a self-administrated questionnaire after the objective measurement of their workplace (see Table 1). The subjective responses of the dental professionals were recorded in five sections. The first section was the five 5-point Likert scale questions about dental professionals' noise sensitivity (NS1-5: hear noise, think noise frequently occurs, take notice of noise, suffer from own equipment noise, suffer from others' equipment noise). For example, the dental professionals were asked to give the response to the question "*How often do you **hear noise**?*". A response ("Not at all", "Occasionally", "Medium", "Often" or "Very often") of a 5-point Likert scale question was coded into the score ranging from 1 to 5 for further statistical analyses. The second and third sections were the 5-point Likert scale questions about six health risk perceptions (HRP1-6: memory loss, stress, poor sleep quality, headache, nausea, and fatigue) and the job-performance drops (JPD1-5: communication difficulty, a scare feeling, disturbance, passion loss, and concentration difficulty), respectively. In the fourth section, the dental professionals' avoidance of noise was recorded by a Yes/No question followed by five choices (complain to colleagues or hospital authority, apply protective measures, use less noisy equipment, move to a less noisy workplace, and others). Five questions about the professionals' background information of their workplace, gender, age range, service length, self-rated health state (HS: very bad, bad, medium, good, and very good) were included in the last section.

Table 1

Information of a self-administrated questionnaire in subjective measurement

Section	Question	Rating scale
I: Noise sensitivity (NS)	*How often do you ________?* NS1: ***hear noise*** NS2: ***think noise frequently occurs*** NS3: ***take notice of noise*** NS4: ***suffer from own equipment noise*** NS5: ***suffer from others' equipment noise***	Five-point Likert scale
II: Health risk perception (HRP)	*How often do you ________?* HRP1: ***memory loss*** HRP2: ***stress*** HRP3: ***poor sleep quality*** HRP4: ***headache*** HRP5: ***nausea*** HRP6: ***fatigue***	Five-point Likert scale

III: Job-performance drop (JPD)	*How often do you have ________ from the noise during work?* JPD1: ***communication difficulty*** JPD2: ***a scare feeling*** JPD3: ***disturbance*** JPD4: ***passion loss*** JPD5: ***concentration difficulty***	Five-point Likert scale
IV: Health mediated avoidance (HMA)	Multiple options after the choice "Yes" HMA1: **Complain to colleagues or hospital authority** HMA2: **Apply protective measures** HMA3: **Use less noisy equipment** HMA4: **Move to a less noisy workplace, and others** HMA5: **Other (please specify)**	Yes/No question followed by multiple choices
V: Background information	Workplace; gender; age range; service length; health state (HS: very bad, bad, medium, good, and very good)	Nominal or ordinal

2.3.Statistical Analyses

All the data from statistical analyses were coded and analyzed by the commercial package SPSS, version 23.0 (IBM Corp., Armonk, NY, USA). All statistical tests were two-tailed tests with the significance level of 0.05. The normality of the data of the acoustic parameters (L_{A10}, N_{10}, S_{10}, L_{A50}, N_{50}, S_{50}, L_{Aeq}, N_{eq}, S_{eq}, L_{A90}, N_{90}, and S_{90}) was checked before the test selection. If the parameter was not normally distributed, the nonparametric tests (Mann-Whitney U tests, Kruskal-Wallis tests, and Spearman's rank correlation tests) would be applied. Mann-Whitney U tests or Kruskal-Wallis tests were applied to test the differences of the acoustic parameters between different workplaces. Spearman's rank correlation tests were applied to test the correlations between the acoustic parameters and the dental professionals' responses. After that, an exploratory factor analysis (EFA) was used to explore the possible underlying factor structure of the HRPs without any preconceived structure [43]. Moreover, NS, HRP, and JPD scores were computed by adding up the scores of the corresponding questions to convert the ordinal responses into a continuous variable. The appropriateness of this approach was further checked by a Cronbach's alpha reliability test [44]. The stepwise linear regressions then were applied for NS, HRP, and JPD scores. Pearson's chi-square tests were applied to test the distribution differences of the dental professionals' avoidance between the subjects' characteristics, and a logistic regression was applied to find out the significant predictors of the avoidance.

3. Results

3.1.Acoustical environment in dental workplaces

The sound quality assessments were carried out to 60 dental professionals at the dental surgery rooms, open clinic, implant laboratory and prosthetics laboratory in PPDH. The medians of the acoustic parameters in dental surgery rooms were the lowest among the workplaces (see Table 2). The acoustical influence of noise was the least in the dental surgery rooms. After grouping the workplaces into two major workplace environments (dental clinic and dental laboratory), the acoustical influence of significant noise (L_{A10}, N_{10}, and S_{10}) and ambient noise (L_{A50}, N_{50}, L_{Aeq}, N_{eq}, and S_{eq}) were significantly greater in the workplace environment of dental clinic ($ps < .001$ in the Mann-Whitney U tests). The distributions of the acoustic parameters in the workplace environments of dental clinic and dental laboratory were plotted in Fig. 1.

Table 2

Medians of the acoustic parameters in the dental workplaces.

Workplace environment	L_{A10} [dBA]	N_{10} [phon]	S_{10} [acum]	L_{A50} [dBA]	N_{50} [phon]	S_{50} [acum]	L_{A90} [dBA]	N_{90} [phon]	S_{90} [acum]	L_{Aeq} [dBA]	N_{eq} [phon]	S_{eq} [acum]
Dental clinic (C)												
Surgery room (1)	59.8	78.1	1.41	57.0	75.0	1.43	54.2	72.8	1.44	57.9	77.1	1.43

Open clinic (2)	64.1	82.8	1.51	58.9	78.1	1.56	54.2	73.5	1.56	61.6	80.4	1.54
Dental laboratory (L)												
Implant laboratory (3)	66.3	85.0	1.98	61.4	80.9	1.83	57.4	76.8	1.75	65.2	83.9	2.03
Prosthetics laboratory (4)	68.7	86.4	1.71	60.1	79.0	1.52	54.4	73.3	1.41	66.2	83.9	1.68
Overall	66.3	84.3	1.59	59.7	78.5	1.54	54.7	73.5	1.54	63.8	82.1	1.67
Mann-Whitney U test (C vs L)	***	***	***	***	***	-	-	-	-	***	***	***
Kruskal–Wallis test (1 vs 2 vs 3 vs 4)	***	***	***	**	***	0.010	-	0.017	***	***	***	***
Post-hoc tests	1<4	1<3 1<4 2<4	1<4 1<3	1<4 1<3	1<4 1<3	1<3	-	1<3	1<3 3<4	1<3 1<4 2<4	1<3 1<4 2<4	1<3 2<3

***$p < 0.001$ in a Kruskal–Wallis test or a Mann-Whitney U test of an acoustic parameter in different dental workplaces or in different workplace environments.

