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Title

Development of a subjective scale for sound quality assessments in building acoustics

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Keywords

Acoustic subjective scale

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Abstract

In building acoustics, it is necessary to conduct both objective and subjective evaluations in a holistic sound quality assessment. However, there is a huge variety in a selection of psychological tools. This arouses the concern about reliability and validity of the tools. Although various perceptions can be affected by environmental sounds, the underlying structure of acoustic perceptual influences was recently investigated by the researchers in their systematic review study. This is a first study aiming at the development of a valid and reliable subjective scale to quantitatively assess the three fundamental perceptual dimensions of sound via the investigation of its psychometric properties. Nine semantic differential questions in the psychoacoustics perception scale (PPS) covered the assessments about the subjects' responses to the general judgement (Evaluation (E)), energy content (Potency (P)), and temporal and spectral content (Activity (A)) of sound. The reliability test results (Cronbach's αs > .80) indicated the acceptable internal consistencies of the items in the E, P, and A factors. The construct validity in characterizing the structure of perceptual influences was confirmed by the goodness-of-model-fit indexes in the confirmatory factor analysis (CFA, $N = 128$) for the factorial structure of the hypothetical EPA model behind the PPS. The further invariant tests verified the invariances of the model across gender except the error variance of the E factor. A total EPA score, representing the joint attribution of the factors, was a significant predictor of the other perceptions. The concurrent validity of the PPS to the modified dental anxiety scale (MDAS), a well-developed psychometric tool, was also supported by the result that the E factor was a significant predictor of the MDAS score.

1. Introduction

Environmental well-being is not merely about the physical environments [1-3], but also about the human subjective responses to surroundings [4-8]. The reliable and valid subjective assessments are critical to the success in the analysis of human-environment interactions [9] as well as decisions of on building designs [9]. Various international standards (ISOs) are hence developed as guidance on the measures of physical environments and human psychological responses (see Fig. 1). The ISOs well cover the objective assessment methods about the different environmental components such as the general [10], thermal [11-14], acoustic [15-20], vibration [21, 22], visual and lighting [23], and air quality [24] environments. Although there are the guidelines on the subjective scale construction [25] and on the measures of the stress and discomfort perceptions [26] for the thermal environment, the discussion on the subjective scale construction for the other environments is still inadequate. The human-environment interactions in acoustic environments are a series of the processes from the environmental sound generation and transmission to the human perceptions of sound, and ultimately to the different behavioral responses. Even though there are the ISO 15666 [27] and ISO 12913 [18, 19] about the subjective evaluation of human perceptions, the questions [28] applied in psychological measures can vary greatly from study to study in building acoustics [29]. For example, the focus of the studies can be acoustic comfort [30-32], preference [33, 34], or annoyance [35] depending on the researchers' interests. One of the common psychological tools in subjective evaluation to quantitatively assess the subjective meaning of objective things is semantic differential method (SDM) [36]. The questions in the SDM applications are formed by a list of bipolar adjective pairs (APs) in opposite meanings. The SDM applications allowed the researchers to figure out the conceptual frameworks of the environmental influences on occupants [37]. Therefore, SDM was commonly seen in the environmental assessments of the general indoor [38], visual and lighting [39, 40], thermal [41, 42], and outdoor [43] situations. Even though the SDM was applied to the same environmental component such as an acoustic environment, the selected APs were inconsistent across the different studies (sounds in music halls [44], air-conditioning sounds [45], urban sounds [46], sounds in public area [47], sounds in classroom [48], daily sounds [49], and sounds of virtual acoustic environments [50]). Human psychological responses are complex and governed by many latent factors, which are not easily measured or observed. It is feasible to extract the structure of the acoustic perceptual influences from a factor analysis [51] of SDM data. Recently, the researchers found a underlying structure of acoustic perceptual influences from the systematic review of human perceptual dimensions of sound [52]. The results provided the insight into the development of a generally applicable subjective scale for acoustic environments. The scale only has a constraint on the compulsory measures to the fundamental elements but keeps a free selection of other interested psychological responses.

