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Title

A systematic review of human perceptual dimensions of sound: Meta-analysis of semantic differential method applications to indoor and outdoor sounds

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Acoustics index development

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Abstract

People spend most of their lives in buildings and unavoidably perceive the sound in their surroundings. The understanding of human perceptual dimensions of sound is important for obtaining the occupant-oriented decision-making in future building designs. This paper presented a systematic review of the studies in analysing the human perceptual dimensions of sound. Studies with the use of principal component analysis (PCA) or factor analysis (FA) to their semantic differential method (SDM) applications of the subjective measurements of the human perceptions of sound were identified in the study selection process and included in the quantitative synthesis. Forty-five eligible studies covered a wide range of sounds in the general indoor environment, machines, building facilities, human voices, human activities, transports, and urban environment. The meta-analysis of factor analysis integrated the data from the thirty-nine individual studies and generated the evidence-based results of the review. Three major perceptual dimensions of sound were found to be "Evaluation", "Potency" and "Activity" which referred to the human general judgement, the sensation to the magnitude, and the sensation to the temporal and spectral compositions of the perceived sound respectively. It implied that not only the energy level but also the energy distribution of the stimulations in the environment would affect our perceptions. The review also provided the insights of the selection of the suitable perceptions, the suggestions to the SDM applications, and the acoustics index development for the quantification of the psychological impacts of sound on the occupants in the indoor and outdoor environment. It gave the directions of the future psychoacoustics studies to analyse the correlations between the objective stimulations and the human perceptions.

1. Introduction

Sound is inseparable from our daily life. As people spend most of their lives in buildings, it is important to investigate the acoustical environmental influences on human perceptions in the field of building acoustics [1]. Acoustic comfort is one of the key elements in the indoor environmental quality assessments [2]. Human perception of sound is the composite of both auditory and non-auditory responses to stimulations in the surroundings. Auditory responses are regarding human abilities of sound detection in creating a hearing sensation of objective stimulations; while non-auditory responses are about human psychological perceptions of stimulations together with their subjective evaluations and effects in their affective states. In general, noise is referred to unwanted sounds in the environment, and is a result of auditory and non-auditory responses. Many studies have showed that noise exposure would cause negative physiological impacts on human bodies such as headache, fatigue [3], tinnitus [4], and hearing loss [5]. The international standard of the protection from hearing loss is no more than 85 dB(A) sound pressure level exposure in any working environment for 40 hours per week [6]. However, the assessments of loudness and sound pressure level have been criticised to be insufficient to explain the effects of noise on people [7-13]. The sound spectrum of the noise in the environment would also have influences on people. Also, the non-auditory effects on health [14] were not negligible. Moreover, the acoustical environment was found to be related to the occupant's productivity [15-17], performance [18, 19], and satisfaction [20], and served as an occupant concern [21] other than the impacts on health. This raised researchers' interest to have both objective and subjective assessments on human interaction with different acoustical environments such as classrooms [22, 23], offices [24], hypermarkets [25], restaurants [26], hostels [27], hospitals [28, 29], and churches [30]. The main purpose of a psychoacoustics approach study is to investigate the correlations between objective sound properties and human subjective perceptions, as well as the mechanism behind human perceptions. The reliability of the measurements and study results would be limited if the measurement tools used in a study are inappropriate. For objective measurements, the measurement precision would be improved by applications of more precise sound recording equipment and well-developed psychoacoustics parameters. Nevertheless, there is no standard of what psychological responses should be measured in assessing human perceptions of sound. The understanding of human psychological perceptual dimensions of sound is essential for the future assessments of environmental influences on people, acoustics index development, and better building designs. A systemic review has been recommended to conclude such issues using meta-analysis [31].

Semantic differential method (SDM) is the psychological measurement tool proposed by Osgood [32] in 1952. The quantitative measurements of the subjective meaning of things were obtained from the subjects' ratings on the bipolar adjective pairs (APs) formed by two opposite meaning descriptors. The meaning of things would then be represented by their position on the semantic spaces contributed by the measured APs. It would provide a general picture of human perceptions of tested objects and facilitate the comparison between the objects instead of only the magnitude estimation of the certain criteria. The dimensionality of the semantic spaces of the objects was dependent on the factor analysis result of the measurements. Also, Osgood discovered that “Evaluation”, “Potency”, and “Activity” were the three major semantic spaces found for human perceptions of things. The first SDM application in studying human perceptual dimensions of sound was carried out by Solomon [33] in 1959. Seven dimensions were found for the subjects' perceptions to twenty passive sonar recordings. Other researchers later had different approaches in SDM applications to various sounds in the environment such as indoor air conditioning sounds [34], sounds in music halls [35], product sounds [36], human voices [37], and outdoor sounds in open public spaces [38]. These studies showed the possibility of SDM application on measuring human perceptions of sound. However, the diversity of selections of APs, AP scales, and analytical methods in SDM applications would create a discrepancy of analytical results of the studies. The selection of suitable APs is hence the first and the most important step in a SDM application. The inclusion of improper or unrelated APs of human perceptions of sound would lengthen the assessment time, decrease the participants' willingness and concentration, limit the sample size, and reduce the internal consistency and reliability of assessments [39]. In contrast, the missing of the important APs would limit the validation and generality of the results. Although some studies [40-42] performed a pilot study of the AP selections prior to their main study, the rules of the suitable AP selections in assessments of human perceptions of sound have not well established. In this systemic review, the importance analysis was conducted to assess the appropriateness of APs in measurements of human perceptions of sound prior to the meta-analysis. It would give insights of the selection of suitable perceptions and SDM application designs for subjective measurements in future studies.

Principal component analysis (PCA) and Factor analysis (FA) [43] are the most common analytical methods applied together with the SDM. Although the mathematical approaches behind these methods are different, the computed analytical results are both useful for the item reduction, and the dimensional analysis of the measurement data. PCA is a computationally efficiency approximate of FA [44] without any assumption of the underlying structure between the measured variables [45]. PCA tackles the dominant patterns in the matrix on creating the PCA-based indices [46], while FA targets on the discovery of the unmeasurable latent factors which underlie the variables. In psychology and the social science studies, numerous approaches would be found in the studies for a particular research question. The findings of the individual studies could be frail because of a small sample size and the varied findings could scatter the valuable information in the studies. Meta-analysis, firstly proposed by Glass in 1976 [47], was a widely used statistical technique to synthesize the similar research findings quantitatively. In order to minimize the bias in the study selection, systematic review is an explicit and reproducible method to identify all empirical evidence of the studies which fulfil the pre-defined eligibility criteria to a particular research question [48]. It also provides more precise data of the similar research findings in a meta-analysis. The flow and required items of the review were clearly stated in the "Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISRMA)" guidelines [49]. Therefore, a systematic review together with a meta-analysis could provide a more accurate and deliberate review in drawing a coherent, useful, generalizable, and evidence-based conclusion [50] from research literatures especially in human related studies compared to traditional literature reviews. Previous studies revealed the feasibility of meta-analyses of factor analysis [51, 52] in investigating the magnitude of relationships between variables. Results of individual studies were extracted and integrated to the pooled data, which were used for the meta-analysis to obtain more reliable results.

The purpose of the study was to have a systematic review in analysing the human perceptual dimensions of sound and their corresponding content. In this systemic review, studies fulfilled the criteria of using SDM in measuring participants' psychological perceptions of sound and using PCA/FA in their data analysis were identified and reviewed. The meta-analysis of factor analysis was applied to the pooled data of these studies to find out human perceptual dimensions of sound. It would provide new knowledge to the understanding of human-environment interactions, the verification of quantitative measurement of subjects' responses to the environment, and the decision-making in future building designs.

2. Material and methods

2.1. Search strategy and selection criteria

The English-language literatures of human studies in measuring human perceptions of sound with SDM applications were systematically searched. This review was restricted to studies of using PCA/FA in their data analysis. The initial search was conducted by using the following electronic bibliographic databases from their commencement to Sept 2017: PubMed, Institute for Scientific Information (ISI) Web of Science, ScienceDirect, Scopus, The Journal of the Acoustical Society of America (JASA), ProQuest Research Library, SciTech Premium Collection, Technology Collection, Medical Database, Natural Science Collection, PsycARTICLES, Research Library: Social Sciences, Biological Science Database, Materials Science & Engineering Database, Research Library: Health & Medicine, Research Library: Science & Technology, British Nursing Index, Library & Information Science Abstracts (LISA), ComDisDome, etc. (via ProQuest). The core search was based on the terms related to the measurement methods (e.g., "semantic differential" and "adjective pairs"), combined with the terms for acoustic studies (e.g., "sound" and "noise", and the terms for data analysis methods (e.g., "principal component analysis", "factor analysis" and "dimension"). The full search strategy is provided in supplemental Appendix A. Additional studies were identified by reference linkage.

The inclusion criteria were as follows:

1. Published and accessible English-language studies
2. Acoustics related studies
3. Not testing for multiple sensations such as hearing and visual sensations
4. Description of SDM applications: APs used, number of participants, number of assessed sounds
5. Description of data analysis methods and results; PCA/FA, rotation methods, details of included APs in PCA/FA, number of found components/factors, details of APs in components/factors
6. Description of component/factor loadings in PCA/FA results (the criterion for meta-analysis)

2.2. *Data extraction*

The abstract and full text of each relevant study were independently reviewed by two investigators (KWM and CMM). *κ* Statistics were used to evaluate the inter-reader agreement. A reviewer (HMW) was consulted to resolve disagreements. The review of abstracts and full texts followed the PRISMA guidelines. A data extraction sheet was developed, including the interpretation of methodologies and results. The extracted information included the following: methodology (study designs, settings, participants, variables, measurements, and statistical methods) and outcome (management of missing data, and presented statistical results, and result interpretations). A data extraction sheet was prepared by one reviewer (KWM) from the included eligible studies. The sheet was then checked by the other reviewers (CMM and HMW) to reduce bias and minimize errors. Disagreements were resolved by the consensus of the three reviewers.

2.3. *Importance analysis and paring of reviewed APs*

As the selection and pairing of descriptors in AP formations were not identical in eligible studies, the importance analysis of this review was started at the descriptor level. Every descriptor included in the studies were first extracted with the counts on their numbers of included studies (N_{stu}), participants, and measurements. Varimax rotation is the most common orthogonal rotation option [53] in PCA/FA to generate uncorrelated components/factors which are ranked in the order of the percentage of the total variance be explained, in the analytical solutions. Thus, the importance analysis was based on the varimax-rotated solutions of the studies. If the PCA/FA solutions of the studies was not varimax-rotated, the varimax rotation of the solutions would be applied to the provided information of the correlation between the variables in the studies. The represented component/factor of the descriptors were the component/factor of the highest loading. The proportion variance explained by the component/factor was usually below 10% if it is the 4th or later component/factor in the solutions. The importance score was set from 4 to 1 corresponding to the descriptor in the 1st, 2nd, 3rd, and 4th component/factor of the solutions of the studies. Zero important score was referred to the descriptor in the 5th or later component/factor or not in any component/factor of the solutions. The descriptor with N_{stu} less than 6 or the average importance score per study/measurement less than 2 would be excluded in the meta-analysis. The APs contained the remained descriptors would then be assembled to the reviewed APs according to the measured perceptions.

