https://doi.org/10.1016/j.apacoust.2020.107570

Title

Effects of environmental sound quality on soundscape preference in a public urban space

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Abstract

A public urban space is undoubtedly one of the key elements in urban planning. It allows citizens with different backgrounds to freely accesses for various healthy, social, or individual reasons. User experience of the space is hence valuable data for the improvement of urban land use. This study aims to investigate how the environmental sound quality influence visitors' soundscape perceptions, preferences, and behavior. Multidimensional acoustics characterization, in terms of a series of acoustic and psychoacoustic metrics, of the acoustic environment were conducted in the five locations at Sha Tin Park of Hong Kong. Meanwhile, self-administrated questionnaires were distributed to the visitors in the locations to collect the subjective data. Total 150 visitors were surveyed. The results indicated that the visitors' loudness and satisfaction perceptions were associated with the maximum sound levels (L_{Amax} and N_{max}) instead of the time-equivalent sound levels (e.g. L_{Aeq} and N_{eq}) of the environment. Moreover, it was found that the higher degree of satisfaction was predicted if the visitors perceived a more quiet and pleasant soundscape. In addition, the preferences for soundscape elements could be classified into the three principal components "*Natural sounds*", "*Human-made sounds*", and "*Mechanical sounds*". Furthermore, visitors had a greater overall preference for a good soundscape when they perceived a more pleasant soundscape, had a higher preference for natural sounds, and had a higher visit frequency of the park. These findings consolidated the knowledge on further environmental management and designs of public urban spaces to fulfil the public expectation.

Keywords: multidimensional acoustic characterization, public urban space development, psychoacoustic metrics, soundscape perceptions, soundscape preferences

1. Introduction

Successful public space designs are usually at the top of the agenda for urban planning of global cities [1-4]. A public space is an essential element of cities to fulfil the daily needs of the general public. For an ideal public space, "accessibility", "environment and facilities", "public utilization", and "sociability" are the four prerequisites to be achieved [5]. A public space serves as a buffer area to balance the high-density urban environment. The dissatisfaction of the environment affects not only the users' experience but also their willingness to revisit. The public utilization and sociability will therefore be failed because of the poor environmental quality. An urban park that allows citizens to escape from their stressful life is a valuable resource in cities [6]. Environmental management of parks is therefore extremely important for the teeming metropolises [7] in high-density and overcrowded living conditions. How to provide a pleasant environment to the city-users of parks is always in the top priority of urban planning. Unlike the parks at countryside [8, 9], noise from high traffic flow [10-13] and various human activities [14] are unavoidable in urban parks. Moreover, the creation of a restorative environment is linked with the pleasant acoustic environment [15-17]. Hence, a holistic soundscape evaluation was conducted in this study to assess the environmental sound quality in the different locations at an urban park of Hong Kong, the visitors' soundscape perceptions and preferences, and their behavior. The findings of the relationships between the objective acoustic environment and the visitors' subjective responses will be useful for the future environmental management of urban parks as well as other public spaces.

The concept of soundscape, integrating the objective characteristics and subjective perceptual form of acoustic environment to find out the preferred sound settings, was firstly introduced at the end of 1960s [18]. The awareness of soundscape in community-based noise policy development has increased over the past half century [19, 20]. The multi-party needs of "acousticians", "city-users" and "planners" should be considered in a holistic soundscape evaluation [21] (see Fig. 1). Furthermore, the international standard ISO 12913 - 1 [22] gives a clearer definition and conceptual framework of soundscape, and ISO 12913-2 [23] standardizes the data collection and reporting requirements of soundscape. The idea of soundscape is hence defined to be "*Acoustic environment as perceived or experienced and/or understood by a person or people, in context*" [22]. Comparing with the traditional noise management, soundscape approach emphasizes that environmental sounds are regarded as resources (not wastes), loudness is not an only perception of sounds, the responses to different sound sources need to be differentiated, noise level reduction is not equal to the improvement of acoustic environment, measurements of the psychoacoustics metrics other than sound pressure level (SPL) are required [24, 25].