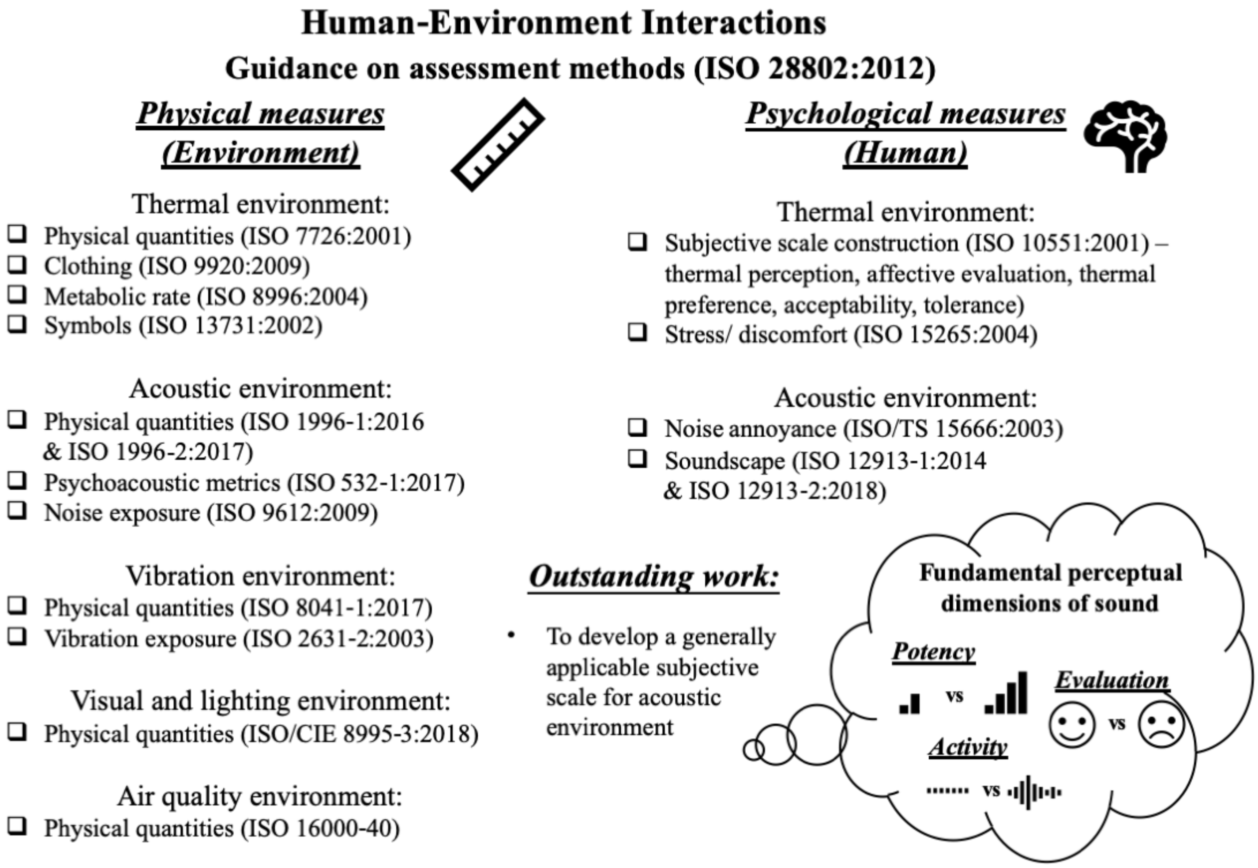

Fig. 1. A summary of the current international standards (ISOs) about guidance on assessment methods for human-environment interactions.

The three principal latent factors in the human perceptual dimensions of sound were discovered to be “Evaluation” (E), “Potency” (P), and “Activity” (A) [52]. The E, P, and A factors are constructed by the assessments of the human perceptions about the general judgement, the energy content, and the temporal and spectral content of sound, respectively. In the traditional acoustic studies, the undue emphasis on the perceptual influence from the energy content of sound, and the physical measures was focused on the assessments of the noise level instead of the general sound quality of the environment. The discussion about the environmental influences from the general judgment and the temporal and spectral content of the environmental noise [53] was limited due to the insufficient assessments of the perceptions about the E and A factors. Also, researchers found that the amplitude of sound [54] or loudness perception [55] was not enough to explain all the subjective responses. Thus, the psychoacoustics perception scale (PPS) is designed to cover both the E, P, and A factors in the balanced proportion. The PPS is the first designed subjective scale to quantitatively assess all fundamental perceptual dimensions of sound [52]. Each dimension (factor) is composed of the three APs. Furthermore, the reduction of the unnecessary variances in the future subjective scale is achieved by the exclusion of the irrelevant items. It simplifies the subjective scale construction but does not ignore any important perception to the acoustic environment. The details of the PPS will be explained in Section 2.2 Questionnaire design. So far there is a lack of the generally applicable, reliable, and valid subjective scale about the fundamental structure of acoustic perceptual influences. A step-by-step statistical testing [56] is required for a successful subjective scale development. The reliability test was applied in this study to evaluate the ability of the PPS in assessing the internal consistency of the APs in constructing the proposed latent factors. Moreover, the different statistical tests regarding content validity, construct validity, and concurrent validity were applied to evaluate the accuracy of the PPS in assessing the hypothetical structure of the acoustic perceptual influence. The details of tests were explained in the sections 2.3. The confirmation of the structure of the acoustic perceptual influence is essential to the development of the subjective scale construction for acoustic environments.

A good subjective scale for the assessment of an acoustic environment should involve not only the assessments of human perceptual influences but also the assessments of other possible psychological responses. It is because numerous psychological responses such as mental health risks [53, 57, 58], discomfort [59, 60], performance drops [61, 62], drops of working productivity [63, 64], dissatisfaction [65], and behavioral changes [66] are also related to the acoustic environment. However, a limited amount of the available scales in assessing psychological responses increases the difficulty in a concurrent validity test of an acoustic subjective scale. This restricted the selections of the assessed sound type and the assessed psychological responses (see sections 2.1 and 2.2). Among the psychological responses more related to the general sound quality, there is a growing awareness of the assessments of the subjects' responses of anxiety [67] and stress [68]. Especially in hospital settings such as wards and clinics, the avoidance of responses of stress [69] and anxiety [70] from the environments is essential to improve health care quality of patients [71]. And hence a well-developed clinical psychometric tool, modified dental anxiety scale (MDAS) [72-74], was designed for the assessments of the subjects' response of anxiety. The effects of the acoustic perceptual influences on the other psychological responses were comprehensively assessed with the help of the concurrent applications of the PPS, the MDAS, and the assessments of the other acoustic perceptions.

The minimization of negative environmental influences on people is a basic criterion of a good system or equipment design. It relies on the fundamental knowledge of human-environment interactions. To date there have not been a well validated subjective scale about the fundamental structure of acoustic perceptual influences. Therefore, this study aimed to (1) evaluate the psychometric properties of the PPS as well as its ability to illustrate the fundamental structure of acoustic perceptual influences, and to (2) analyze how the latent factors behind the PPS affected the other psychological responses. The importance of the PPS in the subjective scale construction for acoustic environments would be showed, if the other psychological responses can be explained by the fundamental perceptual influence. The results gave the guidance on the measures of subjective responses to acoustic environments in a more valid and reliable approach.

2. Material and methods

2.1. Sampling

2.1.1. Selection of the assessed sound types

The considered criteria of the assessed sound type in the PPS application were as follows:

a) It has a great contribution to an acoustic environment;

b) It is not rare;

c) It is impressive and can be explained explicitly;

d) It possibly affects the subjects' perceptions of an acoustic environment;

e) The sustained perceptual influence on subjects remains after their exposure;

f) The perceptual influence is related to the sound quality not only its energy content;

g) The perceptual influence possibly affects the other subjects' psychological response;

h) There is a well-developed assessment for the related psychological response.

Dental scaling sounds from ultrasonic dental scalers [75, 76] contributed the significant changes in the sound pressure level and the spectrum content of the acoustic environment [77]. Moreover, dental scaling is a common experience in Hong Kong because basic dental service is provided to primary school and university students. Numerous studies found a relationship between the acoustic environment and subjects' psychological responses [78-80], especially dental anxiety as an assessable psychological response [81]. Hence, the perceptual influence from dental scaling sounds were selected to be evaluated by the PPS in this study. Besides, the continuous perceptual influence was tested by the correlations between the results from the test and retest (see section 2.3.1.).