2.4. *Meta-analysis procedures*

In meta-analyses, syntheses of research findings were based on analyses of pooled data from individual studies [50]. It was necessary for the data in the meta-analysis of the studies to fulfil all the eligibility criteria in the literature searching inter-reader agreement and importance analysis. Those advance procedures minimized the chances of missing valuable information about the human perceptual dimensions of sound but kept the homogeneity of the data in drawing a coherent, useful, generalizable, and evidence-based conclusion from the individual studies. Differences between PCA and FA were in determination of the number of retained components/factors and magnitudes of loadings in the solutions, but not the discovered patterns by the two methods [44]. Since the data required in meta-analysis of factor analysis was the co-occurrences of reviewed APs in the solutions of the studies, both PCA and FA results were included in the data pooling for meta-analysis of this review. The extraction of similarity coefficients between APs was based on computations of raw co-occurrence matrixes from individual studies and the integration of them with weightings to sample sizes [51, 52] and magnitudes of the loadings. The raw co-occurrence matrix of each eligible study was computed from the count of the co-occurrence of APs in the component/factor of the highest loading. The weighted co-occurrence matrix of each eligible study was then generated by considering the number of co-measurements in the study and the magnitude of the highest loading of APs. The pooled correlation matrix was then computed by summing the weighted matrices and divided by the total number of co-measurements between column and row APs in the studies. The elements of the matrix were similarity coefficients of column and row APs. For example, if there were total three studies contained the co-measurement of API and APII, API and APII co-occurred in the component of the highest loading for study I ($n_I = 50$) and study II ($n_{II} = 90$), but not for study III ($n_{III} = 40$). Also, the weightings to the magnitudes of the loadings in study I and study II are 0.9 and 0.7. The similarity coefficients of API and APII would then be (50*0.9 + 90*0.7 + 40*0)/ (50 + 90 + 40) = 0.6. PCA rather than FA was used in the meta-analysis of factor analysis, as there was no presumption of the underlying structure between selected APs. Screen plots were performed to each PCA to identify the number of components with eigenvalue larger than 1. Different PCA solutions for different combinations of selected APs, different rotation methods, and different numbers of retained components were conducted to acquire the best understanding of human perceptual dimensions of sound.

3. Results

3.1. Selection of eligible studies

Total 3164 citations were identified from electronic databases (PubMed, ISI Web of Science, ScienceDirect, Scopus, JASA, and ProQuest). Forty-five articles were eligible for full-text assessment after removal of duplications and screening of relevant articles. The inter-reader *κ* agreement was 0.84 ± 0.05

(mean ± SE). The flow diagram of the search process is shown in Fig. 1. Thirty-nine articles were included in the meta-analysis of this review. The inter-reader agreement was 0.83 ± 0.12.

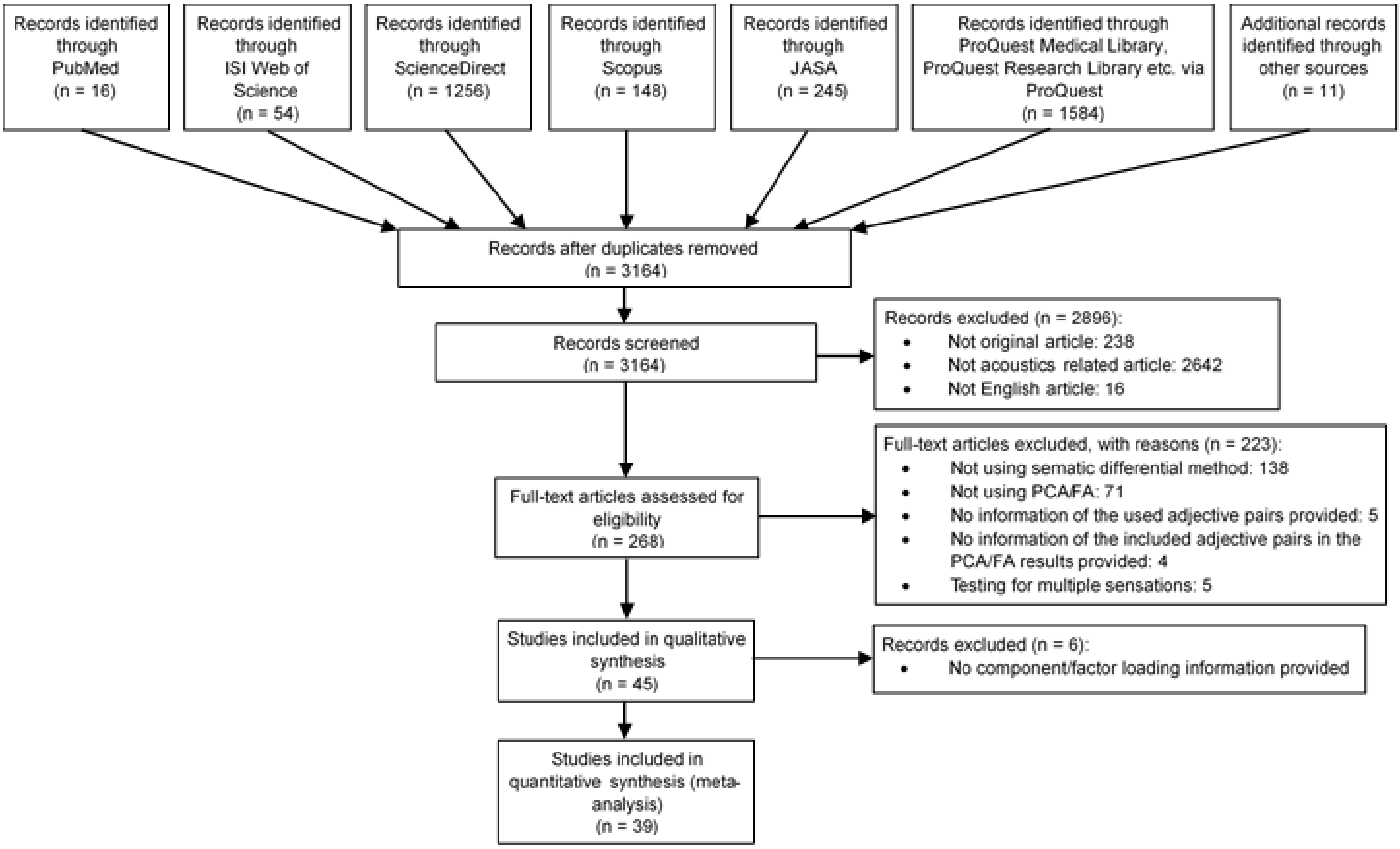

Fig. 1. PRISMA flow diagram of the study selection process. PRISMA, Preferred Reporting Items for Systematic Reviews and Meta-Analyses.

3.2. *Summary of the studies in quantitative synthesis*

All the 45 included articles were published and accessible English-language studies after 1959. Total 5677 participants involved in these studies having total 828,756 ratings on 1365 different sounds (see Table 1). The studies covered SDM applications of participants' perceptions to a wide range of indoor sounds (from general environment [35, 54-57], machines and building facilities [33, 34, 36, 42, 58-63], human voices [37, 40, 64-68], human activities [41, 69, 70], and synthetic sounds [71-76]) and outdoor sounds (from transportation [77-82] and urban environment [38, 83-89]). The APs used in the studies were contributed from 483 different descriptors of sound and 203 of their antonym with the prefix Un/In or adding Not. The occurrence frequency of descriptors in the studies is showed in Table B.1. The numbers of APs used (N_{ap}) and assessed sounds in a measurement (N_s) of SDM applications were ranged from 5 to 82 (Median = *Mdn* = 15) and from 1 to 145 (*Mdn* = 15). The number of included participants (N_p) and total ratings in the studies (N_{total}) were ranged from 8 to 1762 (*Mdn* = 39) and 150 to 120,000 (*Mdn* = 8880). Among the studies, 93.3% used the odd-value scale in their SDM applications. 7-point scale was most common in SDM applications as recommended by Osgood [32]. 57.8% of the studies used PCA in their data analysis while others used FA. Seven studies were required to have the additional varimax-rotation on their unrotated solutions for further analysis. 75.6% of the studies had the number of retained components/factors less than 4. Besides, the naming of the retained components/factors varied with different researchers.

Table 1
Summary of the 45 included studies.

Assessed sounds	Year	Number of used adjective pairs, N_{ap}	Number of assessed sounds N_s	Number of ratings per assessment, N_s*N_{ap}	Number of included participants, N_p	Number of total ratings, N_{total} =N_{ap}*N_s*N_p	Scale	Data analysis method	Number of retained components /factors	The first three named components/factors	Reference
9 electric vehicle sounds	2018	12	9	108	31	3,348	7	PCA	3	Power/Sporty, Comfort, and Deepness	[77]
19 different vehicle sounds	2017	12	1	12	1,762	21,144	5	PCA	4	Roughness/Sharpness, Loudness, and Timbre/Richness	[78]
100 acoustic environment compositions	2017	19	8	152	25	3,800	11	PCA	3	Calmness/Relaxation, Dynamics/Vibrancy, and Communication	[54]
A shopping street soundscape	2016	18	1	18	493	8,874	7	PCA	5	Preference, Loudness, and Richness	[83]
24 dental drill sounds (12 operating and 12 idling)	2016	15	24	360	21	7,560	5	FA	2	Metallic and Unpleasant	[42]
A soundwalk in the 4 locations or reproduced soundscapes in the laboratory	2016	19	1	19	72 (23, 18, 15, 16)	1,368	11	PCA	5	Calmness/Relaxation, Communication and Dynamic	[84]
16 can-opening sounds	2016	14	16	224	11	2,464	5	FA^	3	Strength, Texture, and Comfort	[41]
12 window lift modules (6 ascending and 6 descanting)	2016	9	12 (6, 6)	108 (54, 54)	76	8,208	10	PCA	2	Luxuriousness and Uniformity; Luxuriousness and Strength	[79]
72 operation feedback sound	2016	20	72	1,440	26	37,440	7	FA	4	Artificiality, Liveliness, and Gorgeousness	[69]
15 sounds from two harmonic complexes with different fundamental frequencies and combination tones	2015	16	15	240	37	8,880	11	PCA	4	Pleasant, Power, and Temporal Structure	[71]
27 sounds from different cruiser type motorcycles	2015	12	27	324	20	6,480	7	FA^	2	Pleasant and Crispy	[80]
10 synthetic car horn sounds	2015	9	10	90	41	3,690	7	PCA	2	Luxury and Gentle	[81]
4 reproduced and synthesis soundscapes from different urban, environment, foreground sounds	2014	19	4	76	15	1,140	9	PCA	4	Relaxation/Calmness, Dynamics/Vibrancy, and Communication	[85]
15 urban soundscapes	2013	15	1	15	570	8,550	100	PCA	3	-	[86]
18 car interior noise	2013	11	18	198	41	8,118	7	FA	3	Pleasant, Pitch, and Powerful	[82]
8 different urban soundscape recordings	2013	5	8	40	40 (22, 9, 9)	1,600	9	PCA	2	Calmness and Vibrancy	[87]
24 sounds produced by	2012	16	24 (18, 6)	124 (288, 96)	69 (36, 33)	13,536	7	PCA	5	Attention, Roughness, and Familiarity	[36]