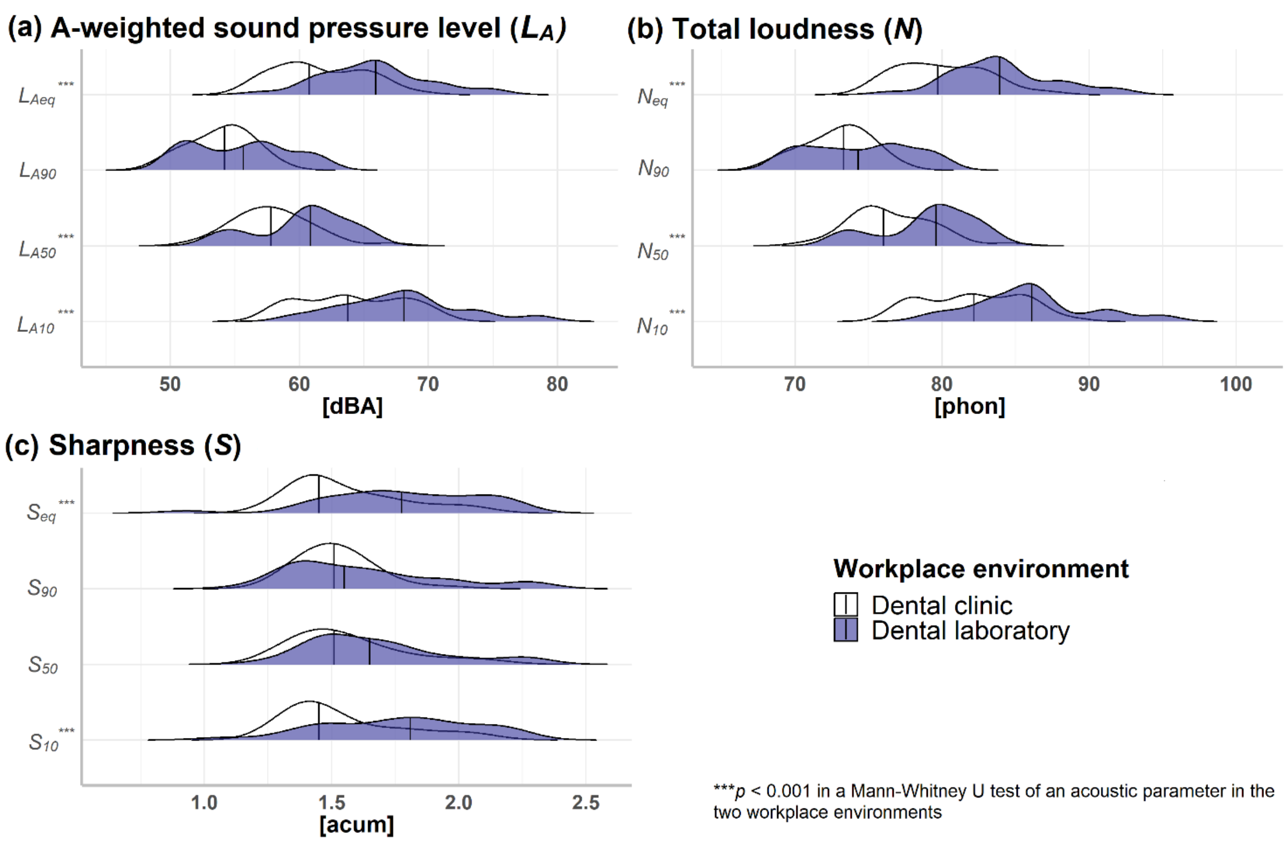

Fig. 1. The density plots of the acoustic parameters in the two dental workplace environments: (a) A-weighted sound pressure level; (b) total loudness; (c) sharpness.

3.2.Statistical description of subjects

Half (50%) of the dental professionals worked in dental clinic while others worked in the dental laboratory, see Table 3. Nearly two thirds (68%) of the professionals were female. The percentages of the professionals in the age ranges "≤ 40 years old", "41 – 50 years old", and "51 – 60 years old" were respectively 30%, 33% and 37%. Half (50%) of the professionals had the service length more than 20 years. 38%, 47%, and 15% of the professionals rated their health state (HS) to be good, medium, or bad, respectively. 53% of the professionals had the health mediated avoidance (HMA) of noise. The naming of the professionals' avoidance would be explained by its logistic regression result in section 3.3. The percentage of the professionals with HMA significantly differed by their workplace environment ($\chi2$ (1, N = 60) = 6.7, p = 0.010), gender ($\chi2$ (1, N = 60) = 14.6, p < 0.001), age range ($\chi2$ (1, N = 60) = 4.1, p = 0.042), and HS ($\chi2$ (1, N = 60) = 7.9, p = 0.005). The professionals with HMA were in the higher chances to have the characteristics of working in the dental laboratory, male, > 40 years old, and without a good HS. For the professionals who applied protective measures, the percentages of them working in the dental laboratory ($\chi2$ (1, N = 60) = 19.2, p < 0.001), being male ($\chi2$ (1, N = 60) = 20.4, p < 0.001), having the service length more than 20 years ($\chi2$ (1, N = 60) = 4.8, p = 0.028), and without a good HS ($\chi2$ (1, N = 60) = 4.3, p = 0.039) were significantly higher. Besides, all the professionals who complained to colleagues or hospital authority about the noise were female.

Table 3

Characteristics of dental professionals and Pearson's chi-square tests of the distribution differences of their health mediated avoidance (HMA) between variables.