2.1.2. Subjects

The questionnaire was distributed to the students in the universities with student dental service so that all enrolled subjects would have the experience of dental scaling sounds. Also, university students were the subject group with the lower chances of having hearing problems [82], suffering occupational noise exposure, and having difficulties in the questionnaire completion. The subjects who had the known hearing problems, lived or worked in a noisy environment, or had no experience of dental scaling sounds in the last six months were excluded in the study. In order to prevent the influence from other significant noise sources, the questionnaire survey was conducted in the indoor environment with the background noise level below 50 dB. This research complied with the tenets of the Declaration of Helsinki and was approved by the Institutional Review Board of the University of Hong Kong/Hospital Authority Hong Kong West Cluster (Reference Number: UW 17-088). Written inform consent was obtained from each participant.

2.1.3. Sample size calculation

Nine variables and twenty-one parameters (nine factor loadings, nine error variances and three factor covariances) were included in the three-factor model (EPA model) behind the PPS. The minimum sample size was calculated to be 90 or 105 based on the rule of ten subjects per variable [83] or the rule of five subjects per parameter [84]. As the response rate was predicted to be 70%, the minimum number of the questionnaire surveys was calculated to be 150. A total of 180 questionnaires were decided to be distributed after considering the chance of having the subject exclusion.

2.2. Questionnaire design

Three parts were included in the self-administered questionnaires of the study (see Table 1). The subjects' background information, dental anxiety level and perceptions to dental scaling sounds were recorded. In part II, the score of each MDAS question was ranged from 1 to 5 corresponding to the rating of "Not anxious", "Slightly anxious", "Fairly anxious", Very anxious", or "Extremely anxious". For example, subjects needed to rate on the hypothesized condition "If you were about to have your TEETH SCALED AND POLISHED, how would you feel?" (MDAS3). The total MDAS score ≥ 19 was defined as high dental anxiety [74]. Since the dental anxiety is a long-term psychological influence [85, 86] from the environment, the continuous perceptual influence from dental scaling sounds rather than the perception to a recorded dental scaling sound was assessed in this study. In part III, the score of the seven levels between each bipolar AP was ranged from -3 to 3. For example, the seven levels of the AP "Quiet-Noisy" were "Extremely Quiet" (-3), "Quite Quiet" (-2), "Slightly Quiet" (-1), "Equally" (0), "Slightly Noisy" (1), "Quite Noisy" (2), and "Extremely Noisy" (3). The first nine questions of part III were the PPS. It is the specific set of nine semantic pairs that resolve human response along the three fundamental perceptual dimensions of sound (see Table 1). The hypothetical latent factors were constructed by the perceptions about the general judgement (E), the energy content (P), and the temporal and spectral content (A) of sound. The E, P, and A scores were defined to be the sum of the three corresponding APs in the factors. The total EPA score was defined to be the sum of all nine APs in the PPS. The remained questions in part III were the assessments of the nine pairs of the selected perceptions. All the level of statistical significance was set at .05. All data in the statistical analysis were coded and analyzed by the commercial package SPSS, version 23.0 (IBM Corp., Armonk, NY, USA).

Table 1
A summary of the questions in the self-administrated questionnaire survey.

Part	**Question (*Latent Variable*)**	**Number of Questions**	**Scale Type**
I: Personal background	Age, gender, possession of hearing problems, and living and working environments	4	Nominal
II: Dental anxiety level	**Modified dental anxiety scale (MDAS):** Anxiety levels to the five hypothesized conditions (*MDAS score*)	5	Five-point Likert scale
III: Perceptions to dental scaling sounds	**Psychoacoustics perception scale (PPS):** Quiet-Noisy, Relaxed-Tense, Pleasant-Unpleasant (*Evaluation: E score*); Quiet-Loud, Light-Heavy, and Weak-Strong (*Potency: P score*); Deep-Metallic, Low-High, and Dull-Sharp (*Activity: A score*)	9	Semantic differential scale
	Other perceptions: Warm-Cold, Comfortable-Uncomfortable, Like-Dislike, Calming-Agitating, Gentle-Violent, Soft-Hard, Pleasing-Annoying, Not Fear-Fear, and Smooth-Rough	9	Semantic differential scale

2.3. Psychometric properties of the PPS

2.3.1. Reliability

The Cronbach's α reliability tests were applied to check the internal consistencies of the items in the E, P, and A factors. The degree of the internal consistency was represented by the reliability coefficient (Cronbach's α). The Cronbach's α > .80, .70, or .60 shows a good, acceptable, or questionable internal consistency of the items in a factor [87]. The retest of the scale was conducted to 10% of the subjects after one week of their first test. The retest reliability was assessed by the retest

Cronbach's α. Moreover, the consistence of the ratings was assessed by the Pearson correlation coefficients between the results of the test and retest.

2.3.2. Validity

The validity was constructed if and only if the model scores could reflect the hypothetical framework. For this study, the validity was constructed for the EPA model behind the PPS in representing the fundamental structure of acoustic perceptual influences. In the stage of the questionnaire design, **face validity** was the qualitative analysis of the appropriateness of the item selection while **content validity** was the quantitative analysis from the experts' agreement on the items. Content validity ratio (CVR) [88] and content validity index (CVI) [89, 90] were the two numerical indexes of the experts' agreement. **Construct validity** was a series of the statistical tests on the appropriateness of the inferential structure in the assessments. Confirmatory factor analysis (CFA) was performed to the EPA model behind the PPS. The goodness of model fit [91] was commonly suggested by the cutoff-values [92, 93] of the ratio of Chi-square to degree of freedom (X^2/df) ≤ 2, root mean square error of approximation (RMSEA) < .06, comparative fit index (CFI) ≥ .95, Tucker–Lewis index (TLI) ≥ .95, and Akaike information criterion (AIC) as smaller as better. In addition, the invariance tests across gender were conducted by step-by-step introducing the constraints of the invariances about the configure, metric, scalar, factor covariance, and separate or joint error variance on the EPA model [94, 95]. The average variance extracted (AVE) and composite reliability (CR) were computed using the standardized loadings in the CFA result. The importance of the factors in the EPA model was also assessed by the calculated their CR and AVE.

After that, the ability of the E, P, and A factors in predicting the other psychological responses (other perceptions and dental anxiety level) was tested by the regression analysis. The separate attributions of the factors on the other perceptions were tested by the stepwise multiple linear regressions for the individual E, P, and A scores as the independent variables. The joint attribution of the factors on the other perceptions was tested by the simple linear regressions for the total EPA score as an independent variable. After that, a stepwise multiple linear regression was applied to the MDAS score with all other variables as input. The **concurrent validity** would be supported if the MDAS score was associated with the latent factor(s) in the PPS.