Assessed sounds	Year	Number of used adjective pairs, N_{ap}	Number of assessed sounds N_s	Number of ratings per assessment, N_s*N_{ap}	Number of included participants, N_p	Number of total ratings, N_{total} =N_{ap}*N_s*N_p	Scale	Data analysis method	Number of retained components /factors	The first three named components/factors	Reference
domestic appliances											
17 concert halls	2012	27	1	27	310 (236, 74)	8,370	5	PCA	>5	Fidelity and Quality, Power, and Intimacy; Balance and Pitch Quality, Intimacy and wide dynamic range, and Power and Brightness	[35]
100 musical excerpts	2012	8	100	800	150	120,000	9	FA	3	Activity, Brightness, and Fullness	[64]
10 air-conditioner sounds	2011	15	10	150	40	6,000	7	PCA	2	Refreshment and Comfort	[34]#
An urban soundwalk	2011	12	1	12	300	3,600	11	PCA	2	-	[88]#
36 environmental sounds and 36 onomatopoeic representations	2010	13	72	936	20	18,720	7	FA	3	Emotion, Clearness, and Powerful	[55]
An urban soundwalk	2010	28	1	28	491	13,748	7	PCA	4	Relaxation, Communication, and Spatiality	[38]
An urban soundwalk	2010	10	1	10	15	150	7	PCA	2	-	[89] #
100 musical excerpts	2010	8	100	800	35	28,000	9	FA	3	Activity, Brightness, and Fullness	[40]
84 sounds from 5 different air-cleaner	2009	7	84	588	25	14,700	5	PCA	2	Performance and Annoyance	[58] #
36 onomatopoeic representations of natural environmental sounds	2006	13	36	468	8	3,744	7	FA	3	Emotion, Clearness and Powerful	[56]
10 performances of two baroque pieces	2006	40	10	400	44	17,600	9	PCA	2	Stylishness and Success	[72]
Prolonged light floor-impact sounds	2004	21	1	21	9	189	7	FA	4	Comfortable Feeling, Sharp Feeling, and Monotonous Feeling	[70]
40 speaker sounds	2003	19	40	760	20	15,200	7	PCA	2	Voice Quality and Pitch	[59]
145 common sounds	2003	20	145	2,900	32	92,800	7	PCA	4	Harshness, Complexity, and Appeal	[57]
15 sounds of flue organ pipes	2001	82 (35, 34, 13)	5	410 (175, 170, 65)	15	6,150	10	PCA	>5	-	[60]
8 series of sound excerpts	2001	25	8	200	128	25,600	7	FA^	>5	Benevolence, Potency, and Naturalness	[65]
12 harmonic intervals	2000	30	12	360	43	15,480	7	FA	3	Affective and Emotional Evaluation, Sense of Activity, and Potency	[73] #
101 amplitude modulated sounds	1994	12	101	1,212	20	24,240	7	FA^	3	Metallic, Powerful, and Rough	[74]
23 frequency-modulated sounds	1992	12	23	276	20	5,520	7	FA^	3	Metallic, Pleasant, and Clamorous	[75]
30 music excerpts	1992	24	30	720	33	23,760	7	PCA	5	Emotional, Inspiration, and Structural Orderliness	[66]
31 esophageal voices	1988	13	31	403	85	34,255	7	PCA	3	Tempo, Quality, and Pitch	[67]
15 recordings of natural sounds	1985	24	15	360	84	30,240	7	PCA	5	Evaluation, Sharpness/Pitch, and Loudness	[61]
10 Dutch speakers' voices	1983	35	10	350	235	82,250	7	FA	>5	Melodiousness, Articulation Quality, and Voice Quality	[62]
24 Infant cry sounds	1983	15	24	360	39	14,040	7	FA	>5	Affect, Potency, Evaluation	[68] #
30 young female voices	1981	20	30	600	40 (20, 20)	24,000	7	PCA	4	-	[37]
35 spectrally	1974	30	35	1,050	16	16,800	7	FA	4	-	[76]

Assessed sounds	Year	Number of used adjective pairs, N_{ap}	Number of assessed sounds N_s	Number of ratings per assessment, N_s*N_{ap}	Number of included participants, N_p	Number of total ratings, N_{total} =N_{ap}*N_s*N_p	Scale	Data analysis method	Number of retained components /factors	The first three named components/factors	Reference
shaped harmonic complex tones					(8, 8)						
10 speaker sounds	1967	12	10	120	20	2,400	7	FA^	2	Activity and Evaluative	[63]
20 passive sonar recording sounds	1959	35	20	700	50	35,000	7	FA^	>5	Magnitude, Aesthetic, and Evaluative	[33]

Note: PCA, Principal Component Analysis; FA, Factor Analysis with varimax rotation; ^ the studies required to have additional varimax rotation on their solution; # the excluded studies in the meta-analysis due to missing information of component/factor loadings.

3.3. Details of the reviewed APs

Sixty-five descriptors with N_{stu} more than 5 were included in the importance analysis (see Table B.2). 11 descriptors “Pleasant” (N_{stu} = 35), “Unpleasant” (31), “Soft” (29), “Weak” (28), “Rough” (24), “Smooth” (23), “Clam” (22), “Dull” (22), “Hard” (21), “Loud” (21), and “Quite” (21) were included in more than 20 studies. Nine descriptors such as “Far”, “Sad”, “Steady”, “Full”, and “Meaningful” were excluded in further analysis as their average importance score per study/measurement was less than 2. Total 27 APs were grouped and remained for quantitative analyses in this review (see Table 2). In addition, the details of contents of the 27 APs were shown in Table B.3.

Table 2
A summary of the 27 adjective pairs (APs) in the quantitative analyses.

Item	Adjective pairs (Number of included studies)	Pooled correlation matrix#	Initial solution of 20-APs PCA^	4 varimax-rotated component solution of 16-APs PCA	3 varimax-rotated component solution of 9-APs PCA	Related components
AP1	**Pleasant - Unpleasant (36)**	✓	✓	✓ (RC3)	✓ (E)	E
AP2	**Weak - Strong (35)**	✓	✓	✓ (RC4)	✓ (P)	P
AP3	**Rough - Smooth (28)**	✓	✓	✓ (RC3)	-	A, E, P
AP4	**Clear - Not clear (26)**	✓	-	-	-	-
AP5	**Quiet - Loud (24)**	✓	✓	✓ (RC4)	✓ (P)	P
AP6	**Sharp - Dull (22)**	✓	✓	✓ (RC1)	✓ (A)	A
AP7	**Soft - Hard (21)**	✓	✓	✓ (RC1)	-	A, E, P
AP8	**Slow - Fast (21)**	✓	-	-	-	-
AP9	**Calming - Agitating (19)**	✓	✓	✓ (RC1)	-	A, E
AP10	**Simple - Complex (19)**	✓	-	-	-	-
AP11	**Light - Heavy (15)**	✓	✓	✓ (RC4)	✓(P)	P
AP12	**Gentle - Violent (15)**	✓	✓	✓ (RC2)	-	A, E, P
AP13	**Relaxed - Tense (14)**	✓	✓	✓ (RC1)	✓ (E)	E
AP14	**Deep - Metallic (14)**	✓	✓	✓ (RC2)	✓(A)	A
AP15	**Bright - Dark (14)**	✓	✓	✓ (RC1)	-	E, A
AP16	**Comfortable - Uncomfortable (12)**	✓	✓	✓ (RC3)	-	E, P
AP17	**Warm - Cold (12)**	-	-	-	-	E
AP18	**Noisy - Quiet (11)**	✓	✓	✓ (RC3)	✓ (E)	E
AP19	**Boring - Interesting (9)**	✓	-	-	-	-
AP20	**High - Low (9)**	✓	✓	✓ (RC2)	✓ (A)	A

Item	Adjective pairs (Number of included studies)	Pooled correlation matrix#	Initial solution of 20-APs PCA^	4 varimax-rotated component solution of 16-APs PCA	3 varimax-rotated component solution of 9-APs PCA	Related components
AP21	**Natural - Artificial (9)**	-	-	-	-	-
AP22	**Beautiful - Ugly (9)**	-	-	-	-	E
AP23	**Thin - Thick (8)**	-	-	-	-	-
AP24	**Harmonic - Discordant (7)**	-	-	-	-	E, A
AP25	**Colourful - Colourless (6)**	-	-	-	-	-
AP26	**Cheap - Expensive (6)**	-	-	-	-	-
AP27	**Like - Dislike (6)**	✓	✓	✓ (RC2)	-	E, A

Note: PCA, Principal Component Analysis; # no missing data of the similarity coefficients extracted from the included studies; ^ all component loadings were greater than 0.4 in the solution; RC1, "Evaluation with activity"; RC2, "Activity", RC3, "Evaluation with potency", RC4: "Potency"; E, "Evaluation", P: "Potency", A: "Activity".

3.4. Meta-analysis results

For the 39 included studies in the meta-analysis, the pooled correlation matrix of the 27 APs was computed and analysed. Seven APs were excluded in the meta-analysis of factor analysis due to missing data of similarity coefficients extracted from the included studies. Then, four other APs were excluded as their component loadings were less than 0.4 in the initial solution of 20-APs PCA. The pooled 16-APs correlation matrix for further meta-analysis is shown in Table 3. The elements of the upper panel of the matrix was the counts of the co-occurrence of the row and column APs in the component/factor of the highest loading over the total number of studies contained the co-measurement of APs. For example, 23 studies contained the co-measurement of AP1 and AP2, in which 3 studies showed that AP1 and AP2 were co-occurred in the component/factor of the highest loading. The elements of the lower panel of the matrix were the similarity coefficients of APs after weightings to the number of co-measurements and the magnitudes of loadings in the studies.

Table 3

The pooled correlation matrix of the 16 adjective pairs (APs) for the meta-analysis of factor analysis.

Item	Pleasant Unpleasant	Weak Strong	Rough Smooth	Quiet Loud	Sharp Dull	Soft Hard	Calming Agitating	Light Heavy	Gentle Violent	Relaxed Tense	Deep Metallic	Bright Dark	Comfortable Uncomfortable	Noisy Quiet	High Low	Like Dislike
AP1: Pleasant - Unpleasant	-	3/23	19/28	11/23	8/20	12/19	10/21	1/11	10/19	8/17	8/15	3/12	10/10	8/11	2/10	8/9
AP2: Weak - Strong	0.07	-	5/17	10/13	4/15	8/24	4/9	6/12	5/10	4/14	1/11	6/21	3/6	4/7	3/6	0/3
AP3: Rough - Smooth	0.42	0.11	-	10/23	10/24	9/16	9/16	1/9	12/15	5/9	7/10	4/9	9/12	6/9	3/10	8/8
AP5: Quiet - Loud	0.23	0.70	0.24	-	6/16	4/7	4/12	2/7	4/8	2/9	2/16	2/6	4/5	0/1	3/6	0/2
AP6: Sharp - Dull	0.21	0.05	0.37	0.09	-	11/21	6/16	0/8	4/13	8/9	2/3	7/11	0/9	1/9	6/8	1/8
AP7: Soft - Hard	0.27	0.45	0.27	0.28	0.52	-	9/12	0/7	10/14	5/6	2/2	2/13	6/9	5/8	3/6	6/8
AP9: Calming - Agitating	0.20	0.06	0.18	0.13	0.57	0.54	-	0/7	11/15	4/8	0/3	5/6	6/12	6/10	2/7	7/8
AP 11: Light - Heavy	0.05	0.63	0.10	0.57	0.00	0.00	0.00	-	1/8	1/6	0/2	2/5	2/5	1/4	2/4	0/2
AP 12: Gentle - Violent	0.28	0.15	0.46	0.23	0.54	0.24	0.35	0.02	-	3/8	4/5	3/7	9/11	7/10	3/7	7/7
AP 13: Relaxed - Tense	0.34	0.10	0.27	0.05	0.76	0.61	0.48	0.01	0.14	-	2/6	4/9	0/2	2/4	3/7	1/1

AP 14: Deep - Metallic	0.42	0.00	0.38	0.04	0.22	0.64	0.00	0.00	0.73	0.16	-	1/2	1/2	1/2	2/2	2/2
AP 15: Bright - Dark	0.30	0.02	0.33	0.11	0.35	0.02	0.75	0.05	0.24	0.52	0.40	-	0/3	2/4	3/6	0/1
AP 16: Comfortable - Uncomfortable	0.73	0.26	0.50	0.64	0.00	0.23	0.10	0.40	0.36	0.00	0.42	0.00	-	8/9	0/3	6/8
AP 18: Noisy - Quiet	0.85	0.31	0.31	0.00	0.00	0.27	0.49	0.32	0.31	0.87	0.06	0.58	0.70	-	0/3	5/8
AP 20: High - Low	0.07	0.08	0.16	0.28	0.68	0.26	0.12	0.41	0.26	0.17	0.83	0.13	0.00	0.00	-	0/1
AP 27: Like - Dislike	0.53	0.00	0.74	0.00	0.27	0.41	0.71	0.00	0.66	0.67	0.74	0.00	0.22	0.19	0.00	-
Total	121/284	66/221	117/247	64/169	74/224	92/200	83/193	19/111	93/185	52/132	35/89	44/129	64/125	56/121	35/99	51/91

Note: Upper panel are the counts of the co-occurrence of the row and column APs in the component/factor of the highest loading over the total number of studies contained the co-measurement of APs; Lower panel are the similarity coefficients of APs after weightings to the number of co-measurements and the magnitudes of loadings in the studies.