Characteristic (Variable)	**Overall sample**	**Health mediated avoidance (HMA)**	***p***	**HMA1: Complain to colleagues or**	***p***	**HMA2: Apply protective measures**	***p***

						hospital authority				
		Yes	No		Yes	No		Yes	No	
Workplace environment *n* (%)				0.010			-			< 0.001
Dental clinic	30 (50.0)	11 (34.4)	19 (67.9)		7 (87.5)	23 (44.2)		2 (10.0)	28 (70.0)	
Dental laboratory	30 (50.0)	21 (65.6)	9 (32.1)		1 (12.5)	29 (55.8)		18 (90.0)	12 (30.0)	
Gender *n* (%)				< 0.001			0.047[a]			< 0.001
Female	41 (68.3)	15 (46.9)	26 (92.9)		8 (100)	33 (63.5)		6 (30.0)	35 (87.5)	
Male	19 (31.7)	17 (53.1)	2 (7.1)		0 (0.0)	19 (36.5)		14 (70.0)	5 (12.5)	
Age range *n* (%)				0.040[b]			-			-
≤ 40 years old	18 (30.0)	6 (18.8)	12 (42.9)		2 (25.0)	16 (30.8)		4 (20.0)	14 (35.0)	
41 – 50 years old	20 (33.3)	12 (37.5)	8 (28.6)		6 (75.0)	14 (26.9)		5 (25.0)	15 (37.5)	
51 – 60 years old	22 (36.7)	14 (43.8)	8 (28.6)		0 (0.0)	22 (42.3)		11 (55.0)	11 (27.5)	
Service length *n* (%)				-			-			0.027[c]
≤ 10 years	18 (30.0)	5 (15.6)	13 (46.4)		1 (12.5)	17 (32.7)		4 (20.0)	14 (35.0)	
11 – 20 years	12 (20.0)	8 (25.0)	4 (14.3)		4 (50.0)	8 (15.4)		2 (10.0)	10 (25.0)	
21 – 30 years	16 (26.7)	10 (31.3)	6 (21.4)		3 (37.5)	13 (25.0)		6 (30.0)	10 (25.0)	
> 30 years	14 (23.3)	9 (28.1)	5 (17.9)		0 (0.0)	14 (26.9)		8 (40.0)	6 (15.0)	
Health state *n* (%)				0.008[d]			-			0.035[d]
Very good	2 (3.3)	1 (3.1)	1 (3.6)		1 (12.5)	1 (1.9)		0 (0.0)	2 (5.0)	
Good	21 (35.0)	6 (18.8)	15 (53.4)		1 (12.5)	20 (38.5)		4 (20.0)	17 (42.5)	
Medium	28 (46.7)	16 (50.0)	12 (42.9)		2 (25.0)	26 (50.0)		13 (65.0)	15 (37.5)	
Bad	8 (13.3)	8 (25.0)	0 (0.0)		4 (50.0)	4 (7.7)		2 (10.0)	6 (15.0)	
Very bad	1 (1.7)	1 (3.1)	0 (0.0)		0 (0.0)	1 (1.9)		1 (5.0)	0 (0.0)	

Note. [a] A Fisher's exact test was applied due to the cell with expected values < 5. [b] The HMA distribution difference was tested for the regrouped age ranges "≤ 40 years old" and "> 40 years old". [c] The HMA distribution difference was tested for the regrouped service lengths "≤ 20 years" and "> 20 years". [d] The HMA distribution difference was tested for the regrouped health states "Very good and good" and "Medium, bad, and very bad". The Pearson's chi-square test results about "HMA3: Use less noisy equipment" and "HMA4: Move to a less noisy workplace" were not significant.

3.3.Responses to the noise in the workplace

The most influential response of the NS questions was the thought about the frequent occurrence of noise (M = 3.15, SD = 0.97; see Fig. 2 (a)). The two highest HRPs from noise were found to be "Fatigue" (M = 3.22, SD = 1.09) and "poor sleep quality" (M = 3.07, SD = 1.22). Meanwhile, the JPD from communication difficulty was the most dominate influence from the noise during work (M = 3.17, SD = 0.83). In general, the acoustic parameters L_{A10}, N_{10}, L_{Aeq}, and N_{eq} were significantly correlated with most of the professionals' responses (Figure 2 (b)). The acoustic parameters L_{A50} and N_{50} were significantly correlated with the professionals' HRPs. The acoustic parameters S_{10} and S_{50} were significantly correlated with the HRPs "headache" and "nausea".

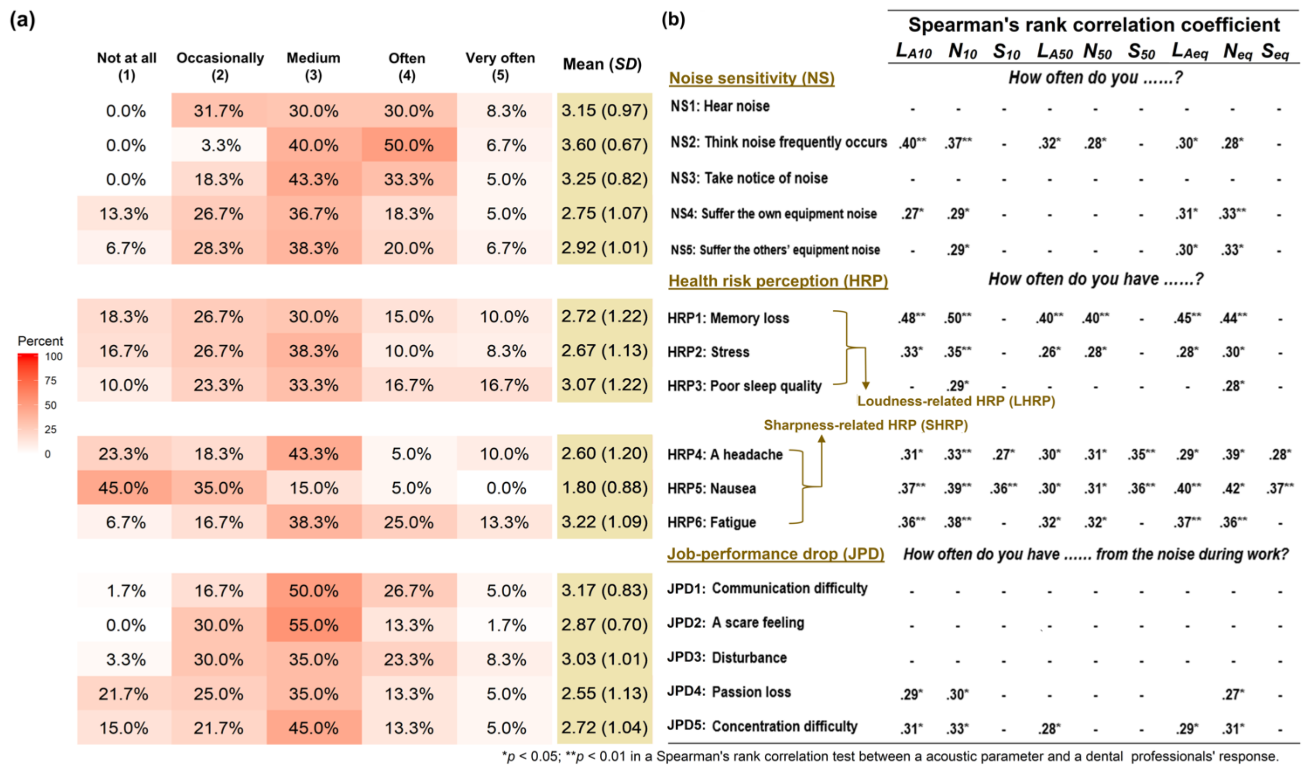

Fig. 2. Dental professionals' responses to the questions about their noise sensitivity, health risk perception, and job-performance drop: (a) a heat map of the response distributions; (b) Spearman's rank correlation coefficients between the acoustic parameters and responses.