3. Results

3.1. Statistical description of the sample

Total 180 questionnaires were distributed to students in the three universities (the University of Hong Kong, the Chinese University of Hong Kong and the Hong Kong Polytechnic University) with student dental service. The number of the returned questionnaires was 145 (response rate = 80.6%). Seventeen subjects were further excluded in the study because of the incompletion (5), the reports of the noisy living environments such as construction sites (6) and busy roads (2), and the reports of the known hearing problems such as mid-ear impairment (1) and tinnitus (3). Therefore, the number of the eligible subjects ($N = 128$) fulfilled the requirement of the minimum sample size of 105. 60.9% of the subjects were male while 39.1% were female. The average age of the subjects was 22.6 years ($SD = 3.1$). About one fifth (19.5%) of the subjects were in high dental anxiety. The distribution of the survey results is shown in Fig. 2.

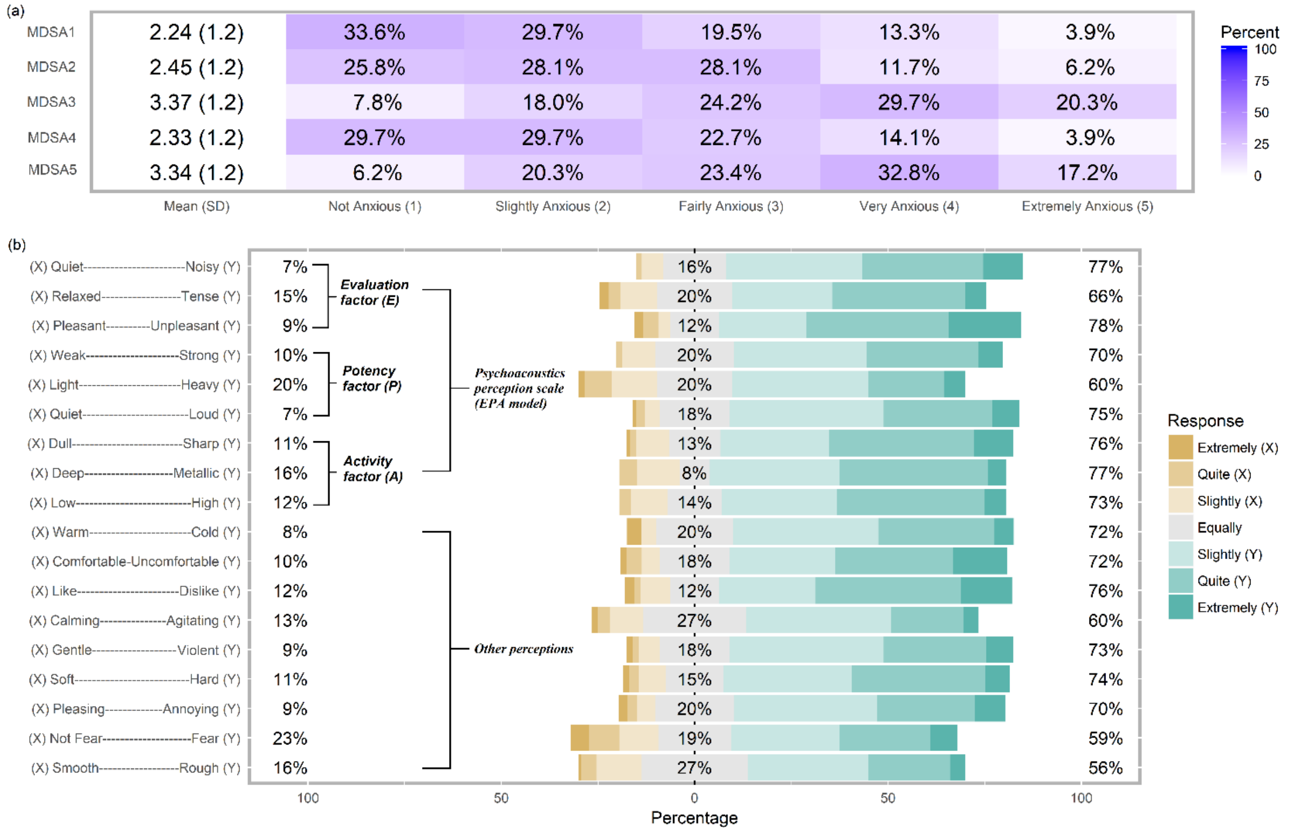

Fig. 2. Distribution of the survey results: (a) a full-stacked bar chart of the questions in the modified dental anxiety scale (MDAS1-5); (b) a diverging stacked bar chart of the subjects' perceptions towards dental scaling sounds.

3.2. *Psychometric properties*

3.2.1. *Reliability*

Thirteen subjects (10.6% of the 128 subjects) were asked to complete the questionnaire again after one week of their first test. In the item level, all the Person correlation coefficients between the test and retest of each question were > .90 indicating the good consistency of the ratings in the two assessments (*ps* < *.001*). The results showed the perceptual influence of the acoustic environment on the subjects was sustained. In the factor level, all the test-retest Cronbach's αs of the latent factors in the PPS and the MDAS were > .80 indicating the acceptable internal consistencies of the items in the factors (see Table 2). The Pearson correlation coefficients between the factors in the PPS and the

MDAS score showed that the environmental perceptual influence was correlated with the subjects' dental anxiety level. The CRs and AVEs results will be explained in section 3.2.2.

Table 2
Descriptive statistics, reliability estimates, and inter-correlations of the latent factors in the Psychoacoustics Perception Scale (PPS), and the Pearson correlation coefficients between the scores of the factors in the PPS and the score of the modified dental anxiety scale (MDAS) (N = 128).

Latent factor	No. of Items	Mean (*SD*)	α (retest)	CR	AVE	Correlation Coefficient			
						E	P	A	EPA
Evaluation (E)	3	3.42 (3.29)	.84 (.90)	.81	.59	-	-	-	-
Potency (P)	3	2.66 (3.05)	.85 (.83)	.81	.59	.96	-	-	-
Activity (A)	3	3.30 (3.15)	.85 (.82)	.83	.62	.71	.68	-	-
EPA	9	9.38 (8.26)	.90 (.92)	-	-	-	-	-	-
MDAS score	5	13.73 (4.93)	.89 (.92)	-	-	.42**	.29**	.23*	.37**

Note. *SD* = Standard Deviation; α = Cronbach's α; CR = Composite Reliability; AVE = Average Variance Extracted value; E: the score of Evaluation factor; P: the score of Potency factor; A: the score of Activity factor; EPA: the total score of the E, P, and A factors. *$p < .05$. **$p < .00$l.