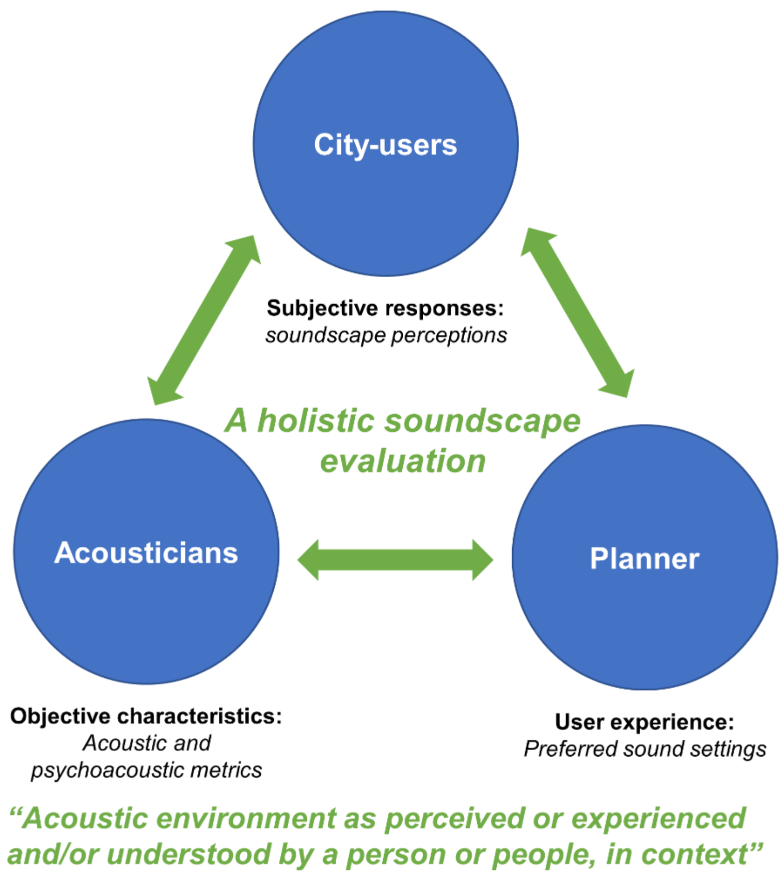

Fig. 1. The schematic diagram of the multi-party needs in a holistic soundscape evaluation.

A proper selection of physical metrics and subjective variables is the first step to successfully establish the predictable relationships in environment-human interactions. The systematic review of the human perceptual dimensions of sounds [26] provided an insight into the human perceptual form of sounds. A completed evaluation of any acoustic environment should cover the three perspectives "*Evaluation*", "*Potency*", and "*Activity*", which are general judgment, sensation of sound energy content, and sensation of temporal and spectral content of sounds, respectively. Therefore, psychoacoustic metrics and statistical noise levels were supplemented to the traditional sound measurements relied on unweighted SPL (L_Z) and A-weighted SPL (L_A) [27, 28]. Psychoacoustic metrics is a series of metrics to estimate the actual sensations of sounds based on the psychoacoustical scale (Bark scale) proposed by Eberhard Zwicker in 1961 [29]. Total loudness (N), estimation of loudness sensation, is the most familiar psychoacoustic metric. ISO 532-1 [30] standardizes the calculation method of N considering the transmission characteristics of the middle ear structure and the relationships between sound stimuli and loudness judgments [31]. Moreover, the spectral content of acoustic environment was characterized by the measurement of Sharpness (S) which is the psychoacoustic metric to estimate the sharpness sensation by calculating the energy skewness of sounds [29]. It is common to have the measurement of statistical noise levels if the noise level of the targeted sound sources such as traffic noise [32] and industrial noise [33] is much higher than the background noise level. More attention is paid to the time distribution of the significant noise sources rather than the time-equivalent noise level. For example, the acoustical influence of significant noise sources is estimated by L_{A10}, representing the noise level exceeded for 10 percent of the elapsed time. The temporal content of acoustic environment can hence be characterized by different statistical noise levels. The detail of the multidimensional characterization of acoustic environment will be explained in the Method section.

Assessments of subjective responses to acoustic environment are of equal importance to objective characterization. Semantic differential scale is the psychometric scale proposed by

Osgood in 1952 [34] to quantify the meaning of things. The applications of the semantic differential scale are not rare in the soundscape studies of urban parks [35-37], but there are the great variation in the selection of perceptual responses. Some of the studies focused on the *Evaluation* and *Activity* perspectives [36] but some of them focused on the *Potency* and *Activity* perspectives [37]. With the help of the found perceptual structure of sound [24], the role and need of the three fundamental perspectives in subjective evaluation were further discovered [38, 39]. Both *Evaluation*, *Potency*, and *Activity* perspectives should be considered in any soundscape evaluation. The requisite for the evaluation of the fundamental perceptions was also checked in this study. Apart from the fundamental perceptions, subjects' satisfaction perception was also found to be an indicator of the quality of urban park [40, 41]. More importantly, the visitors' environmental preference [42] is associated with their visiting experience of parks, and it will affect their behavior such as visit pattern [43]. The huge variation between different-background users is a difficulty in urban planning of public spaces. Different user responses can be obtained for a same environmental setting. It is hard to have an absolute cut-off of good soundscapes quality. Therefore, the preference assessments of this study attempted to differentiate the visitors' responses to different individual sound sources and then to extract the covariance of the responses to find out the predictive principal components. The results will be beneficial to the designs of pleasant urban environment for general public.