In the EFA result of the professionals' HRPs, the two-factor solution was achieved with the oblique rotation. The solution explained 73% of the total variance. The overall Kaiser-Meyer-Olkin (KMO) was measured to be 0.80 which indicated that the sampling was meritorious adequacy [45]. The Bartlett's test of sphericity was statistically significant ($p < 0.001$), indicating that the correlations between the items were sufficiently large for the EFA. The eigenvalues of the two factors were greater than 1. Also, the factor loadings of the variables in the factors (HRP1: 0.75; HRP2: 0.51; HRP3: 0.74 in factor I and HRP4: 0.95; HRP5: 0.77; HRP6: 0.44 in factor II) were greater than 0.40. After considering the correlations between the acoustic parameters and the clustered HRPs in the factors, factor I and II were named to be loudness-related health risk perception (LHRP) and sharpness-related health risk perception (SHRP).

Cronbach's alpha reliability coefficients of the factor variables (NS: α = .763, 5 items; JPD: α = .761, 5 items; LHRP: α = .762, 3 items; SHRP: α = .821, 3 items) indicated the acceptable internal consistencies of the clustered variables in the factors. The results also supported the approach of the factor score calculations. The means of the dental professionals' NS and JPD scores were 15.7 units (*SD* = 3.3) and 14.5 units (*SD* = 3.4) out of 25 units. The means of the LHRP and SHRP scores were 8.5 units (*SD* = 2.9) and 7.6 units (*SD* = 2.7) out of 15 units. Moreover, the normality of the factor scores was confirmed by the normality tests prior to the regression analyses.

In the stepwise linear regression of NS score, only N_{50} was remained in the model (see Table 4). NS score was predicted to be increased by 0.29 unit for each phon of N_{50}. NS score was an intermediary factor variable in predicting other responses, because it was a significant predictor of LHRP, SHRP, and JPD scores. Moreover, LHRP score was predicted to be varied with the acoustic parameter N_{10} and SHRP score was predicted to be variated with the parameters S_{50} and L_{A90}. The regression of JPD score showed that the subjects' JPD were predominantly affected by the perceptual influence on their NS and LHRP.

Table 4

Stepwise linear regressions of scores of dental professionals' noise sensitivity, loudness-related health risk perception, sharpness-related health risk perception and job-performance drop.

Dependent variable	**Remained predictor**	**B (SEB)**	**95% CI**	***β***	***p***
Noise sensitivity (NS)	N_{50}	0.30 (0.13)	[0.04, 0.55]	0.29	0.024

score [a]					
Loudness-related health risk perception (LHRP) score [b]	**NS score**	0.40 (0.10)	[0.21, 0.60]	0.45	< 0.001
	$\boldsymbol{N_{10}}$	0.21 (0.08)	[0.05, 0.36]	0.29	0.010
Sharpness-related health risk perception (SHRP) score [c]	**NS score**	0.45 (0.08)	[0.28, 0.62]	0.54	< 0.001
	$\boldsymbol{S_{50}}$	5.37 (1.34)	[2.58, 8.16]	0.50	< 0.001
	$\boldsymbol{L_{A90}}$	- 0.24 (0.11)	[-0.46, -0.009]	-0.28	0.041
Job-performance drop (JPD) score [d]	**NS score**	0.52 (0.09)	[0.34, 0.70]	0.50	< 0.001
	LHRP score	0.51 (0.10)	[0.30, 0.71]	0.44	< 0.001

Note. B = unstandardized coefficient, SEB = standard error of B, CI = confidence interval for B, β = unstandardized coefficient. [a] $R^2 = 0.09$, $F(1,58) = 5.34$, $p = 0.024$; [b] $R^2 = 0.36$; $F(2,57) = 15.7$, $p < 0.001$; [c] $R^2 = 0.44$, $F(3,56) = 14.9$, $p < 0.001$; [d] $R^2 = 0.68$, $F(2,57) = 60.0$, $p < 0.001$.

Since the subjects' HS was an ordinal variable, an ordinal logistics regression was applied to test the proportional odds of the states (testing model: $\ln(P(state)/(1-P(state))) = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \ldots + \beta_n x_n$). Before conducting the regression, the 5-level HS was regrouped into 3-level (good, medium, and bad) due to a few subjects in the HS "very good" or "very bad". The three remained predictors in the final HS model were S_{eq} ($p = 0.020$), LHRP ($p = 0.018$), and SHRP ($p = 0.004$). The proportional odds of a worse HS was predicted to be increased by 31% (95% CI [4%, 63%]), 34% (95% CI [5%, 71%]), and 51% (95% CI [14%, 99%]) for each increment of 0.1 acum of S_{eq}, 1 unit of LHRP score, and 1 unit of SHRP score, respectively. The Nagelkerke's Pseudo r-square [46] of the model was 0.57, $p < 0.001$. The 3D scatter plot of the predictors and the 3-level HS illustrated the relationships between the variables (Fig. 3).