3.2.2. Validity

The qualitative **face validity** was supported by the results of the systematic review [52]. The hypothesis of the EPA model was based on the in-depth review of the existing subjective assessments about the human perceptions of sound. Subsequently, the CVR of each question was calculated from the ratings of the nine experts (three dental professionals, three acoustics professionals, and three linguists). Furthermore, the CVIs of the items in the item level (I-CVIs) and in the factor level (S-CVIs) were calculated from the ratings of the five experts (three dentists and two acoustics professionals). The **content validity** was supported by the experts' agreements on the item necessity (all CVRs ≥ .78) and the item relevance to the study aims (all I-CVIs > .89; mean of I-CVIs = .97; all S-CVIs > .90).

The factorial structure of the EPA model was tested by the CFA (see Fig. 3). The high internal reliability (CRs > .80 in Table 1) of the E, P, and A factors revealed the ability of the PPS in assessing the intended concepts. The importance of the factors in the model was in similar (AVEs ~ .60 in Table 1).

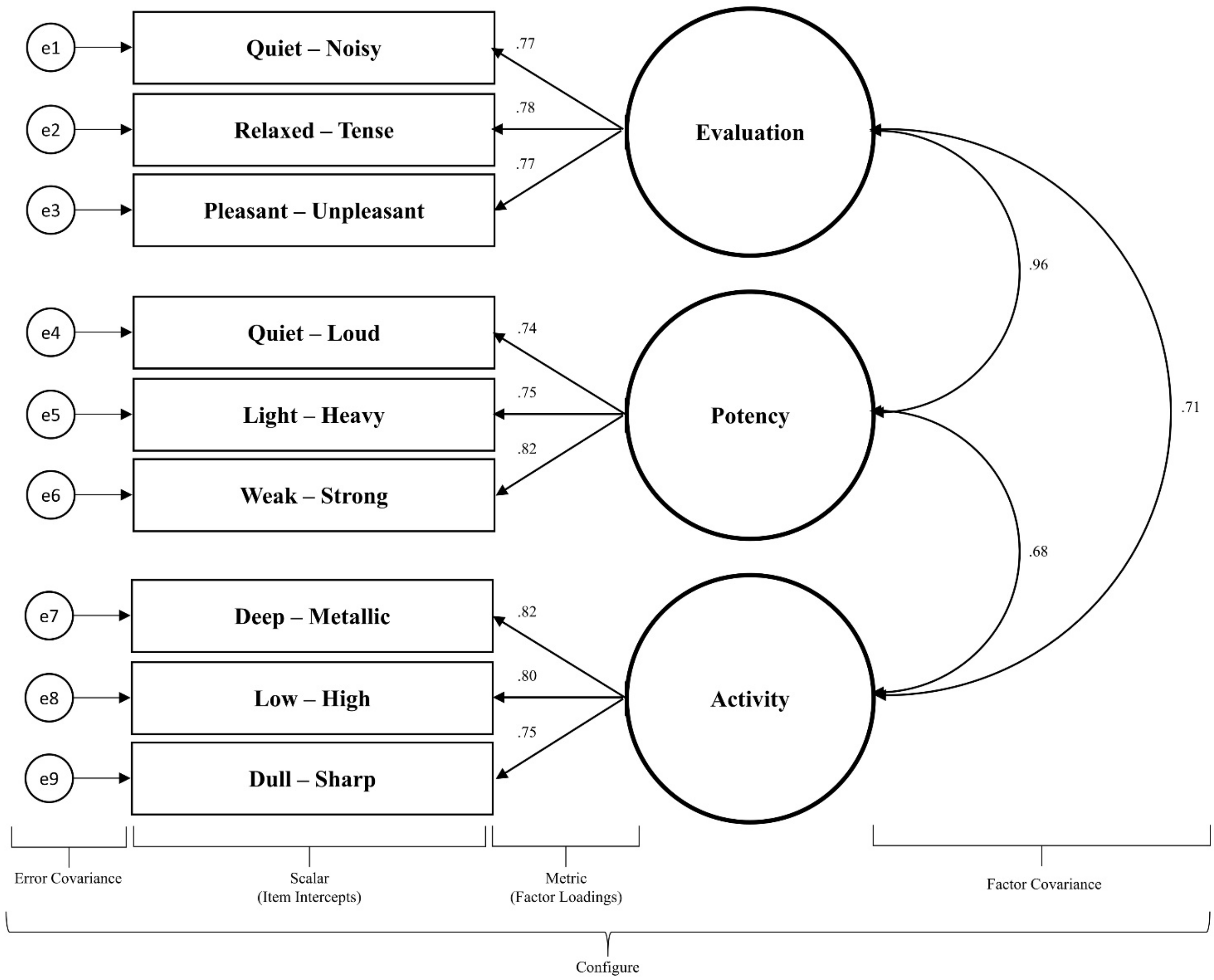

Fig. 3. Results of the confirmatory factor analysis (N = 128) to the factorial structure of the EPA model (Evaluation, Potency, and Activity) behind the Psychoacoustics Perception Scale (PPS)

Furthermore, the EPA model fits in the two subgroups (N_1 = 78 men and N_2 = 50 women) were tested by the invariance tests (T1 to T6) across gender. The constraints of the invariances in the tests were shown in Table 3. Five out of the six invariance tests (except T5) met the cutoff-values of the goodness of model fit indexes. The results showed that the factorial structure of the EPA model was generally invariant across gender except the error variance of the E factor. The **construct validity** was supported by the goodness of model fit indexes in the CFA test results.

Table 3

Invariance tests of the EPA model (Evaluation, Potency, and Activity) behind the psychoacoustics perception scale (PPS) across gender (N = 128; N_1 = 50 males and N_2 = 50 females).