In the first approach of the 16-APs PCA, four unrotated principal component solutions were computed (see Table 4). The first four components of the solution with eigenvalues larger than 1 explained 35 %, 16%, 13%, and 12% of the total variance, respectively. For achieving a better understanding of PCA results, varimax rotations were applied to obtain the solutions of the four and three rotated components in the 16-APs PCA. “Evaluation with activity”, “Activity”, “Evaluation with potency” and “Potency” were the four varimax-rotated components in the solution. They were then confined to be three varimax-rotated components, i.e. “Evaluation”, “Activity” and “Potency” of the16-APs PCA. Further explanation of the results can be found in Section 4 Discussion. Moreover, the correlation matrix of the 9-APs with the highest three component loadings in the 3 rotated components were extracted to have the additional PCA, i.e. “Noisy - Quiet”, “Relaxed - Tense”, Pleasant - Unpleasant”, “Deep - Metallic”, “High - Low”, “Sharp - Dull”, “Quiet - Loud”, “Light - Heavy”, and “Weak - Strong”. The similar solutions of the three varimax-rotated components were found between the 9-APs PCA and 16-APs PCA. The three rotated components in the 9-APs PCA had nearly equal eigenvalues and explained variances (29%, 27%, 25%). The 9-APs PCA solution showed high internal consistency of APs in the components, low correlations between the components, and high percentage (81%) of the explained total variance. The results revealed human perceptual dimensions of sound in the “Evaluation (E)”, “Activity (A)” and “Potency (P)” dimensions.

Table 4
The meta-analysis results of the Principal Component Analyses (PCA) to the reviewed adjective pairs (APs).

	16-APs PCA											**9-APs PCA**		
	4 unrotated principal components				**4 varimax-rotated components**				**3 varimax rotated components**			**3 varimax-rotated components**		
Item	**UPC1**	**UPC2**	**UPC3**	**UPC4**	**RC1**	**RC2**	**RC3**	**RC4**	**E**	**A**	**P**	**E**	**P**	**A**
Noisy - Quiet	**0.69**	0.17	-0.72	0.03	0.63	-0.18	**0.74**	0.22	**0.92**	-0.14	0.37	**0.99**	0.18	-0.10
Relaxed - Tense	**0.71**	-0.35	-0.32	0.39	**0.91**	0.15	0.17	-0.01	**0.80**	0.29	-0.10	**0.85**	-0.05	0.31
Pleasant - Unpleasant	**0.68**	0.15	-0.37	-0.41	0.24	0.18	**0.83**	0.07	**0.70**	0.11	0.36	**0.79**	0.09	0.14
Calming - Agitating	**0.64**	-0.35	-0.25	0.37	**0.83**	0.16	0.11	-0.01	**0.69**	0.30	-0.12	**-**	**-**	**-**
Bright - Dark	**0.53**	-0.24	-0.31	0.31	**0.71**	0.05	0.16	0.02	**0.64**	0.16	-0.05	**-**	**-**	**-**
Rough - Smooth	**0.65**	0.01	0.03	-0.35	0.16	0.48	**0.53**	0.04	**0.43**	0.42	0.23	**-**	**-**	**-**

Deep - Metallic	**0.67**	-0.13	0.58	-0.41	-0.01	**0.95**	0.26	-0.01	0.11	**0.88**	0.12	0.30	-0.05	**0.75**
High - Low	0.43	0.02	**0.72**	0.25	0.13	**0.72**	-0.32	0.35	-0.19	**0.79**	0.19	-0.05	0.25	**0.97**
Sharp - Dull	**0.62**	-0.39	0.32	0.44	**0.66**	0.57	-0.25	0.07	0.31	**0.72**	-0.14	0.09	0.00	**0.80**
Gentle - Violent	**0.67**	-0.10	0.30	-0.29	0.15	**0.70**	0.33	0.02	0.29	**0.66**	0.15	-	-	-
Like - Dislike	**0.74**	-0.33	0.05	-0.39	0.32	**0.63**	0.50	-0.24	0.56	**0.58**	-0.05	-	-	-
Soft - Hard	**0.66**	-0.06	0.21	0.22	**0.46**	0.50	0.06	0.25	0.34	**0.58**	0.18	-	-	-
Quiet - Loud	0.38	**0.74**	0.19	0.20	-0.02	0.16	0.16	**0.85**	-0.03	0.19	**0.83**	0.06	**0.86**	0.09
Light - Heavy	0.26	**0.73**	0.11	0.31	0	0	0.08	**0.84**	-0.06	0.05	**0.78**	0.00	**0.85**	0.12
Weak - Strong	0.33	**0.69**	0.06	0.38	0.12	0	0.07	**0.84**	0.03	0.07	**0.77**	0.15	**0.88**	-0.06
Comfortable - Uncomfortable	0.57	**0.62**	-0.18	-0.44	-0.10	0.18	**0.82**	0.45	0.38	0.07	**0.77**	-	-	-
Eigenvalue	5.62	2.58	2.08	1.85	3.33	2.23	2.88	2.64	3.85	3.49	2.94	2.58	2.45	2.22
Proportion variance	35%	16%	13%	12%	21%	20%	18%	17%	24%	22%	18%	29%	27%	25%

Note: RC1, "Evaluation with activity"; RC2, "Activity"; RC3, "Evaluation with potency"; RC4, "Potency"; E, "Evaluation"; P, "Potency"; A, "Activity"; **Bold:** the loadings in the component of the highest loading.

4. Discussion

In a building environment, both indoor and outdoor sounds would be noise sources to occupants. Hence, there was no limitation on the type of assessed sounds in SDM applications of the studies. Also, the inclusion of subjective measurements to sounds with various sound properties would increase the generality of quantitative analysis results. Although many psychoacoustics studies applied SDM applications to measure human perceptions of sound, large variations were found in the applications. The non-standardization in SDM allows researchers to have their freedom in selection of APs, AP scales, and analytical methods to the measurements, because SDM is a general assessing method of human perceptions (meanings) of things. The consequences were not only the discrepancies in analytical results of the different studies, but also the limitation of comparisons between results of the studies. A valid and reliable assessment tool is essential for the verification of measurements of subjects' response to the environment. The validity of the measurements would be affected by the selection of improper or unrelated items and the missing of important items. However, it is almost impossible for a single study of SDM application contains numerous different APs, assessed sounds, and participants. The amount of the assessed sounds and the correlations between the items are limited in the individual studies. Hence, meta-analysis of factor analysis to the pooled data, which integrated the individual study results, would provide more evidence-based results in investigating the magnitude of relationships between variables. The importance analysis prior to the meta-analysis ensures that all the important human perceptions of sound are included in the analysis. It also provides the evidence that the meta-analysis results are based on major human perceptual dimensions of sound.

The selection of proper measured perceptions is important not only for SDM applications but also for all subjective assessments of acoustical environmental influences on people. Human perceptions of sound are the series of processes from the objective stimulations to the sensation captured by ears, and then to the subjective interpretations by people. Unlike objective measurements of the sound properties, large variances of assessment methods would be found in the subjective measurements of human perceptions of sound. Further analyses of the relationship between objective measurements and subjective measurements would be dependent on the selection of measured perceptions [90]. Mismatches would occur when the unsuitable perceptions are measured. The ability of assessments of human perceptions of sound would be limited if important items are missing. However, including too many measured perceptions in subjective assessments is not a good approach. Most quantitative objective acoustics variables are measured and calculated during and after assessments if soundscapes are recorded during the experiments. This is not the case for the subjective assessments. One rating in the subjective assessments usually represents only a certain human perception of sounds. The increment of ratings affects not only the length of assessments, but also the synchronicity of objective and subjective assessments. Thus, time span as well as item limitations should be considered in subjective assessments to prevent memory error. Among the reviewed studies, the effect of the length of an assessment (estimated by the value of N_s*N_{ap}) on the number of assessments in the studies was clearly demonstrated. Most of the studies with more than one hundred ratings per assessment only had less than one hundred included participants. The three largest N_p studies [78, 83, 86] achieved the large sample size by reducing the number of ratings per assessment to less than 20. It illustrated that the simplification of the assessment would have the benefit of sample size enlargement.

Apart from discovery of the underlying structure, the reduction of irrelevant items was another main purpose of PCA/FA. The first screening of the irrelevant items to measurements of human perceptions of sound was conducted in the importance analysis. The restrictions of N_{stu} and average important scores ensured the reviewed APs to be of high research interest and importance to the human perceptions of sound. The result demonstrated that some APs were not suitable or less effective in measuring human perceptions of sound. For example, variances of objective properties of sound stimulations was less likely to affect the listeners' near/far perception. Listeners would have the concern for the loud/quiet perception rather than the near/far perception even if sound sources were coming to the listeners. Moreover, it was difficult for the listeners to have interpretations on meaningful/not meaningful, sad/happy, full/empty, steady/not steady, stable/not stable, and reverberant/not reverberant perceptions to the assessed sounds. The secondary screening of the irrelevant items was shown in the metanalysis result of the 20-APs PCA. Four additional perceptions (clear/not clear, slow/fast, simple/complex, and boring/interesting) were found to be not suitable in measurements of human perceptions of sound, even though they were of research interest. The participants might be confused by the items or rated the item mainly according to their own experience but not from the variance of sound stimulations. The third screening of irrelevant items was performed by the correlation analysis of reviewed APs to the E, P, and A dimensions, which will be explained later. Four additional perceptions (natural/artificial, thin/thick, colourful/colourless, and cheap/expensive) were found to be not suitable in the measurements of human perceptions of sound. Since the inclusion of irrelevant items would reduce the internal consistency of assessments, inclusion of irrelevant APs in measurements of human perceptions of sound in future psychoacoustics studies should be avoided.

The high ability of SDM in assessing semantic spaces of things is derived from the advantages of bipolar descriptors in opposite meaning. The use of bipolar descriptors provides a clear definition of the measured perceptual spaces. If a Likert scale is applied to measure the participants' "Soft" perception, the participants may be confused by the cognitive differences on the measurements of soft/hard, rough/soft, or loud/soft perceptions. The naming of reviewed APs from the representative of their contents would also provide the insight of the pairing of descriptors in SDM applications of human perceptions of sound. Future subjective assessment tool designs should be focused on quality rather than quantity.

This study also provided the interpretation of meta-analysis results to acquire human perceptual dimensions of sound. The 3D-biplots of 16-APs PCA results were plotted in Fig. 2. Most of the APs were grouped in the first unrotated principal component (UPC1) of the solution to obtain the component of highest proportion variance. The second and third components (UPC2 and UPC3) showed the likelihoods of human sensations to the magnitude of sound and the pitch of sound affecting human perceptions of sound other than the general evaluation of sound as the understanding of the solution was impeded by clustering most of the APs in UPC1. Compared to the unrotated 16-APs PCA solution, the varimax solutions, in which the rotated components (RCs) were expressed by their dominant items, provided more interpretable results of human perceptual dimensions of sound. After considering the clustered APs in RCs, the 4 RC solution were interpreted to be the "Evaluation with activity", "Activity", "Evaluation with potency" and "Potency" components. The 3 RC solution confined the result into three components, "Evaluation", "Activity" and "Potency", which provided the understanding of human interaction with acoustical environments. The found human perceptual dimensions of sound in results matched well with "Evaluation (E)", "Potency (P)", and "Activity (A)" dimensions of Osgood [32].

Human perceptions of sound were governed by general judgement, sensation to the magnitude, and sensation to temporal and spectral compositions of perceived sound. Meanwhile, the determination of the E, P, and A dimensions promoted the understanding of the differences between different PCA solutions. The relatively more amount of the APs related to the E dimension increased the variances in the E dimension and made the E dimension be the dominated component in the UPC solution. In addition, the inclusion of the APs related to more than one dimension would generate the hybrid dimensions in the solution. The inclusion of the APs “Calming - Agitating”, “Gentle - Violent”, and “Bright - Dark” related to both E and A dimensions directed the component in the 4 RC solution to be “Evaluation with activity”. While the inclusion of APs “Comfortable - Uncomfortable “and “Rough - Smooth” related to both P and A dimensions directed the component in the 4 RC solution to be “Evaluation with activity”. It demonstrated that the selection of measured perceptions would have a great impact on dimensional analysis of individual studies. It also explained the diversity of analytical results of the found dimension similar to E, P, and A dimensions [55, 56, 71, 73, 75, 77, 82], in two dimensions [42, 63], or in more than E, P, and A dimensions [33, 61, 83].