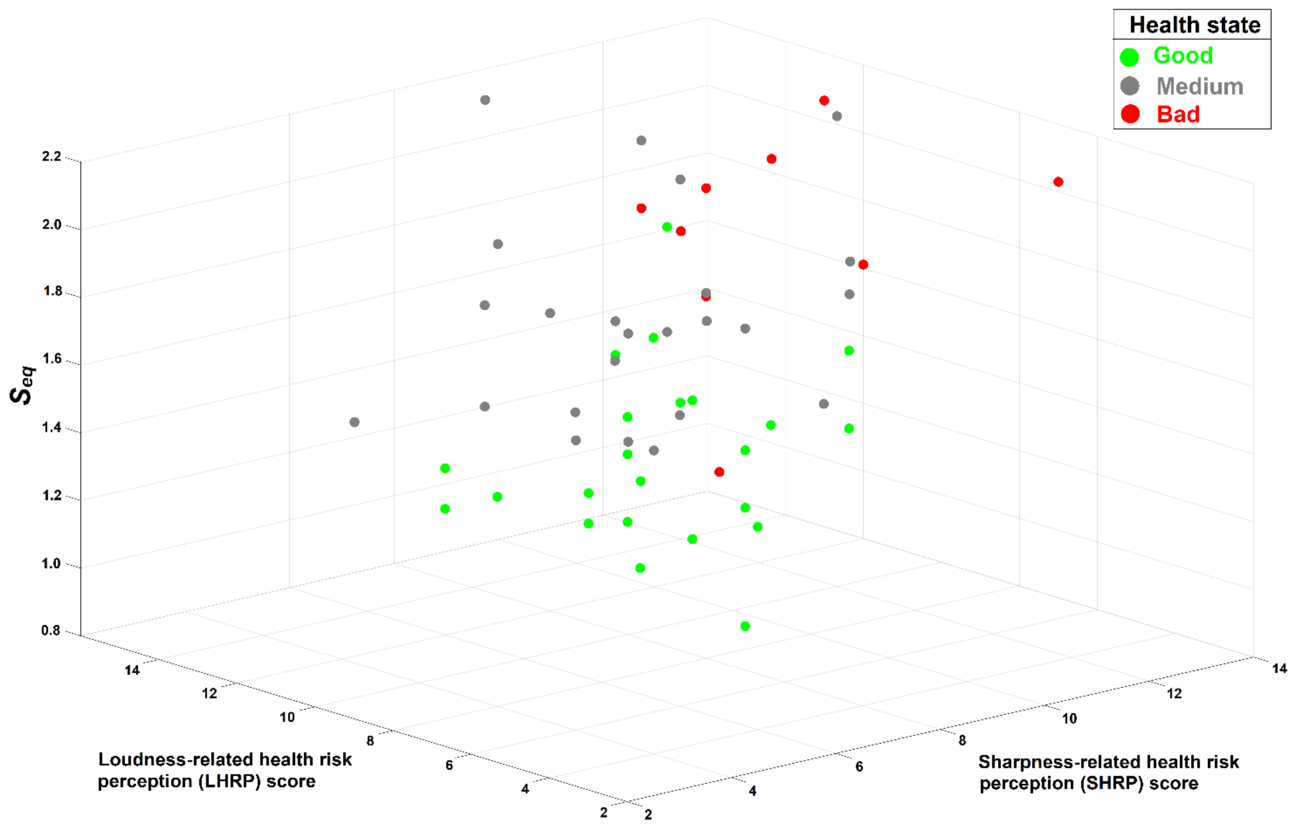

Fig. 3. A 3D scatter plot of loudness-related health risk perception (LHRP) score, sharpness-related health risk perception (SHRP) score, and the time-equivalent sharpness (S_{eq}) in the workplaces.

Finally, a logistic regression was applied to test the odds ratio of the subjects with the HMA to the subjects without the HMA (Table 5). Three acoustic parameters L_{A90}, N_{90}, and S_{90} and two subjects' characteristics HS and Gender was remained in the final HMA model. The result showed that the dental professionals' avoidance of noise was prompted by the worse of their HS. The chance of having the HMA become 3.19 times as likely for a HS being worse. As a result, the professionals' avoidance of noise was named to be HMA. In addition, the odds ratio of the HMA become 4.56 or 2.49 times as likely when L_{A90} was increased by 1 dBA or S_{90} was increased by

0.1 acum, respectively. But the odds ratio of the HMA become 0.12 times as likely for each increment of 1 phon of N_{90}.

Table 5

A logistic regression of the dental professionals' health mediated avoidance (HMA)

Remained predictor	B (SE)	*Odds ratio* (SEO)	95% CI	*p*
L_{A90}	1.52 (0.74)	4.56 (2.10)	[1.07, 19.5]	0.041
N_{90}	-2.11 (0.88)	0.12 (2.41)	[0.22, 0.68]	0.017
S_{90} [a]	0.91 (0.41)	2.49 (1.50)	[1.11, 5.58]	0.027
HS	1.16 (0.51)	3.19 (1.67)	[1.17, 8.71]	0.023
Gender				
Female	2.53 (0.97)	12.3 (2.65)	[1.87, 84.8]	0.009
Male [b]				

Note. B = unstandardized coefficient, SEB = standard error of B, SEO = standard error of odds ratio, CI = confidence interval for odds ratio. Nagelkerke's R^2 = .56, p < .001. [a] The odds ratio is for a 0.1-acum increment. [b] Reference group.

4. Discussion

4.1. Principal results

The dental surgery rooms (length × width × height = 4 m × 3 m × 2.8 m) were the closed rooms located next to the dental open clinic (40 m × 10 m × 2.8 m). There was only one dental chair with different clinical instruments in the middle of a surgery room, while there were more than thirty dental chairs at the open clinic. The implant laboratory and the prosthetics laboratory were two adjacent laboratories with the same dimension (15m × 7.5m × 2.8m) but with different laboratory machines inside. In spite of the difference between the room dimensions of the workplaces, the acoustical influence from the background noise sources such as broadcasting systems, air-conditioning systems, and human activities was not significantly different between the workplaces. Since the walls of the dental surgery rooms acted as a shield against the others' equipment noise, the acoustical influence of the equipment noise in the workplaces was further diminished. This was referred to the finding that the medians of the acoustic parameters in dental surgery room were the minimum. The Mann-Whitney U tests of L_{A10}, N_{10}, and S_{10} suggested that the noise from dental equipment operations had the significant acoustical influence on the workplace environments. The results agreed with other researchers' finding that the noise levels of the dental laboratory machines were higher than that of the clinical instruments [9]. The dental equipment noise also affected the ambient noise as regards to the parameters L_{A50}, N_{50}, L_{Aeq}, N_{eq}, and S_{eq}. This implied that the controls on dental equipment noise are crucial for the reduction of the daily noise exposure of dental professionals.

The subjects' responses to noise was a complicated process (see Fig. 4). The time-equivalent acoustic parameters about the sound energy levels were not enough to explain all the relationships between acoustic environment and human responses. The neglect of the assessments to psychological effects [47] could limit the scientific and statistical evidence [48] in the analysis of human-environment interactions. The multidimensional sound quality assessments of this study provided a more thoughtful analysis to the human-environment interactions from the psychoacoustic measurements (for spectral content) and statistical noise level measurements (for temporal content) to cover the fundamental human perceptual dimensions of sounds [14]. The influence of different kinds of noise was distinguished by the measurements of the acoustic parameters in different statistical noise levels. In the Spearman's rank correlation test results, the subjects' NS was found to be correlated with the equipment and ambient noise where N_{50} was the most significant predictor. The occurred noise, on top of the background noise, affected the dental professionals' loudness sensation and then to their perceptions on NS. For those professionals with a higher NS, the chances of having JPD and HRP were also significantly increased. There was a similar result in the study [49] of the relationship between the NS and headache. The EFA result suggested that the professionals' HRPs could be divided into two types. Some of them were more related to the subjects' loudness sensation and the others were more related to the sharpness sensation. The louder the equipment noise, the higher chances of having the LHRPs "memory loss", "stress" and "poor sleep quality". If the situation becomes worse, the behavioral influence on the job performance other than the perceptual influence could then be found for dental professionals. The results matched with that of the other environmental behavioral studies [37, 40]. At the same time, the SHRPs "headache", "nausea" and "fatigue" were correlated with the sharpness sensation to the high-frequency ambient noise. As SHRP score was decreased by 0.28 unit for each dBA of L_{A90}, the background noise level increment may ease the influence of the sharpness sensation. Sound masking [50] in a lower frequency range than dental equipment noise could be one of the solutions to ease the dental professionals' SHRPs.