Test	Constraint of the Invariance(s) on the EPA Model	X^2 (*df*)	X^2/df	RMSEA	CFI	TLI	AIC	Comparison	Invariance (Y/N)
T0 [a]	N/A	25.9 (24)	1.08	.025	.997	.994	85.9	N/A	N/A
T1	Configure	49.2 (48)	1.03	.014	.998	.997	169.2	T0 vs T1	Y
T2	Configure and metric	55.5 (54)	1.03	.015	.997	.996	163.5	T1 vs T2	Y
T3	Configure, metric, and scalar	77.3 (63)	1.23	.042	.974	.970	167.3	T2 vs T3	Y
T4	Configure, metric, scalar, and factor covariance	86.2 (69)	1.25	.045	.969	.967	164.2	T3 vs T4	Y
T5	Configure, metric, scalar, factor covariance, and error variance	113.1 (78)	1.45	.060	.936	.941	173.2	T4 vs T5	N
T6	Configure, metric, scalar, factor covariance, and the error variances of the P and A factors.	99.8 (75)	1.33	.051	.955	.957	179.2	T4 vs T6	Y

Note. [a] Confirmatory factor analysis of the EPA model (N = 128) without any subgrouping. X^2 = Chi-square; *df* = Degree of Freedom; RMSEA = Root Mean Square Error of Approximation (RMSEA); CFI = Comparative Fit Index; TLI = Tucker–Lewis Index; AIC = Akaike Information Criterion. Goodness of model fit required $X^2/df \leq 2$, RMSEA < .06, CFI ≥ .95, TLI ≥ .95, and AIC as smaller as better.

The separate and joint attributions of the E, P, and A factors in predicting the other perceptions were shown in Table 4. The results illustrated that the total EPA score was a significant predictor of the other human perceptions.

Table 4

A summary of regression analysis for the latent factors (Evaluation, Potency, and Activity) in the EPA model behind the Psychoacoustics Perception Scale (PPS) in predicting the other perceptions (N = 128).

Dependent Variable [a]	Regression Model	B_1 (SEB_1)	β_1	B_2 (SEB_2)	β_2	B_3 (SEB_3)	β_3	R^2 (adjusted)
Warm - Cold	$\beta_0 + \beta_1$**E** + β_3**A**	.12 (.04)	.32**	-	-	.13 (.04)	.37**	.61 (.37)
	$\beta_0 + \beta_1$**EPA**	.09 (.01)	.60***	-	-	-	-	.60 (.36)
Comfortable - Uncomfortable	$\beta_0 + \beta_1$**E** + β_3**A**	.10 (.03)	.53***	-	-	.11 (.03)	.27**	.73 (.53)

	$\beta_0 + \beta_1$**EPA**	.11 (.01)	.71***	-	-	-	-	.71 (.51)
Like - Dislike	$\beta_0 + \beta_1$**E** + β_3**A**	.24 (.31)	.61***	-	-	.08 (.03)	.18*	.74 (.55)
	$\beta_0 + \beta_1$**EPA**	.11 (.01)	.72***	-	-	-	-	.72 (.52)
Calming - Agitating	$\beta_0 + \beta_1$**E** + β_2**P** + β_3**A**	.10 (.04)	.27*	.12 (.04)	.32**	.08 (.03)	.20*	.72 (.51)
	$\beta_0 + \beta_1$**EPA**	.10 (.01)	.71***	-	-	-	-	.71 (.51)
Gentle - Violent	$\beta_0 + \beta_1$**E** + β_3**A**	.19 (.03)	.55***	-	-	.10 (.03)	.26**	.75 (.55)
	$\beta_0 + \beta_1$**EPA**	.11 (.01)	.74***	-	-	-	-	.74 (.55)
Soft - Hard	$\beta_0 + \beta_1$**E** + β_3**A**	.21 (.03)	.56***	-	-	.10 (.03)	.24**	.71 (.54)
	$\beta_0 + \beta_1$**EPA**							
Pleasant - Annoying	$\beta_0 + \beta_1$**E** + β_3**A**	.18 (.03)	.49***	-	-	.11 (.03)	.28**	.71 (.51)
	$\beta_0 + \beta_1$**EPA**	.10 (.01)	.72***	-	-	-	-	.72 (.51)
Not Fear - Fear	$\beta_0 + \beta_1$**E**	.25 (.03)	.57***	-	-	-	-	.57 (.33)
	$\beta_0 + \beta_1$**EPA**	.09 (.01)	.55***	-	-	-	-	.55 (.30)
Smooth - Rough	$\beta_0 + \beta_2$**P** + β_3**A**	-	-	.12 (.04)	.33***	.13 (.04)	.33***	.60 (.36)
	$\beta_0 + \beta_1$**EPA**	.08 (.01)	.60***	-	-	-	-	.60 (.37)

Note. [a] A higher perception score indicated a tendency to the right-side perception. E: the score of Evaluation factor; P: the score of Potency factor; A: the score of Activity factor; EPA: the total score of the E, P, and A factors. **p* < .05. ***p* < .0l. ****p* < .00l.

Age, gender, E score, and the score of the fear perception were the four remained variables (predictors) in the final model of the stepwise multiple linear regression of the MDAS score (see Table 5). The four predictors in the final model explained 34.6% of the variance ($R^2 = .35$, $F(4,123) = 16.3$, $p < .001$). The mean MDAS score of the males was found to be 2.0 units higher than that of the females. Also, the mean MDAS score of the subjects was significantly decreased by .43 units for each unit increment of the subjects' age, increased by 1.3 units for each unit increment of the score of the fear perception, and increased by .36 units for each unit increment of the E score. The association of the E score and the MDAS score supported the **concurrent validity** of the PPS (see Fig. 4).

Table 5

A summary of the stepwise multiple linear regression for the variables in predicting the subjects' dental anxiety level (the modified dental anxiety scale score) (*N* = 128).

Remained Variable	B	SEB	*β*	95% CI	t	*p*
Gender						
Male	2.0	.77	.19	[.43, 3.5]	2.5	.012

Female ^						
Age	- .43	.12	-.27	[-.67, -.19]	-3.6	< .001
Fear perception [a]	1.3	.28	.42	[.73, 1.8]	4.6	< .001
Evaluation score	.36	.12	.27	[.12, .60]	3.0	.003
Intercept	19.9	2.7	-	[14.6, 25.3]	7.4	< .001

Note. [a] A higher score of the fear perception indicated a tendency to the rating from “extremely not fear” to “extremely fear”. CI = confidence interval for B. ^ Reference group. $R^2 = .35$ (adjusted $R^2 = .33$), $F(4,123) = 16.3$, $p < .001$.