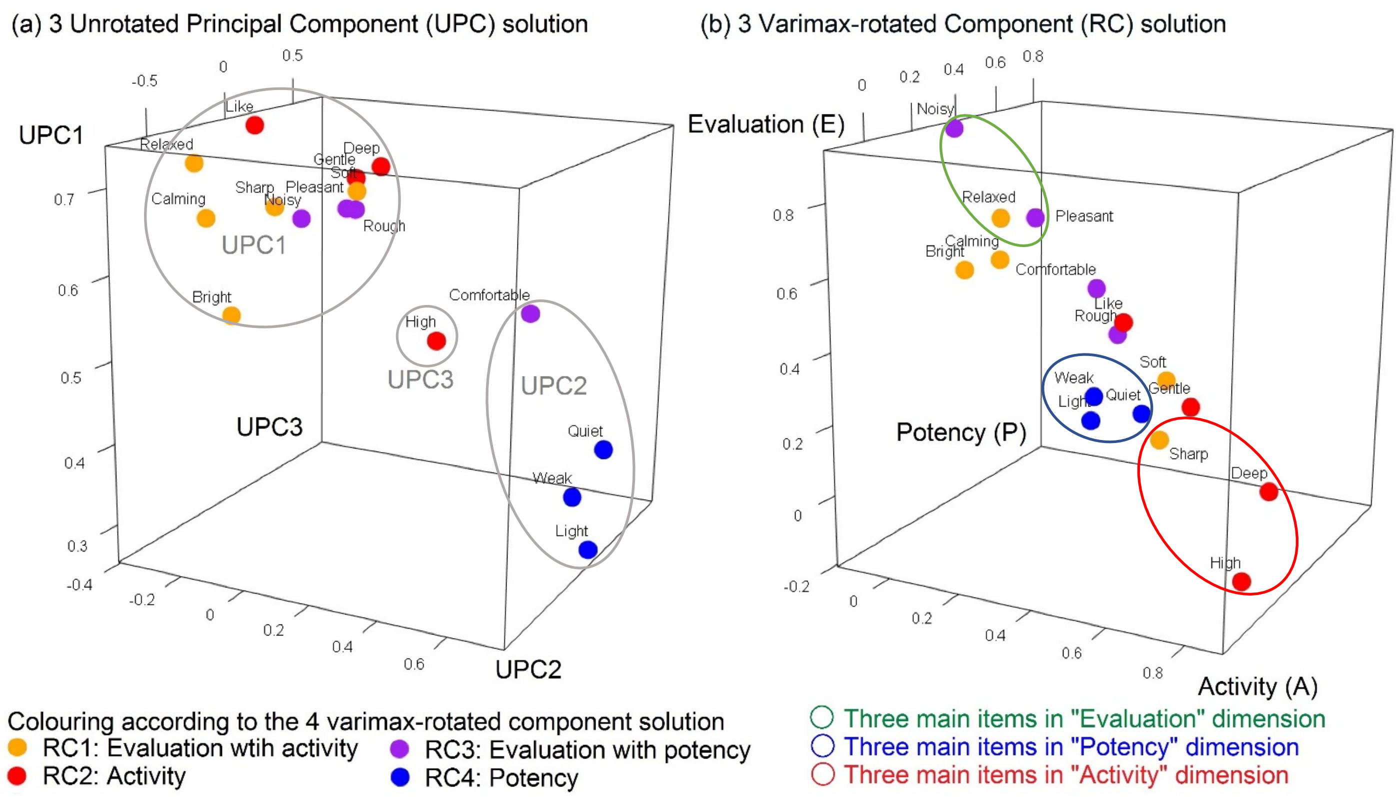

Fig. 2. 3D-biplots of the 16-APs principal component analysis results: (a) 3 unrotated principal component solution; (b) 3 varimax-rotated component solution.

The high internal consistency of APs in the components, the low correlations between components, and the high percentage of explained total variance in 9-APs PCA solution showed the implication of the PCA-based index development. It extended the understanding of perceptual dimensions of sound to the verification of quantitative measurements of subjects’ responses. The use of 9 APs was sufficient to obtain reliable quantitative assessments of subjects’ responses in the E, P, A dimensions. The E-dimension score should be computed by measurements on APs “Noisy - Quiet”, “Relaxed - Tense”, and “Pleasant - Unpleasant” to estimate subjects’ general judgement of sound. The P-dimension score should be computed by measurements on APs “Quiet - Loud”, “Light - Heavy”, and “Weak - Strong” to estimate subjects’ sensation to the magnitude of sound. The A-dimension score should be computed by measurements on APs “Deep - Metallic”, “High - Low”, and “Sharp - Dull” to estimate subjects’ sensation to the temporal and spectral compositions of sounds. Although subjective assessments were not restricted to these 9 APs, the E, P, and A dimension scores calculation should be relied only on the measurements of 9 APs. Since the included APs might related to more than one dimension, it would affect the reliability of dimension scores and hinder findings in further analyses. Thus, analyses other than these 9 APs should be in the way of analysing corresponding spaces of APs in the E, P, A coordinates, i.e. the correlations of the APs to the E, P, and A dimensions. The correlation analysis of the remained 18 APs of the 27 reviewed APs to the E, P, and A dimensions was served as a demonstration. The measurements on the corresponding APs of the dimension in the individual studies was treated as the measurements on the dimension. For example, all the measurements on the “Quiet - Loud”, “Light - Heavy”, and “Weak - Strong” APs was served as the measurements on E dimension. The additional pooled correlation matrix of 21 items was extracted for the measurements on 18APs and the E, P, and A dimensions. The correlations between the APs and the dimensions were represented by the similarity coefficients in the matrix. The result showed that most of the measured perceptions (10 APs) of sound were related to the E dimension. The two perceptions (warm/cold, and beautiful/ugly) were highly correlated to the E dimension only. The comfortable/uncomfortable perception was related to both E and P dimensions. The five perceptions (harmonic/discordant, gentle/violent calming/agitating, like/dislike, and bright/dark) were related to both E and A dimensions. Two perceptions (rough/smooth, soft/hard) were related to all E, P, and A dimensions. It illustrated the feasibility of the E, P, and A indices in understanding human perceptions of sound. The result also suggested that these 10 perceptions related E, P, and A dimensions were suitable in subjective assessments.

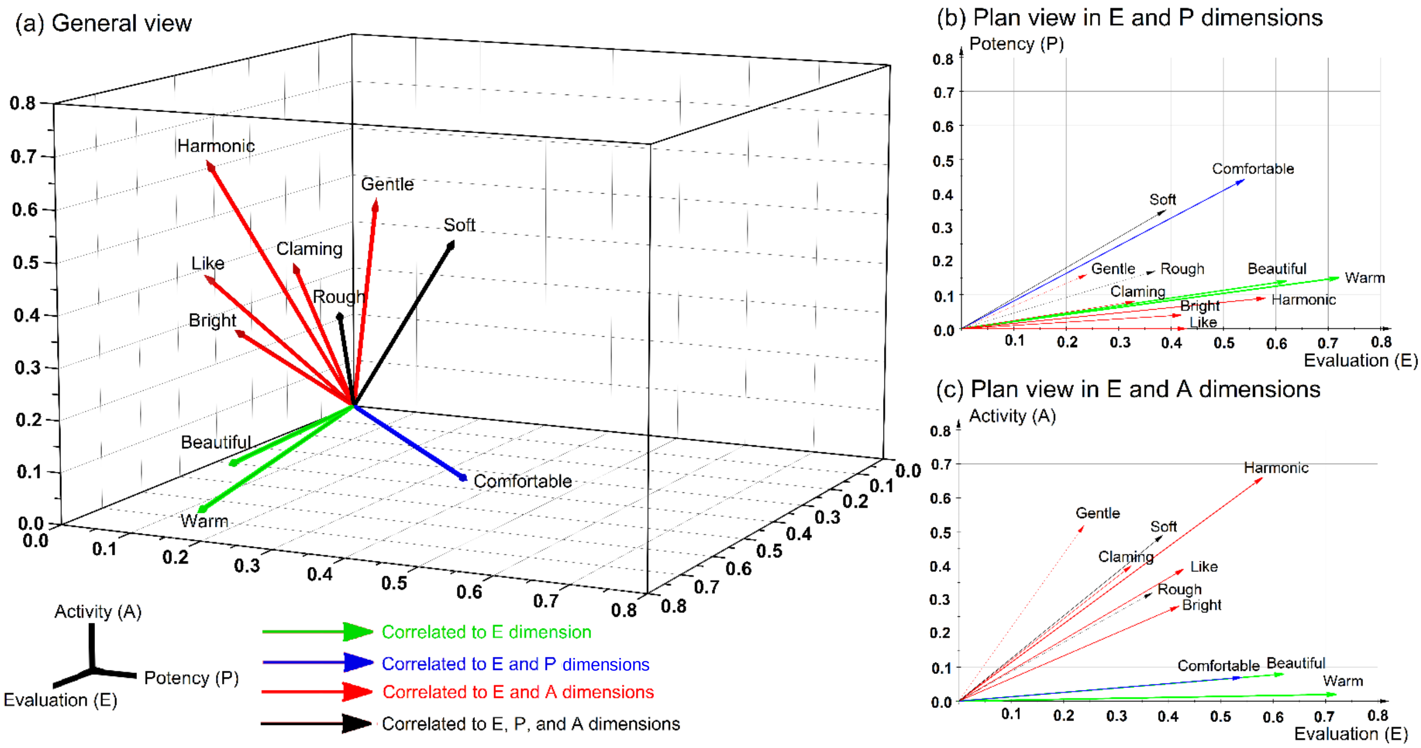

Fig. 3. A plot of the correlations between the 10 adjective pairs to the “Evaluation (E)”, “Potency (P)”, and “Activity (A)” dimensions: (a) general view; (b) plan view of E and P dimensions; (c) plan view of A and P dimensions.

In additional to the selection of proper measured subjective perceptions, the selection of proper measured objective sound properties was important for the analysis of acoustical environmental influences on human. It was observable that the P and A dimension were specific to the human sensations to objective stimulations, while E dimension were the general judgement with human affective responses and interpretations of sound quality. It explained why the AP “Quiet - Loud” was included in the P dimension but “Noisy - Quiet” was included in the E dimension. Although the E dimension was depended on people’ experience, preference, and background, P and A were depended mainly on sound quality of stimulations. The variations of human perceptions of sound were generated from both variations in the energy level (P dimension) and energy distribution (A dimension) of sounds. With the help of discovered human perceptual dimensions of sound, future studies should be focused on finding the effects of sound stimulations on the E, P, and A dimensions and then to the different perceptions (see Fig. 4.). The relations between the sound stimulations and the different perceptions were multivariate instead of bivariate correlations. The E, P, and A dimension scores served as indictors of the perceptual environmental sound quality. The correlation test between measured perceptions and dimension scores would be a method to provide supplementary understanding of environmental influences on human perceptions [91, 92]. It also raised the attention to the use of psychoacoustics parameters such as sharpness, roughness, and fluctuation strength [93], and the use of spectrum analysis in assessments of acoustical environments on the occupants [94]. It is shown that measurements of spectral compositions of sounds assist in analyses of environmental impacts on occupants' health, hearing, and satisfaction statuses [7]. The uncertainty of a certain research question such as the evaluation of the acoustic environmental comfort does not necessarily reduce if the approaches and finding in the studies are different. Especially in psychoacoustics studies, large degree of freedom in selectin of objective parameters, psychoacoustics parameters, and measured subjective responses of listeners. The results of the review hence could reduce this uncertainty in psychoacoustics studies as it gave the direction of what should be measured in assessing the human perceptions of sounds from the objective stimulation.