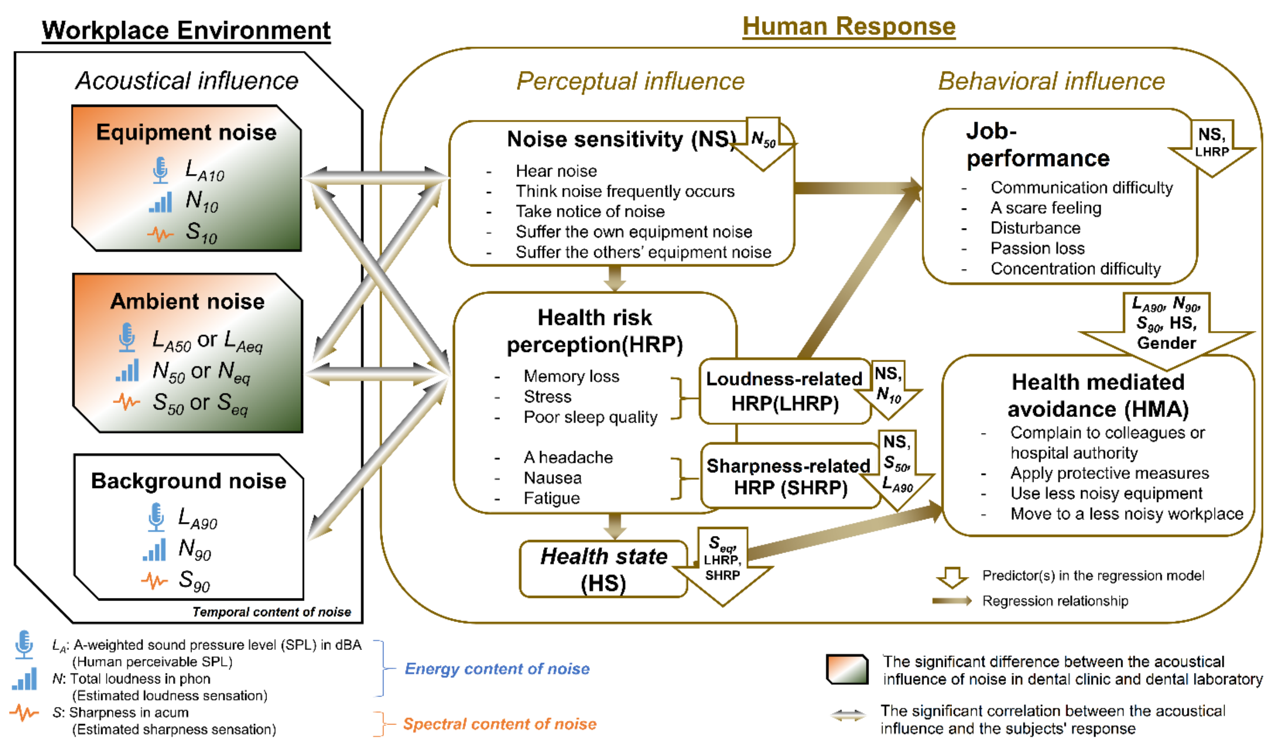

Figure 4. Summary of the relationships between the acoustical influence of noise and the perceptual and behavioral influence on dental professionals.

The dental professionals' HS of was found to be a worthy indicator of the influence of noise. The professionals' HS was the result of their HRPs and was the significant predictor of their HMA. More attention should be paid to the environmental sound quality if the self-rated HS of dental professionals becomes worse. A good noise management strategy can improve the occupants' health quality [51] and their satisfaction to work [52]. The understanding of the HMA permitted future noise management works to control the influence of noise in appropriate ways. Although the magnitude of background noise is smaller than that of the other noise, the long-term influence of background noise was also remarkable owing to the remains of L_{A90}, N_{90}, and S_{90} in the HMA model. The need of the regular on-site monitoring [53] for workplace environments to attenuate the influence of noise was also demonstrated. In building acoustics, a well-developed noise prediction model [54] considering different indoor [55-61] and outdoor [62] noise sources is a prime requisite for a good building design [63]. The results of this study gave the insights into the development of a more advanced prediction model to predict the acoustical influence as well as the perceptual and behavior influence on occupants.

4.2.Limitations and future work

Although the importance of *N* and *S* in the sound quality assessments of dental workplaces were studied, the analyses of the other psychoacoustic metrics such as annoyance [64], suddenness [65], roughness [66] and pleasantness [18] were still outstanding. The noise impacts on the other psychological influence and the physiological influence such as noise-induced hearing loss [67, 68] and hearing impairment [69] require additional investigations. Principally, there is a need of the guidelines on appropriate levels of noise exposure in term of psychoacoustic metrics. The existing L_{Aeq} regulation is insufficient in considering all human subjective responses to the environment. Not only the energy content but also the temporal and spectral content of noise were supposed to be controlled. Dental equipment operations are inseparable from oral health service provisions, so the design and adoption of dental equipment are critical to the acoustic environment of dental workplaces. Moreover, better building designs with noise partitions, noise protective measure supplies, and the control on the number of concurrent operating equipment are of the essence to improve the dental workplace environments and hence to reduce the daily noise exposure of dental professionals.

5. Conclusion

The study linked the acoustical influence of the noise in dental workplaces with the perceptual and behavioral influence on the dental professionals in the multidimensional approach. In general, the acoustical influence of the dental equipment noise in term of L_{A10}, N_{10}, and S_{10} and that of the ambient noise in term of L_{A50}, N_{50}, L_{Aeq}, N_{eq}, and S_{eq} were found to be significantly lower in the dental clinic than the dental laboratory. The analysis of the psychoacoustic metric N disclosed the perceptual influence on the dental professionals' NS and LHRP scores from their loudness sensation of noise. The behavioral influence on the JPD score as the consequence of the perceptual influence was also observed. Moreover, the analysis of the psychoacoustic metric S disclosed the perceptual influence on the dental professionals' SHRP score and their HS which is the significant indicator of the behavioral influence on the HMA. A chance of having HMA can be decreased for a dental professional who has a better HS and works in the workplace with smaller L_{A90}, N_{90}, and

S_{90}. These findings gave the insights into future noise management works to assess, monitor, evaluate, predict, and control the influence of noise on occupants.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Declarations of interest

None.