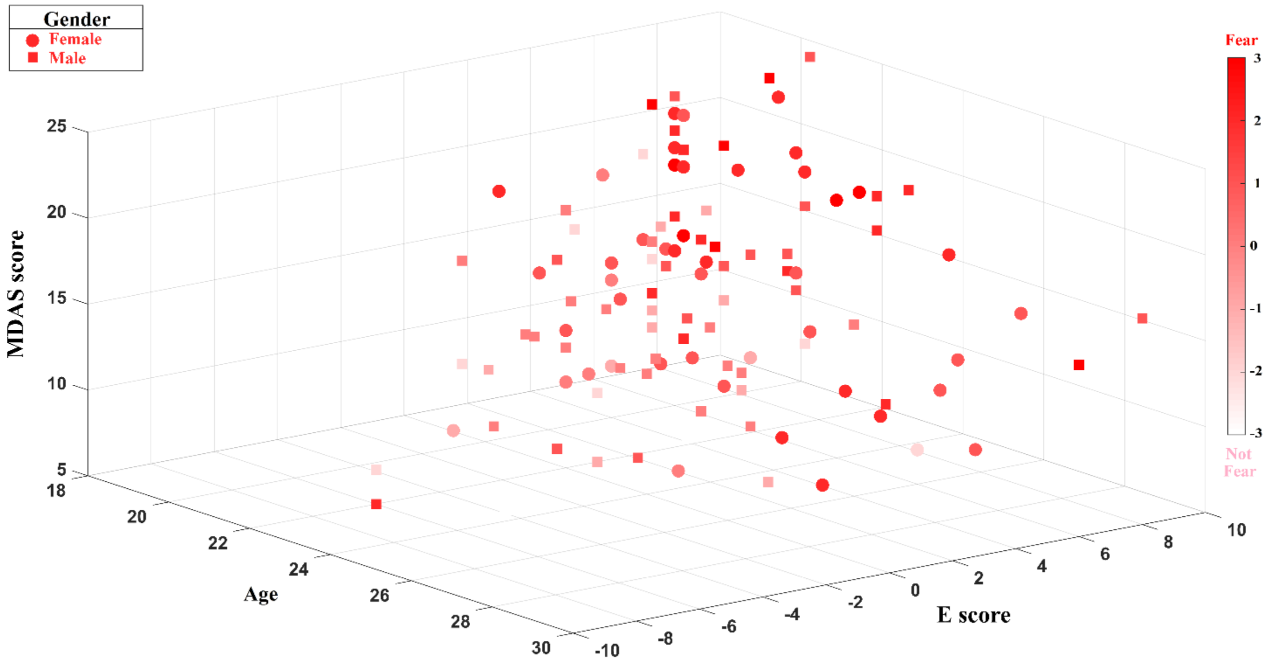

Fig. 4. A 3D scatter plot of the subjects’ modified dental anxiety scale (MDSA) score against their age and the score of the evaluation (E) factor in the Psychoacoustics Perception Scale (PPS).

4. Discussion

4.1. Principal results

Sound is inseparable from daily life. The perceptual influences of sound cannot be denoted easily by the vague words such as good, bad, want, or unwanted. The quantitative assessment of the perceptions requires the comprehensive subjective scale construction. First, the experts’ agreements on the necessity, relevance, and appropriateness of the paired perceptions in the PPS to assess the fundamental perceptual dimensions of sound were achieved. Secondly, the test-retest Cronbach's αs and the CRs of the E, P, and A factors illustrated the acceptable internal reliabilities in constructing the latent factors behind the PPS. The sustained perceptual influence of the acoustic environment on the subjects was also examined by the consistency of the ratings in the test and retest. Thirdly, the existence of the proposed factorial structure of the EPA model behind the PPS was verified by the goodness of model fit indexes in the CFA and the invariance tests. Furthermore, the structure of the human perceptual influence was generally invariant across gender except the error variance of the E factor. As there were many other factors affecting the subjects' judgement of sound such as the subjects' experience, background, culture, and preference, it is reasonable for the error variance of the E factor to be invariant across gender. Those results showed the ability of the PPS in illustrating the fundamental structure of the acoustic perceptual influence.

More importantly, the PPS invention promoted the understanding of the acoustic perceptual influence from the item level to the factor level. In the past, the non-standardization of the subjective scales for acoustic environments caused the problems not only on the validity and reliability of the scales, but also on the comparability and generality of the results in the different studies. In the regression analysis of the other perceptions, the ability of the latent factors as the predictors of the other perceptions was illustrated. The attribution of the A factor to most of the other perceptions implied that the perceptual influence from the temporal and spectral content of the acoustic environment will affect the subjects' perceptions. It also explained why objective noise level assessments are not enough to estimate all the acoustic environmental influence on people. In the last step of the step-wise multiple regression of the MDAS score, the explained variance was found to be significantly higher in the four-predicator model (R^2 = .35, F (4,123) = 16.3, p < .001) than that in the three-predictor model (R^2 = .30, F (3,124) = 17.6, p < .001) after introducing the E score as a predictor. The results disclosed that the dental anxiety development was a complex process and was contributed from the perceptual influence of the subjects' evaluation on the dental scaling sounds. The analysis of the latent factors under the acoustic perceptual influence hence provided the additional understanding in the environmental influence on the subjects' psychological responses.

The similar AVEs of the E, P, and A factors demonstrated that the importance of the factors in the EPA model was comparable. The joint attribution of the factor could be represented by the total EPA score. Although the combination of the factor attributions was different for the different perceptions, the joint factor attribution was meaningful for all perceptions. The positive linear regression results presented with the capability of the total EPA score in predicting the other perceptions.