Promotion of occupants' acoustical satisfaction [95] is one of the concerns in building designs. The acoustical environment of buildings are affected by room acoustics [96] and systems in buildings [97-100]. The findings of this review would facilitate the development of more evidence based building performance assessments [101]. In addition, It could promote predictions and assessments [102] of the energy level, and temporal and spectral compositions of sounds in buildings [103] or urban environments [104], and predictions of perceptual influences on occupants. The assessments of the occupants' subjective perceptual responses were important in decision making [105] in building designs such as sound insulations [106], sound masking [107], spatial settings [108], roadside noise barriers [109], and building locations [110]. Findings of the understanding of human perceptual dimensions of sound hence were the juncture to connect noise prediction works and environmental influence studies to improve the occupant-oriented management [111] of acoustical environments.

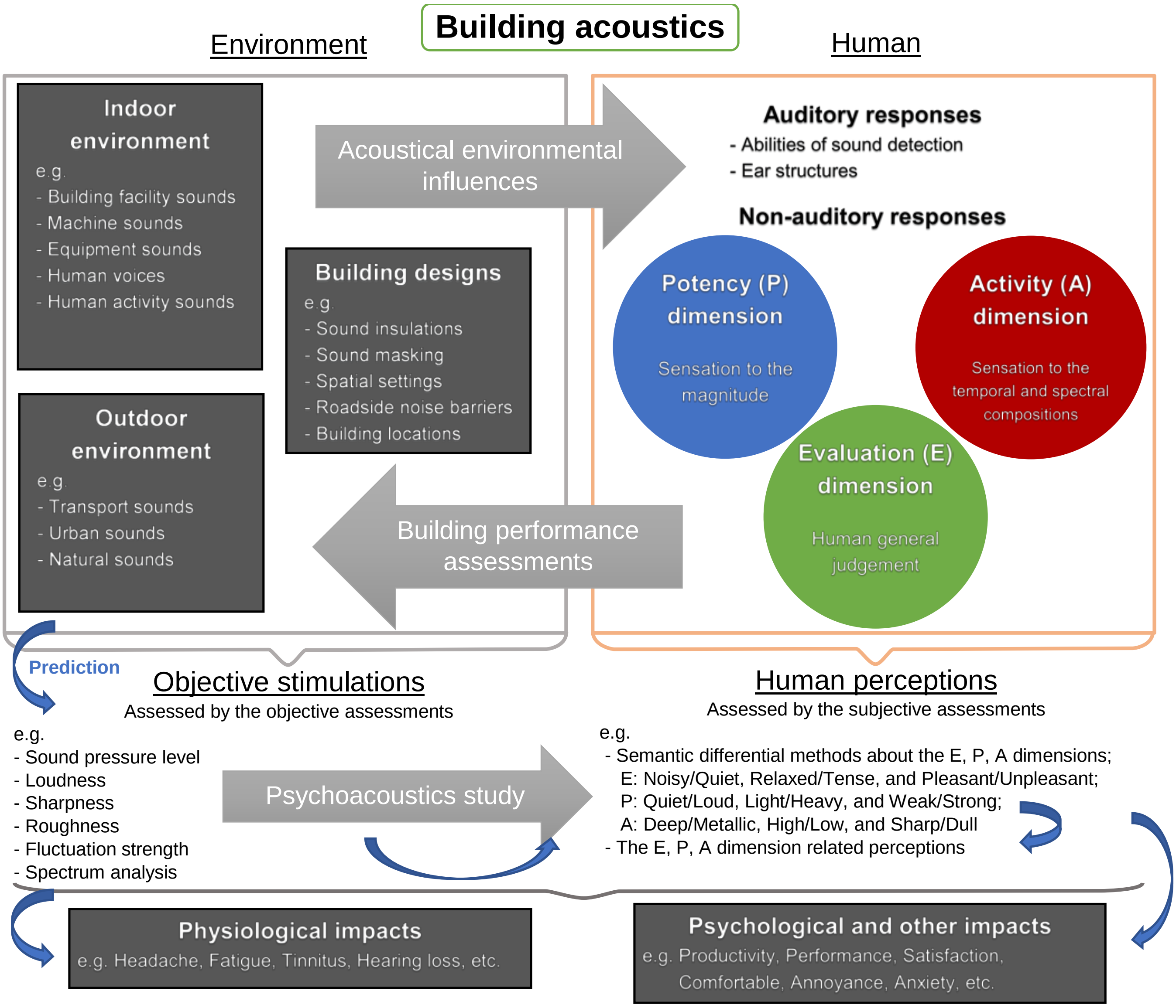

Fig. 4. A summary of the roles of human perceptions in building acoustics.

5. Limitation

The heterogeneous of the individual studies was unavoidable as researchers would have numerous approaches to address the research question about human perceptual dimensions of sound. That was why the meta-analysis came into being. In order to control the homogeneity and quality of the studies, the findings in the studies with the methods other than SDM in subjective measurement and PCA/FA in data analysis or insufficient data provision were excluded in the quantitative analysis. It might have the chance of missing the related information from the studies. Also, the meta-analysis of the study was based on the estimation of the correlation between the measured perceptions. No criteria about AP scale and number of APs of the individual studies were set in balancing the acquirement of valuable information and the effect of the heterogeneous. Therefore, this review did not cover the discussions about the suggested number of APs and AP scale for the future SDM applications. Moreover, the objective of the review was to obtain the general human perceptual dimensions of sound. The divisions of the data into different subgroups such as gender, age range, nationality, and occupation were also not included in this review. In addition, the tested sounds and APs were not the same in all individual studies. The analytical results of the meta-analysis were focused on the structures between the perceptions. The magnitude of the item loadings and the unexplained variance of the solution need to be confirmed by the further studies of using the set of the suitable APs. The meta-analysis of the review systematically cumulated the knowledge of human perceptual dimensions of sound from the findings in the individual studies to have a more generalizable and evidence-based result. Although future validity studies were need for the review result, it saved the researchers' time from spending on the item reduction works for the irrelevant items and made psychoacoustics studies to next stages.

6. Conclusions

The understanding of human perceptual dimensions of sounds is important for acoustic environmental management works as it promotes the possibility of prediction works from objective sound properties to subjective responses. Total 45 eligible studies in measuring human perceptions of sound with SDM applications were systematically searched. Total 5677 participants, 828, 756 ratings, 1365 sounds, 686 descriptors were included in subjective assessments of the studies covered on numerous indoor and outdoor sounds. The importance analysis ensured that all the important human perceptions of sound were included in the quantitative analysis. Three major perceptual dimensions of sound were found to be "Evaluation", "Potency" and "Activity" dimensions in the meta-analysis of factor analysis. It showed that human perceptions of sound were governed by human general judgement, sensation to the magnitude, and sensation to temporal and spectral compositions of perceived sounds. It also implied that objective assessments in psychoacoustics studies should contain both sound energy level, and temporal and spectral composition measurements. Meanwhile, the quantitative representation of the perceptual environmental sound quality would be acquired from the computation of the E, P, and A dimension scores from the 9 APs "Noisy - Quiet", "Relaxed - Tense", Pleasant - Unpleasant", "Deep - Metallic", "High - Low", "Sharp - Dull", "Quiet - Loud", "Light - Heavy", and "Weak - Strong". These APs could be used, with flexibility, as items in an index in analyses of perceptual influences from acoustical environments on human. The measurements of perceptions related to the E, P, and A dimensions were also suitable in subjective assessments according to researchers' interest.

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Appendix A. Full search strategy

PubMed
(("Semantic Differential"[Mesh Terms] OR ("Semantic"[All Fields] AND "Differential"[All Fields]) OR "Semantic Differential"[All Fields]) OR "Adjective Pairs"[All Fields]) AND (("Noise"[Mesh Terms] OR "Noise"[All Fields]) OR ("Sound"[Mesh Terms] OR "Sound"[All Fields])) AND (Factor [All Fields] OR "Factor Analysis"[All Fields] OR "Principal Component Analysis"[All Fields] OR Component [All Fields] OR "Dimension"[All Fields])

ProQuest, Institute for Scientific Information (ISI) Web of Science, and The Journal of the Acoustical Society of America (JASA)
(“Semantic Differential” OR “Adjective Pairs”) AND
(Noise OR Sound) AND
(Factor OR “Factor Analysis” OR “Principal Component Analysis” OR Component OR Dimension)

Scopus and ScienceDirect
({Semantic Differential} OR {Adjective Pairs}) AND
(Noise OR Sound) AND
(Factor OR {Factor Analysis} OR {Principal Component Analysis} OR Component OR Dimension)

Appendix B. Details of the Importance analysis and the paring of the reviewed APs

Table B.1

The occurrence frequency of the descriptors in the 45 studies of the qualitative synthesis.