Acknowledgements

The Prince Philip Dental Hospital is especially acknowledged for the kind help of the assessment. We would like to thank dental professionals in the study for spending their time in completing the assessments. The PhD student Xiaofeng Shi as well as the master students Lishan Chen and Zhenbin Wu from The Hong Kong Polytechnic University are also acknowledged for their assistance in the on-site measurements and data collection.

References

1. Passchier-Vermeer W, Passchier WF. Noise exposure and public health. Environ Health Perspect. 2000;108(Suppl 1):123-31.

2. Tezel MN, Sari D, Erdol M, Hamamci SF, Ozkurt N. Evaluation of some health impact indices in two airports' domain. Applied Acoustics. 2019;149:99-107.

3. World Health Organization. Occupational noise: assessing the burden of disease from work-related hearing impairment at national and local levels. Geneva World Health Organization; 2004.

4. Acun V, Yilmazer S. A grounded theory approach to investigate the perceived soundscape of open-plan offices. Applied Acoustics. 2018;131:28-37.

5. Yassi A, Gaborieau D, Gillespie I, Elias J. The noise hazard in a large health care facility. J Occup Environ Med. 1991;33(10):1067-70.

6. Stanbury M, Rafferty AP, Rosenman K. Prevalence of hearing loss and work-related noise-induced hearing loss in Michigan. J Occup Environ Med. 2008;50(1):72-9.

7. Singh S, Gambhir RS, Singh G, Sharma S, Kaur A. Noise levels in a dental teaching institute - A matter of concern! Journal of Clinical and Experimental Dentistry. 2012;4(3):e141-5.

8. Kadanakuppe S, Bhat PK, Jyothi C, Ramegowda C. Assessment of noise levels of the equipments used in the dental teaching institution, Bangalore. Indian Journal of Dental Research. 2011;22(3):424-31.

9. Choosong T, Kaimook W, Tantisarasart R, Sooksamear P, Chayaphum S, Kongkamol C, et al. Noise exposure assessment in a dental school. Saf Health Work. 2011;2(4):348-54.

10. Setcos JC, Mahyuddin A. Noise levels encountered in dental clinical and laboratory practice. The International Journal of Prosthodontics. 1998;11(2):150-7.

11. Burk A, Neitzel RL. An exploratory study of noise exposures in educational and private dental clinics. J Occup Environ Hyg. 2016;13(10):741-9.

12. Dutta A, Mala K, Acharya SR. Sound levels in conservative dentistry and endodontics clinic. Journal of Conservative Dentistry. 2013;16(2):121-5.

13. Jadid K, Klein U, Meinke D. Assessment of noise exposures in a pediatric dentistry residency clinic. Pediatr Dent. 2011;33(4):342-7.

14. Ma KW, Wong HM, Mak CM. A systematic review of human perceptual dimensions of sound: Meta-analysis of semantic differential method applications to indoor and outdoor sounds. Building and Environment. 2018;133:123-50.

15. ISO 12913. PD ISO/TS 12913-2:2018: Acoustics. Soundscape. Part 2: Data collection and reporting requirements. Geneva, Switzerland: International Organization for Standardization; 2018.

16. ISO 532-1. ISO 532-1: Acoustics. Methods for calculating loudness. Zwicker method. Geneva, Switzerland: International Organization for Standardization; 2017.

17. Stevens SS. The measurement of loudness. The Journal of the Acoustical Society of America. 1955;27(5):815-29.

18. Zwicker E, Fastl H. Psychoacoustics: Facts and models: Springer Science & Business Media; 1990.

19. BS 4142. BS 4142: Methods for rating and assessing industrial and commercial sound. The British Standards Institution; 2014.

20. Department of Transport Welsh Office. Calculation of Road Traffic Noise. London: Her Majesty's Stationery Office; 1988.

21. de Souza TB, Alberto KC, Barbosa SA. Evaluation of noise pollution related to human perception in a university campus in Brazil. Applied Acoustics. 2020;157:107023.

22. Shepherd D, Welch D, Dirks KN, Mathews R. Exploring the relationship between noise sensitivity, annoyance and health-related quality of life in a sample of adults exposed to

environmental noise. International Journal of Environmental Research and Public Health. 2010;7(10):3579-94.

23. Zannin PHT, Bunn F. Noise annoyance through railway traffic-a case study. Journal of Environmental Health Science and Engineering. 2014;12(1):14.

24. Abbasi M, Monazzam MR, Akbarzadeh A, Zakerian SA, Ebrahimi MH. Impact of wind turbine sound on general health, sleep disturbance and annoyance of workers: a pilot-study in Manjil wind farm, Iran. Journal of Environmental Health Science and Engineering. 2015;13(1):71.

25. Wong HM, Mak CM, Xu YF. A four-part setting on examining the anxiety-provoking capacity of the sound of dental equipment. Noise Health. 2011;13(55):385-91.

26. Wong HM, Mak CM, To WM. Development of a Dental Anxiety Provoking Scale: A pilot study in Hong Kong. Journal of Dental Sciences. 2015;10(3):240-7.

27. Tzivian L, Winkler A, Dlugaj M, Schikowski T, Vossoughi M, Fuks K, et al. Effect of long-term outdoor air pollution and noise on cognitive and psychological functions in adults. Int J Hyg Environ Health. 2015;218(1):1-11.

28. Alimohammadi I, Soltani R, Sandrock S, Azkhosh M, Gohari MR. The effects of road traffic noise on mental performance. Iranian Journal of Environmental Health Science & Engineering. 2013;10(1):18.

29. Molesworth BRC, Burgess M, Koh S. The relationship between noise and mode of delivery on recognition memory and working memory. Applied Acoustics. 2017;116:329-36.

30. Stansfeld SA, Matheson MP. Noise pollution: non-auditory effects on health. British Medical Bulletin. 2003;68(1):243-57.

31. Huang Y, Li D. Subjective discomfort model of the micro commercial vehicle vibration over different road conditions. Applied Acoustics. 2019;145:385-92.

32. Yoshida T, Osada Y, Kawaguchi T, Hoshiyama Y, Yoshida K, Yamamoto K. Effects of road traffic noise on inhabitants of Tokyo. Journal of Sound and Vibration 1997;205(4):517-22.