4.2. Practical significance

Environmental evaluation, prevention, and control are the three indivisible elements [96] in building and environmental acoustics. Since the physical acoustic parameters are more easily predicted and measured than the human subjective responses, the noise monitoring [97-99], noise prevention from the better environmental designs [100, 101] and prediction methods [102-108], noise control measures [109-112], and noise index development [113] were mainly focused on the evaluation of the objective parameters. Nowadays, the analysis of the human-environment interactions is essential for the advances in building and environmental acoustics (see Fig. 5). A good environmental evaluation should contain both objective and subjective assessments. This provided guidance on the development of the subjective scale construction for acoustic environments with the PPS application. The quantification of the acoustic perceptual influences from the general judgement, the energy content and the temporal and spectral content of sound can be achieved by calculating the E, P, and A scores of the EPA model behind the PPS. The overall perceptual influence can also be obtained by calculating the total EPA score. The PPS application in the future subjective assessments will make the assessment results more valid, reliable, comparable, analytical, and representative. Moreover, the PPS application only restricted the inclusion of the nine basic assessed APs, but not restricted the selection of the other psychological responses. The concurrent applications of the PPS and the assessments of the other responses will allow the researchers to have an advanced understanding of the acoustic perceptual influence on occupants. It hopes to strengthen the statistical power of the discussion between physical environments and subjects' responses [43, 114, 115] and reduce the chances of having the mismatch between the assessments [116, 117]. Furthermore, a valid and reliable method for the subjective scale construction is critical to the future forecast work of the environmental influence.

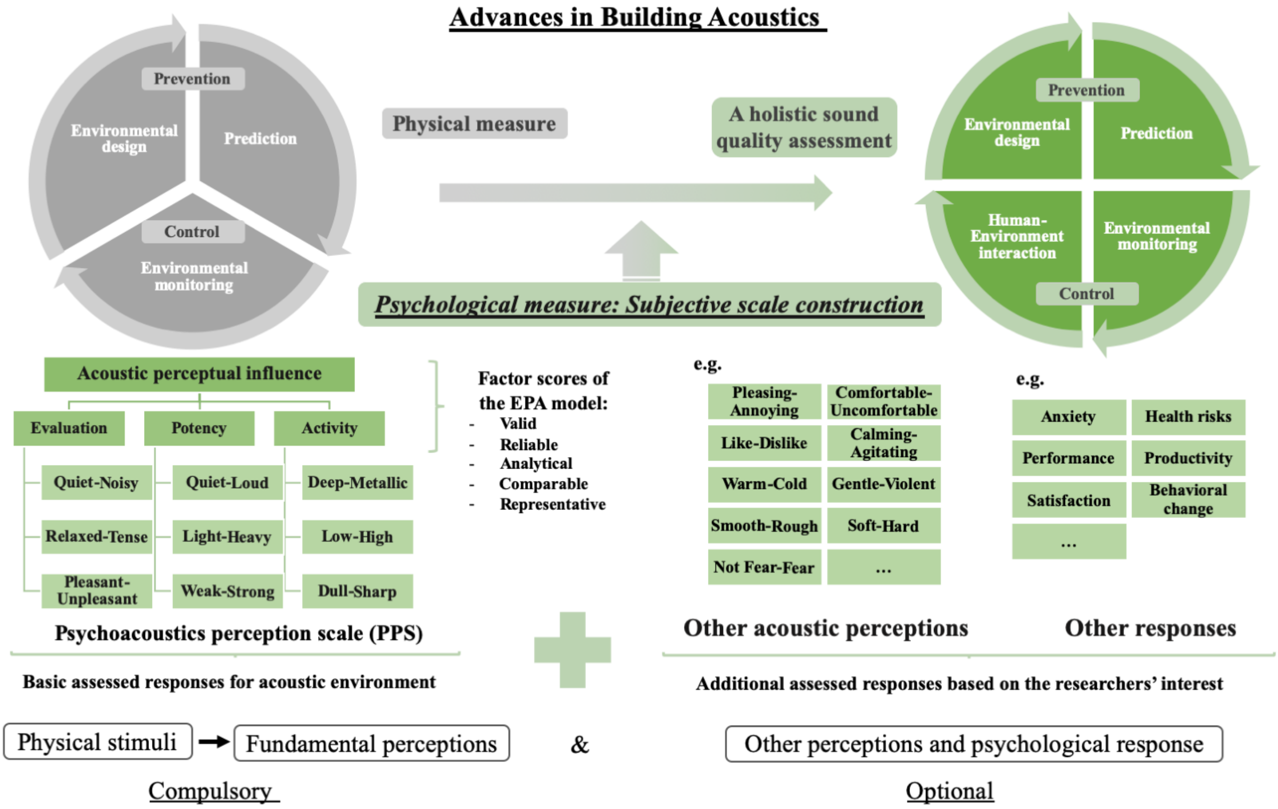

Fig. 5. A summary of the way to have a holistic sound quality assessment in building acoustics.

4.3. Limitations and future work

One of the necessities of having the PPS was that there had been a lack of valid and standardized subjective scale for sound evaluation. However, the comparison of the non-valid and non-standardized scales in other acoustic studies and the PPS was not effective. Also, the aim of this study was to investigate the psychometric properties of the PPS in assessing the fundamental structure of the acoustic perceptual influences but not the ability of the PPS to illustrate the instantaneous feedback to the physical changes. The replay of sound and the analysis of the correlations between physical quantities and the scale were therefore not included. Nonetheless, there was a need for the further comparison between the abilities of PPS and the scales in the other acoustic studies in assessing the subjective responses of people. In addition, the number of psychological responses was limited in the study because a little well-developed psychometric tool was available. After the reliability and validity of the PPS were confirmed, the further analysis between the human perceptual influence of sound and the other psychological responses would become possible. The applicability and generality of the PPS to other sound types and the role of the E, P, A factors in human-environment interactions also need to be further investigated. Moreover, the invariance tests in the study only covered the discussion about the model fits across gender. The invariance tests of the factorial structure of the EPA model across other variables such as nation, age group and occupation should also be considered in future studies.

5. Conclusions

The PPS was found to be a valid, reliable and applicable psychometric tool to quantitatively assess the acoustic perceptual influence from the perceptions of the general judgement, energy content and temporal and spectral content of sound. The reliability of the measures on the E, P, and A factors was verified by their test-retest Cronbach's αs and CRs which indicated the acceptable internal consistency. In general, the factorial structure (configure, metric, scalar, factor covariance, and the error variances of the P and A factors) of the EPA model behind the PPS was invariant across gender. The total EPA score, which represents the joint attribution of the E, P, and A factors, was a significant predictor of the other perceptions. The effect of the perceptual influence from the subjects' general judgement of sound on the subjects' dental anxiety level was also exposed. The results provided the applicable guideline on the subjective scale construction for acoustic environments and gave the insights into the development of the subjective scale construction for acoustic environments. More applications of the PPS to other acoustic environments are needed to assess its generality in future studies.

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