No.	Descriptor	$N_{stu}^{\#}$
1	Pleasing, Not Unpleasant	35
2	Not Pleasant, Unpleasing*	31
3	Soft	29
4	Weak	28
5	Rough	24
6	Smooth, Smooth Flowing	23
7	Calm, Calming, Calmness	22
8	Dull	22
9	Hard	21
10	Loud	21
11	Quite	21
12	Clear	20
13	Slow Tempo	17
14	Powerful	16
15	Relaxation, Relaxed, Relaxing	16
16	Sharp	16
17	Strong	16
18	Light, Light Tone	15
19	Fast, Fast Tempo	14
20	Bright	13
21	Comfort, Comfortable	13
22	Gentle	13
23	Heavy	13
24	Simple	13
25	Tense, Tensed	13
26	Uncomfortable, Discomfort*	12
27	Harsh	12
28	Noise, Noisy	12
29	Boring	11
30	Deep	10
31	High	10
32	Beautiful	9
33	Dark	9
34	Interesting	9
35	Low	9
36	Natural	9
37	Shrill	9
38	Ugly	9
39	Varied	9
40	Cold	8
41	Complex	8
42	Thin	8
43	Warm	8
44	Agitated, Agitating	7
45	Artificial	7
46	Colourless, Not Colourful, Uncolourful*	7
47	Distinct	7
48	Far	7
49	Flat	7
50	Harmonic, Harmonious	7
51	Monotonous	7
52	Sad	7
53	Steady	7
54	Thick	7
55	Cheap	6
56	Colourful	6
57	Full	6
58	Happy	6
59	Dislike*	6
60	Like, Not Dislike	6
61	Meaningful	6
62	Near, Nearby	6
63	Reverberant, Reverberation	6
64	Round, Rounded	6
65	Not Stable, Unstable*	6
66	Annoying	5
67	Directional	5
68	Empty	5
69	Exciting	5
70	Expensive	5
71	Familiar	5
72	Mild	5
73	Rumbling	5
74	Safe	5
75	Stable	5
76	Strange	5
77	Tight	5
78	Violent	5
79	Active	4
80	Breathy	4
81	Not Breathy, Unbreathy*	4
82	Clamorous	4
83	Clean	4
84	Not Clear, Unclear*	4
85	Dangerous	4
86	Dirty	4
87	Discordant	4
88	Disturbing	4
89	Not Dull *	4
90	Expressive	4
91	Not Fast Tempo *	4
92	Friendly	4
93	Intense	4
94	Large	4
95	Lively	4
96	Loose	4
97	Low Pitch	4
98	Melodious	4
99	Metallic	4
100	Muddy	4
101	Not Powerful, Powerless*	4
102	Pure	4
103	Small	4
104	Social	4
105	Unsocial*	4
106	Unsteady*	4
107	Not Weak *	4
108	Aggressive	3
109	Disagreeable*	3
110	Anechoic	3
111	Angular	3
112	Not Bright *	3
113	Brisk	3
114	Cheerful	3
115	Close, Closed	3
116	Coarse	3
117	Communal	3
118	Definite	3
119	Delicate	3
120	Diffuse	3
121	Forced/Intense Tone Quality, Forceful	3
122	Not Harmonious, Disharmonious*	3
123	High Pitch	3
124	Impure	3
125	Insignificant	3
126	Intelligible	3
127	Not Intelligible, Unintelligible*	3
128	Jerking	3
129	Meaningless	3
130	Not Mechanical, Not Mechanistic *	3
131	Modest	3
132	Narrow	3
133	Normal	3
134	Disordered, Disorderly*	3
135	Passive	3
136	Private	3
137	Quick	3
138	Rich	3
139	Not Rough*	3
140	Not Sharp*	3
141	Not Slow*	3
142	Universal	3
143	Not Warm *	3
144	Whining	3
145	Wide	3
146	Accurate	2
147	Acoustic	2
148	Not Aggressive*	2
149	Agreeable	2
150	Airy	2
151	Not Annoying*	2
152	Arousing	2
153	Bad	2
154	Balanced	2
155	Not Balanced, Unbalance *	2
156	Bold	2
157	Broad	2
158	Busy	2
159	Careless	2
160	Classical	2
161	Not Cold*	2
162	Compact	2
163	Concentrated	2
164	Constant	2
165	Not Constant*	2
166	Creaky	2
167	Not Creaky*	2
168	Crisp, Crispy	2
169	Not Defined, Undefined*	2
170	Delightful	2
171	Depressed, Depressing	2
172	Desirous of Hearing	2
173	Not Desirous of Hearing, Undesirous of Hearing*	2
174	Deviant, Deviating	2
175	Dissonant	2
176	Not Disturbing *	2
177	Dragging	2
178	Dry	2
179	Even	2
180	Uneven*	2
181	Everywhere	2
182	Expressionless	2
183	Not Familiar*	2
184	Fearful	2
185	Feminine	2
186	Fine	2
187	Firm	2
188	Not Focused, Unfocused*	2
189	Not Forced/Intense Tone Quality *	2
190	Unfriendly*	2
191	Functional	2
192	Not Gentle*	2
193	Good	2
194	Hazy	2
195	High Energy	2
196	Hollow	2
197	Irregular	2
198	Not Light Tone, Not Light*	2
199	Not Loud*	2
200	Low Energy	2
201	Mechanical	2
202	Mellow	2
203	Not Natural, Unnatural*	2
204	Not Noisy*	2
205	Obtrusive	2
206	Obvious	2
207	Old	2
208	Oppressed, Oppressive	2
209	Ordered	2
210	Painful	2
211	Performance	2
212	Plain	2
213	Pressed, Pressing	2
214	Real	2
215	Unreal*	2
216	Refined	2
217	Repetitive	2
218	Not Repetitive*	2
219	Reserved	2
220	Restless	2
221	Not Reverberant, Not Reverberation*	2
222	Not Round*	2
223	Rugged	2
224	Rural	2
225	Scattered	2
226	Shallow	2
227	Silent	2
228	Slack	2
229	Not Soft *	2
230	Solid	2
231	Sonorous	2
232	Spit, Spitting	2
233	Not Spitting*	2
234	Not Strange*	2
235	Not Strong*	2
236	Subtle	2
237	Synthetic	2
238	Tasteful	2
239	Tasteless	2
240	Tender	2
241	Not Tense, Not Tensed*	2
242	Not Thin*	2
243	Uncertain	2
244	Urban	2
245	Vague	2
246	Worried, Worrying	2
247	Abnormal	1
248	Not Accurate *	1
249	Acute	1
250	Aesthetic	1
251	Affected	1
252	Not Airy*	1
253	Alert	1
254	All Baroque Instruments	1
255	Not All Baroque Instruments *	1
256	Angelic	1
257	Appropriate	1
258	Articulated	1
259	Not Articulated *	1
260	Artless	1
261	Attending	1
262	Attention Getting	1
263	Authoritarian	1
264	Bass Enhanced	1
265	Not Bass Enhanced *	1
266	Bearable	1
267	Unbearable*	1
268	Benevolent	1
269	Bewildered	1
270	Big	1
271	Not Big*	1
272	Bitter	1
273	Not Blooming*	1
274	Booming	1
275	Brave	1
276	Brilliant	1
277	Bubbly	1
278	Not Bubbly*	1

No.	Descriptor	$N_{stu}^{\#}$
279	Burlesque	1
280	Bursty	1
281	Casual	1
282	Changing	1
283	Chaotic	1
284	Cheerless	1
285	Chiff	1
286	Not Chiff*	1
287	Childish	1
288	Not Classic*	1
289	Not Clean*	1
290	Clear Structure	1
291	Not Clear Structure *	1
292	Not Close *	1
293	Not Coarse*	1
294	Common	1
295	Not Complex*	1
296	Confident	1
297	Confusing	1
298	Conservative	1
299	Consonant	1
300	Conspicuous	1
301	Inconspicuous*	1
302	Constructive	1
303	Continuo	1
304	Not Continuo *	1
305	Continuous	1
306	Discontinuous*	1
307	Convincing	1
308	Not Convincing*	1
309	Cool	1
310	Cough	1
311	Not Cough*	1
312	Courteous	1
313	Not Crispy*	1
314	Cultured	1
315	Curt	1
316	Dampened	1
317	Not Dark*	1
318	Dead	1
319	Deadening	1
320	Deadly	1
321	Decorative	1
322	Not Deep*	1
323	Dejected	1
324	Deliberate	1
325	Demoniac	1
326	Dense	1
327	Not Dense*	1
328	Desperate	1
329	Despondent	1
330	Destructive	1
331	Detailed	1
332	Not Detailed *	1
333	Not Diffuse*	1
334	Dim	1
335	Direct Sound	1
336	Not Direct Sound *	1
337	Not Dirty*	1
338	Not Dissonant *	1
339	Distant	1
340	Not Distant *	1
341	Not Distinct*	1
342	Distorted	1
343	Dominant	1
344	Not Dominant*	1
345	Drowsy	1
346	Not Dynamics *	1
347	Dynamics	1
348	Easy	1
349	Not Easy*	1
350	Echoed	1
351	Effortless	1
352	Elated	1
353	Electrical	1
354	Not Electrical*	1
355	Unemotional*	1
356	Emotional	1
357	Enlivening	1
358	Enveloping Sound	1
359	Not Enveloping Sound *	1
360	Even Dynamics	1
361	Not Even Dynamics *	1
362	Expressionless	1
363	Not Expressive *	1
364	Exterior	1
365	Not Fearful*	1
366	Unfeminine*	1
367	False	1
368	Flexible Tempo	1
369	Not Flexible Tempo *	1
370	Floppy	1
371	Not Floppy*	1
372	Flowy	1
373	Not Flowy*	1
374	fluctuating	1
375	Not fluctuating*	1
376	Fluent	1
377	Fluffy	1
378	Not Fluffy*	1
379	Fluttering	1
380	Fluty	1
381	Not Fluty*	1
382	Focused	1
383	Forceless	1
384	Unforgettable*	1
385	Forgettable	1
386	Formal	1
387	Free	1
388	Not Free*	1
389	Fresh	1
390	Not Fresh*	1
391	Frivolous	1
392	Not Full*	1
393	Not Functional*	1
394	Furious	1
395	Future	1
396	Futuristic	1
397	Gloomy	1
398	Glossy	1
399	Not Good Pitch Quality *	1
400	Gorgeous	1
401	Grave	1
402	Guilty	1
403	Hammering	1
404	Not Hammering*	1
405	Unhappy*	1
406	Not Hard*	1
407	Not Harsh*	1
408	High Degree	1
409	High for A Man	1
410	Not High Pitch*	1
411	High Quality	1
412	Hiss	1
413	Not Hiss*	1
414	Homogeneous	1
415	Not Homogeneous *	1
416	Hopeful	1
417	Horn	1
418	Not Horn*	1
419	Hostile	1
420	Hot	1
421	Hubbub	1
422	Human	1
423	Husky	1
424	Not Husky*	1
425	Ill-Sounding	1
426	Important	1
427	Unimportant *	1
428	Impressive	1
429	Unimpressive*	1
430	In Motion	1
431	Inappropriate	1
432	Indefinite	1
433	Indistinct	1
434	Indulgent	1
435	Inferior	1
436	Informative	1
437	Not Informative*	1
438	Inhuman	1
439	Innocent	1
440	Innocuous	1
441	Insane	1
442	Insecure	1
443	Insincere	1
444	Uninspiring*	1
445	Inspiring	1
446	Intrusive	1
447	Intentional	1
448	Unintentional*	1
449	Interior	1
450	Intimate	1
451	Not Intimate *	1
452	Intrusive	1
453	Not Intrusive*	1
454	Intrusiveness	1
455	Not Irregular*	1
456	Irritating	1
457	Joyful	1
458	Keen	1
459	Languid	1
460	Leaky	1
461	Not Leaky*	1
462	Least Preferred	1
463	Legato	1
464	Not Legato *	1
465	Likable	1
466	Little Attending	1
467	Long	1
468	Not Long*	1
469	Not Loose*	1
470	Low Degree	1
471	Low for A Man	1
472	Not Low Pitch*	1
473	Low Quality	1
474	Lowly	1
475	Lugubrious	1
476	Luxurious	1
477	Machine	1
478	Not Machine*	1
479	Malevolent	1
480	Manifest	1
481	Masculine	1
482	Massive	1
483	Not Massive*	1
484	Matte	1
485	Matter-of-Fact	1
486	Not Matter-of-Fact*	1
487	Mature	1
488	Mechanistic	1
489	Unmelodious*	1
490	Merry	1
491	Mixed	1
492	Mobile	1
493	Not Monotonous *	1
494	Most Preferred	1
495	Motionless	1
496	Moved	1
497	Unmoved *	1
498	Murky	1
499	Mysterious	1
500	Nasal	1
501	Not Nasal*	1
502	New	1
503	No Background Noise	1
504	Not No Background Noise *	1
505	Noiseless	1
506	Non-aesthetic*	1
507	Noticeable	1
508	Not Obtrusive*	1
509	Not Old*	1
510	Opaque	1
511	Open	1
512	Not Oppressive*	1
513	Orderly	1
514	Organized	1
515	Disorganized*	1
516	Ornate	1
517	Over	1
518	Not Over*	1
519	Not Painful*	1
520	Past	1
521	Patterned	1
522	Bad Performance*	1
523	Not Performance *	1
524	Phrased	1
525	Not Phrased *	1
526	Pitch Quality	1
527	Placid	1
528	Pointed	1
529	Polished	1
530	Poor	1
531	Poor-Cleaning	1
532	Precise	1
533	Predictable	1
534	Not Pressed*	1
535	Profane	1
536	Pulsating	1
537	Not Pulsating*	1
538	Pulse	1
539	Not Pulse *	1
540	Not Quite*	1
541	Random	1
542	Raw	1
543	Not Raw*	1
544	Reading Performance	1
545	Bad reading Performance*	1
546	Reassurance	1
547	Rebellious	1
548	Reedy	1
549	Not Reedy*	1
550	Refreshing	1
551	Regular	1
552	Regular Accents	1
553	Not Regular Accents *	1
554	Not Relaxed*	1
555	Relieving	1
556	Resigned	1
557	Resounding	1
558	Not Resounding *	1
559	Resting	1
560	Rhetorical	1
561	Not Rhetorical *	1
562	Rhythmicized	1
563	Not Rhythmicized *	1
564	Not Rich*	1
565	Ringing	1
566	Romantic	1
567	Not Romantic *	1
568	Rubato	1
569	Not Rubato *	1
570	Sacred	1
571	Unsafe*	1
572	Sandy	1
573	Not Sandy*	1
574	Sane	1
575	Unsatisfactory*	1
576	Secure	1
577	Self-Confident	1
578	Sense of Self	1
579	Serene	1
580	Serious	1
581	Severe	1
582	Sexy	1
583	Unsexy*	1
584	Shaking	1
585	Short	1
586	Not Short*	1
587	Not Shrill(Dull)*	1
588	Not Simple*	1
589	Sincere	1
590	Singing	1
591	Not Singing*	1
592	Sinister	1