33. Martin PR, Todd J, Reece J. Effects of Noise and a Stressor on Head Pain. Headache: The Journal of Head and Face Pain. 2005;45(10):1353-64.

34. Ali SAA. Study effects of school noise on learning achievement and annoyance in Assiut city, Egypt. Applied Acoustics. 2013;74(4):602-6.

35. Huss A, Küchenhoff J, Bircher A, Heller P, Kuster H, Niederer M, et al. Symptoms attributed to the environment–a systematic, interdisciplinary assessment. Int J Hyg Environ Health. 2004;207(3):245-54.

36. Saeki T, Fujii T, Yamaguchi S, Harima S. Effects of acoustical noise on annoyance, performance and fatigue during mental memory task. Applied Acoustics. 2004;65(9):913-21.

37. Techera U, Hallowell M, Stambaugh N, Littlejohn R. Causes and consequences of occupational fatigue: Meta-analysis and systems model. J Occup Environ Med. 2016;58(10):961-73.

38. Mak CM, Lui YP. The effect of sound on office productivity. Building Services Engineering Research and Technology. 2012;33(3):339-45.

39. Kang SX, Ou DY, Mak CM. The impact of indoor environmental quality on work productivity in university open-plan research offices. Building and Environment. 2017;124:78-89.

40. Chowdhury RB, Dey R, Alam MS, Chakraborty P. Extent of traffic induced noise in the noise sensitive institutions of Chittagong city, Bangladesh. Noise Vibration Worldwide. 2010;41(1):28-36.

41. Job RS. Noise sensitivity as a factor influencing human reaction to noise. Noise Health. 1999;1(3):57-68.

42. Fortes-Garrido JC, Velez-Pereira AM, Gázquez M, Hidalgo-Hidalgo M, Bolívar JP. The characterization of noise levels in a neonatal intensive care unit and the implications for noise management. Journal of Environmental Health Science and Engineering. 2014;12(1):104.

43. Child D. The essentials of factor analysis: Cassell Educational; 1990.

44. Gliem JA, Gliem RR, editors. Calculating, interpreting, and reporting Cronbach's alpha reliability coefficient for Likert-type scales2003: Midwest Research-to-Practice Conference in Adult, Continuing, and Community Education.

45. Kaiser HF. An index of factorial simplicity. Psychometrika. 1974;39(1):31-6.

46. Nagelkerke NJ. A note on a general definition of the coefficient of determination. Biometrika. 1991;78(3):691-2.

47. Hatfield J, Job R, Carter N, Peploe P, Taylor R, Morrell S. The influence of psychological factors on self-reported physiological effects of noise. Noise Health. 2001;3(10):1-13.

48. Seidman MD, Standring RT. Noise and quality of life. Int J Hyg Environ Health. 2010;7(10):3730-8.

49. Drummond P. Sensitivity to light and noise in tension-type and cervicogenic headache. SAGE Publications Sage UK: London, England; 1998.

50. Cai J, Liu J, Yu N, Liu B. Effect of water sound masking on perception of the industrial noise. Applied Acoustics. 2019;150:307-12.

51. Brown AL, van Kamp I. WHO Environmental Noise Guidelines for the European Region: A Systematic Review of Transport Noise Interventions and Their Impacts on Health. International Journal of Environmental Research and Public Health. 2017;14(8):873.

52. Sakellaris IA, Saraga DE, Mandin C, Roda C, Fossati S, de Kluizenaar Y, et al. Perceived indoor environment and occupants' comfort in European "modern" office buildings: the OFFICAIR study. International Journal of Environmental Research and Public Health. 2016;13(5):444.

53. Ibekwe TS, Folorunsho DO, Dahilo EA, Gbujie IO, Nwegbu MM, Nwaorgu OG. Evaluation of mobile smartphones app as a screening tool for environmental noise monitoring. J Occup Environ Hyg. 2016;13(2):D31-D6.

54. Mak CM, Wang Z. Recent advances in building acoustics: An overview of prediction methods and their applications. Building and Environment 2015;91:118-26.

55. Mak CM, Yang J. A prediction method for aerodynamic sound produced by closely spaced elements in air ducts. Journal of Sound and Vibration 2000;229(3):743-53.

56. Mak CM. Development of a prediction method for flow-generated noise produced by duct elements in ventilation systems. Applied Acoustics. 2002;63(1):81-93.

57. Mak CM, Au WM. A turbulence-based prediction technique for flow-generated noise produced by in-duct elements in a ventilation system. Applied Acoustics. 2009;70(1):11-20.

58. Cai C, Mak CM. Noise control zone for a periodic ducted Helmholtz resonator system. The Journal of the Acoustical Society of America. 2016;140(6):EL471-EL7.

59. Cai CZ, Mak C, Shi XF. An extended neck versus a spiral neck of the Helmholtz resonator. Applied Acoustics. 2017;115:74-80.

60. Mak CM, Wu J, Ye C, Yang J. Flow noise from spoilers in ducts. The Journal of the Acoustical Society of America. 2009;125(6):3756-65.

61. Shi XF, Mak CM. Sound attenuation of a periodic array of micro-perforated tube mufflers. Applied Acoustics. 2017;115:15-22.

62. To WM, Mak CM, Chung WL. Are the noise levels acceptable in a built environment like Hong Kong? Noise Health. 2015;17(79):429-39.

63. Zhang W, Mak CM, Wong HM. Pollutant dispersion in a natural ventilated dental clinic. Building Services Engineering Research and Technology. 2013;34(3):245-58.

64. Novaković T, Ogris M, Prezelj J. Validating impeller geometry optimization for sound quality based on psychoacoustics metrics. Applied Acoustics. 2020;157:107013.

65. Ai ZT, Mak CM, Wong HM. Noise level and its influences on dental professionals in a dental hospital in Hong Kong. Building Services Engineering Research and Technology. 2017;38(5):522-35.

66. Dragonetti R, Ponticorvo M, Dolce P, Di Filippo S, Mercogliano F. Pairwise comparison psychoacoustic test on the noise emitted by DC electrical motors. Applied Acoustics. 2017;119:108-18.

67. Masterson EA, Themann CL, Calvert GM. Prevalence of Hearing Loss Among Noise-Exposed Workers Within the Health Care and Social Assistance Sector, 2003 to 2012. J Occup Environ Med. 2018;60(4):350-6.

68. World Health Organization. The world health report 2002: reducing risks, promoting healthy life: World Health Organization; 2002.

69. Messano GA, Petti S. General dental practitioners and hearing impairment. Journal of dentistry. 2012;40(10):821-8.