2. Materials and methods

2.1.Soundscape evaluation

Hong Kong is a teeming metropolis of extraordinary high population (7.34 millions) and high population density (6777 persons per km^2 of land area) [44]. The median of the residential area of a 4-person family is only 44 m^2 [44]. Therefore, urban spaces such as public parks in their living area have a key role to provide the restorative environment that allow people to escape from their stressful life and crowded living environment. Sha Tin Park of Hong Kong [45] is one of the public urban parks with a high visitor flow rate. It is managed by the leisure and cultural services department of Hong Kong Special Administrative Region. It occupies 8.05 hectares of land and located along the Shing Mun River. It is also situated next to plaza, city hall, public library, cycle track and roads. North and South gardens of the Park are the two popular rendezvous of visitors. Therefore, the soundscape evaluation was conducted in the locations of the five facilities at the Park in a random weekday (see Fig. 2). The five locations were labeled to be G1 (North garden), P1 (North garden children playground, P2 (South garden children playground), G2 (South garden), and G3 (South garden entrance). People with self-reported hearing problems were excluded in the study. An oral informed consent was obtained from everyone prior to any evaluation. The evaluation day was a fine day (not raining) with low wind speed. The means of the temperature, humidity, and wind speed of the assessed environments were 25.8 ˚C, 87 %, and 3.5 ms^{-1}, respectively.