No.	Descriptor	N_{stu}#
593	Slick	1
594	Sloppy	1
595	Slovenly	1
596	Not Slow Tempo *	1
597	Slumped	1
598	Slurred	1
599	Not Slurred *	1
600	Not Smooth*	1
601	Solo Performance	1
602	Not Solo Performance *	1
603	Soothing	1
604	Speech	1
605	Not Speech*	1
606	Spirited	1
607	Spiritless	1
608	Sporty	1
609	Springy	1
610	Not Springy *	1
611	Stately	1
612	Stereotyped	1
613	Straight Tone	1
614	Not Straight Tone *	1
615	Strained	1
616	Strict	1
617	Not Strict *	1
618	Stringy	1
619	Not Stringy*	1
620	Unstructured*	1
621	Structured	1
622	Stylistically Appropriate	1
623	Not Stylistically Appropriate *	1
624	Submissive	1
625	Substantial	1
626	Not Substantial*	1
627	Superior	1
628	Sweet	1
629	Tactful	1
630	Distasteful *	1
631	Tempo	1
632	Not Tempo *	1
633	Texture	1
634	Not Texture *	1
635	Threatening	1
636	Not Threatening*	1
637	Thrilling	1
638	Throaty	1
639	Not Throaty*	1
640	Not Tight*	1
641	Tire of	1
642	Not Tire of*	1
643	Tonal	1
644	Tragic	1
645	Transparent Texture	1
646	Not Transparent Texture *	1
647	Treble Enhanced	1
648	Not Treble Enhanced *	1
649	True	1
650	Not Undefined*	1
651	Not Unfocused*	1
652	Uniform	1
653	Unique	1
654	Not Unstable*	1
655	Uproarious	1
656	Usual	1
657	Vibrancy	1
658	Vibrato Tone	1
659	Not Vibrato Tone *	1
660	Vigorous	1
661	Vivacious	1
662	Wavering	1
663	Well Accented	1
664	Not Well Accented *	1
665	Well Cleaning	1
666	Well Ornamented	1
667	Not Well Ornamented *	1
668	Well Phrased	1
669	Not Well Phrased *	1
670	Well-Sounding	1
671	Wet	1
672	Wide Dynamic Range	1
673	Not Wide Dynamic Range *	1
674	Wiggling	1
675	Wild	1
676	Windy	1
677	Not Windy*	1
678	With Intonation	1
679	With Texture	1
680	Not with Texture *	1
681	Without Echo	1
682	Not Without Echo *	1
683	Without Intonation	1
684	Wooly	1
685	Not Wooly*	1
686	Not Worrying*	1

Note: # N_{stu}, *n*umber of included studies; * antonyms of the descriptors with the prefix Un/In or using Not.

Table B.2

The importance analysis result of the descriptors included in more than 5 studies.

No.	Descriptor	Number of included studies	Number of included participants	Number of included measurements	Average importance score per study#	Average importance score per measurement#	Involved in the adjective pair of the review
1	Pleasing, Not Unpleasant	35	2581	28062	3.29	3.24	AP1
2	Not Pleasant, Unpleasing	31	2424	25277	3.39	3.21	AP1
3	Soft	29	3722	40663	3.24	3.15	AP3, AP5, AP7
4	Weak	28	2601	42008	2.36	2.76	AP2
5	Rough	24	1839	15991	3.33	3.44	AP3
6	Smooth, Smooth Flowing	23	1983	20277	3.17	3.34	AP3
7	Calm, Calming, Calmness	22	2220	19229	2.95	3.25	AP9
8	Dull	22	2851	22798	2.86	2.95	AP6
9	Hard	21	2867	33675	3.38	3.31	AP7
10	Loud	21	3505	23001	3.14	2.64	AP5
11	Quite	21	4663	17248	3.24	2.76	AP5
12	Clear	20	1579	19244	3.05	3.00	AP4
13	Slow Tempo	17	1252	12366	2.71	2.51	AP8
14	Powerful	16	991	18638	2.50	2.24	AP2
15	Relaxation, Relaxed, Relaxing	16	1835	16257	3.00	3.58	AP13
16	Sharp	16	2663	12764	3.25	3.60	AP6
17	Strong	16	1669	25734	2.31	3.11	AP2
18	Light, Light Tone	15	1501	11775	2.07	2.14	AP11
19	Fast, Fast Tempo	14	912	6581	2.93	2.28	AP8
20	Bright	13	2989	26477	2.62	3.32	AP15
21	Comfort, Comfortable	13	1694	4527	3.54	3.60	AP16
22	Gentle	13	838	7222	3.15	2.98	AP12
23	Heavy	13	1442	11260	2.23	2.22	AP11
24	Simple	13	1372	11913	2.46	2.24	AP10
25	Tense, Tensed	13	756	15063	2.92	3.56	AP13
26	Uncomfortable, Discomfort	12	1654	4207	3.58	3.62	AP16
27	Harsh	12	869	10577	3.00	3.70	AP3, AP12
28	Noise, Noisy	12	1601	4715	3.25	3.30	AP18
29	Boring	11	1332	10245	3.00	2.62	AP19
30	Deep	10	506	10259	1.90	2.41	AP14
31	High	10	1606	10253	2.89	3.43	AP20
32	Beautiful	9	2581	24376	2.56	3.34	AP22
33	Dark	9	843	8701	2.33	2.51	AP15
34	Interesting	9	1268	8976	2.78	2.43	AP19
35	Low	9	843	8701	2.33	2.51	AP20
36	Natural	9	1407	5529	3.33	3.75	AP21
37	Shrill	9	498	11558	3.00	2.84	AP14
38	Ugly	9	1606	10253	2.89	3.43	AP22
39	Varied	9	1925	4260	2.78	3.34	AP10
40	Cold	8	373	22787	2.75	3.59	AP17
41	Complex	8	276	10597	2.13	2.27	AP10
42	Thin	8	229	4914	2.13	2.28	AP23
43	Warm	8	664	20635	3.25	3.82	AP17
44	Agitated, Agitating	7	1447	4679	2.29	2.25	AP9

No.	Descriptor	Number of included studies	Number of included participants	Number of included measurements	Average importance score per study#	Average importance score per measurement#	Involved in the adjective pair of the review
45	Artificial	7	1057	4019	3.14	3.67	AP21
46	Colourless, Not Colourful, Uncolourful	7	565	24546	2.57	3.41	AP25
47	Distinct	7	1181	6279	3.43	2.89	AP4
48	Far	7	1601	2717	1.71	1.70	N/A
49	Flat	7	674	3582	2.29	2.03	AP6
50	Harmonic, Harmonious	7	936	4591	3.86	3.90	AP24
51	Monotonous	7	978	6819	2.57	3.42	AP10
52	Sad	7	816	9597	0.71	1.89	N/A
53	Steady	7	1632	5950	1.57	1.99	N/A
54	Thick	7	210	4634	2.71	2.88	AP23
55	Cheap	6	305	6572	4.00	4.00	AP26
56	Colourful	6	330	22196	2.33	3.34	AP25
57	Full	6	309	20651	1.83	3.35	N/A
58	Happy	6	783	8607	0.67	1.99	N/A
59	Dislike	6	1117	1820	3.83	3.73	AP27
60	Like, Not Dislike	6	1117	1820	3.83	3.73	AP27
61	Meaningful	6	1135	2252	2.00	2.21	N/A
62	Near, Nearby	6	1110	2226	1.67	1.63	N/A
63	Reverberant, Reverberation	6	958	1178	1.50	1.84	N/A
64	Round, Rounded	6	345	8449	2.83	3.72	AP6
65	Not Stable, Unstable	6	250	2099	1.67	1.95	N/A

The importance score was set from 4 to 1 corresponding to the descriptor in the 1st, 2nd, 3rd, and 4th component/factor in the solutions of the studies. Zero important score was referred to the descriptor in the 5th or later component/factor or not in any component/factor of the solutions.

Table B.3

The content details of the 27 adjective pairs in the meta-analysis.

Item	Number of included studies (N_{stu})	Adjective pairs (N_{stu})
AP1	36	**Pleasant - Unpleasant (29);** Pleasing - Unpleasing (1); Pleased - Unpleased (1); Pleasing - Annoying (1); Pleasing - Disturbing (1); Not Unpleasant - Unpleasant (1); Not Annoying - Annoying (2)
AP2	35	**Weak - Strong (14);** Weak - Powerful (10); Weak - Not Weak (4); Not Strong - Strong (2); Not Powerful - Powerful (5)
AP3	28	**Rough - Smooth (17);** Rough - Not Rough (3); Rough - Soft (2); Harsh - Smooth (3); Jerking - Smooth Flowing (2); Not Smooth - Smooth (1)
AP4	26	**Clear - Not Clear (4);** Clear - Muddy (4); Clear - Dull (3); Clear - Hazy (2); Clear - Thick (2); Clear - Confusing (1); Clear - Distorted (1); Clear - Indefinite (1); Clear - Murky (1); Clear - Vague (1); Distinct - Dull (2); Distinct - Indistinct (1); Distinct - Not Distinct (1); Distinct - Hubbub (1); Distinct - Vague (1)
AP5	24	**Quiet - Loud (8);** Quiet - Clamorous (4); Quiet - Not Quiet (1); Soft - Loud (7); Not Loud - Loud (2); Silent - Loud (1); Calm - Loud (1)
AP6	22	**Sharp - Dull (9);** Sharp - Flat (4); Sharp - Not Sharp (3); Pointed - Rounded (1); Angular - Round (1); Angular - Rounded (2); Not Round - Round (2)
AP7	21	**Soft - Hard (18);** Soft - Not Soft (2); Not Hard - Hard (1)
AP8	21	**Slow - Fast (11);** Slow - Not Slow (2); Slow Tempo - Not Slow Tempo (1); Not Fast Tempo - Fast Tempo (1); Slow - Quick (2);
		Not Fast - Fast (4)
AP9	19	**Calming - Agitating (4);** Calm - Agitated (2); Calm - Agitating (1); Calm - Exciting (2); Calming - Exciting (1); Calm - Lively (1); Calm - Restless (1); Boring - Exciting (1); Boring - Thrilling (1); Dull - Lively (1); Quiet - Restless (1); Relaxed - Busy (1); Relaxing - Intense (1); Relaxing - Irritating (1)
AP10	19	**Simple - Complex (7);** Simple - Varied (5); Simple - Not Simple (1); Not Complex - Complex (1); Monotonous - Varied (3); Monotonous - Not Monotonous (1); Stereotyped - Varied (1)
AP11	15	**Light - Heavy (13);** Light - Not Light (2)
AP12	15	**Gentle - Violent (4);** Gentle - Active (1); Gentle - Harsh (4); Gentle - Not Gentle (2); Gentle - Hard (2); Tender - Violent (1); Tender - Harsh (1)
AP13	14	**Relaxed - Tense (11);** Relaxed - Not Relaxed (1); Not Tense - Tense (2)
AP14	14	**Deep - Metallic (4);** Deep - Shrill (3); Deep - Not Deep (1); Not Shill - Shrill (1); Calm - Shrill (5)
AP15	14	**Bright - Dark (8);** Bright - Dull (1); Bright - Not Bright (3); Bright - Opaque (1); Not Dark - Bright (1)
AP16	12	**Comfortable - Uncomfortable (7);** Comfort - Discomfort (5)
AP17	12	**Warm - Cold (5);** Warm - Not Warm (3); Mild - Cold (1); Not Cold - Cold (2); Hot - Cold (1)
AP18	11	**Noisy - Quiet (6);** Noisy - Calm (2); Noise - Not Noise (1);

Item	Number of included studies (N_{stu})	Adjective pairs (N_{stu})
		Noisy - Noiseless (1); Noisy - Not Noisy (1)
AP19	9	**Boring - Interesting (9)**
AP20	9	**High - Low (9)**
AP21	9	**Natural - Artificial (7);** Natural - Not Natural (1); Natural - Unnatural (1)
AP22	9	**Beautiful - Ugly (9)**

Item	Number of included studies (N_{stu})	Adjective pairs (N_{stu})
AP23	8	**Thin - Thick (5);** Thin - Not Thin (2); Thin - Rich (1)
AP24	7	**Harmonic - Discordant (4);** Harmonic - Disharmonious (2); Harmonic - Not Harmonious (1)
AP25	6	**Colourful - Colourless (5);** Colourful - Uncolourful (1)
AP26	6	**Cheap- Expensive (5);** Cheap- Luxurious (1)
AP27	6	**Like - Dislike (5);** Not Dislike - Like (1)

Bold: the representative of the adjective pairs.