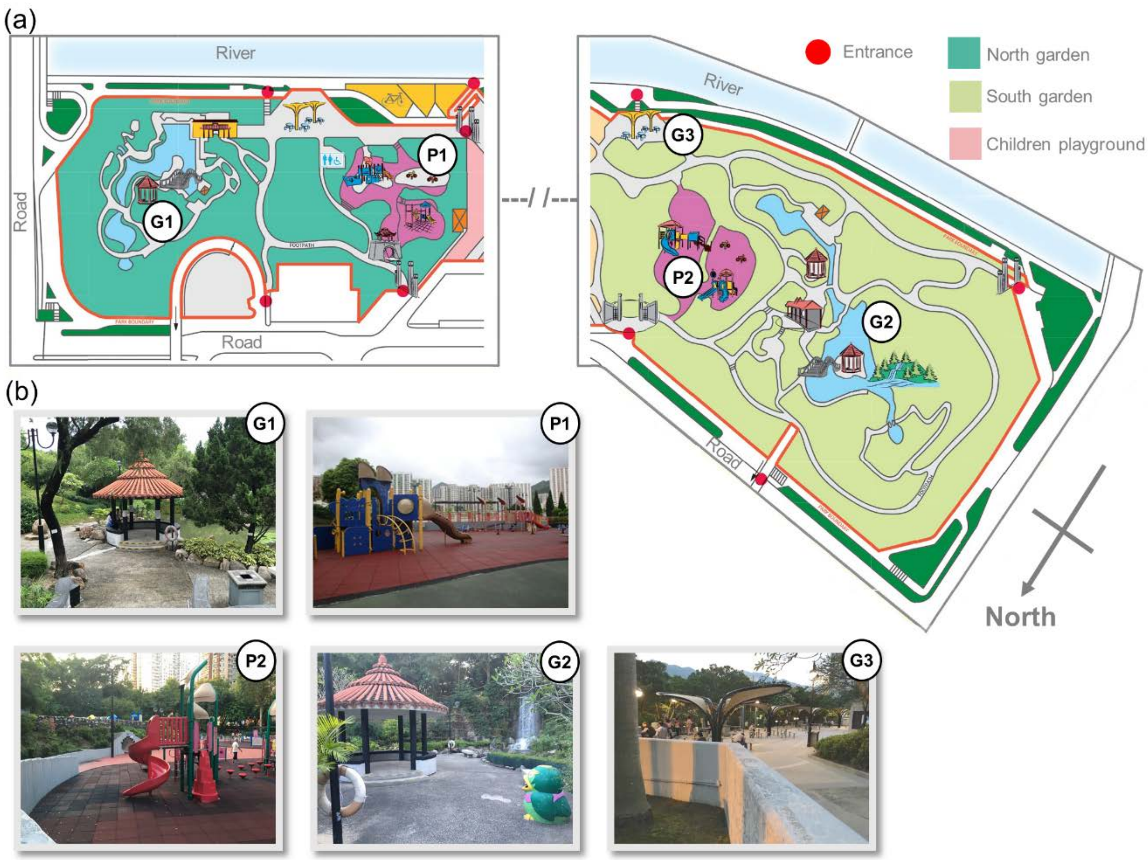

Fig. 2. (a) Park map of the North and South gardens of Sha Tin Park of Hong Kong (full map of the park: https://www.lcsd.gov.hk/en/parks/stp/layout.html); (b) onsite photos of the five evaluated locations.

2.1.1. Multidimensional acoustic characterization

The objective characteristics of the acoustic environment of the five locations were measured by the advanced, two-channel, handheld analyzer (Type 2270; Bruel & Kjaer, Naerum, Denmark). The elapsed time of each measurement was 10 minutes. The values of time-equivalent (L_{Zeq} and L_{Zeq}), maximum (L_{Zmax} and L_{Amax}), and 10%, 50%, and 90% (L_{A10}, L_{A50}, and L_{A90}) sound levels in the acoustic environment were directly recorded by the internal sound level meter software of the analyzer. For the calculation of the psychoacoustic metrics, 24-Bark band spectrum of specific loudness (*N'*) was converted from the 1/3 octave band spectrum of L_z. The conversion method was based on ISO 532-1 [30]. The value of *N* was the sum of *N'* over the 24 Bark bands, while the value of *S* was calculated with the help of the critical-band-rate dependent. The larger degree of the skewness of sound energy to high frequency the higher value of *S* is. The derivation of the psychometrics metrics can refer to the Zwicker's book [29]. Moreover, the change in noise level due to the significant noise sources at the environment was represented by the value of L_{A10} - L_{A90}.

2.1.2. Subjective assessment

The subjective responses of the park visitors were recorded by a self-administrated questionnaire (see Table 1) after the objective acoustic measurements. Part I of the questionnaire was the four questions about the visitors' background information of gender and their visit behaviour in terms of frequency, duration, and aim. Part II was the four semantic differential questions about the visitors' soundscape perceptions of the acoustic environment. The first three questions (*Evaluation*: Unpleasant – Pleasant; *Potency*: Quiet – Loud; *Activity*: Simple – Varied) were based on the three fundamental human perceptual dimensions of sounds [26], and the fourth question was about the visitors' satisfaction perceptions of the acoustic environment. After that, the visitor preferences for the 11 soundscape elements (sound of/from bird, water, wind, insect, human activity, music, pet, chatting, children playing, traffic, and construction), and their overall preference for a good soundscape were also recorded in Part III and IV, respectively. The score of the questions was ranged from 1 to 5 instead of -2 to 2 in some sematic differential method applications. For example, the response of "Very unpleasant", "Slightly unpleasant", "Neutral", "Slightly pleasant" and "Very pleasant" was coded to be 1 to 5 for the further statistical analyses.

Table 1

Summary of the questions in the self-administrated questionnaire survey.

Parts	Questions	Number of Questions	Scales
Part I: Background information	Gender; Visit frequency; Duration of staying; Aim of the visit	4	Nominal and Ordinal
Part II: Soundscape perceptions	Unpleasant – Pleasant (Pleasantness); Quiet – Loud (Loudness); Simple – Varied (Sound variation); Not satisfied – satisfied (Satisfaction)	4	Semantic differential scale (1-5)
Part III: Preferences for soundscape elements	Bird sound; Water sound; Wind sound; Insect sound; Human activity sound; Music; Sound from pet; Chatting sound, Sound from children playing; Traffic sound; Construction sound (Not to be preferred – To be preferred)	11	Semantic differential scale (1-5)
Part IV: Overall preference for a good soundscape	Overall soundscape (Not to be preferred – To be preferred)	1	Semantic differential scale (1 -5)

Notes. The variables “Pleasantness”, “Loudness”, and “Sound variation” represented the evaluation on the three fundamental perceptual dimensions of sounds “*Evaluation*”, “*Potency*”, and “*Activity*”, respectively.

2.2.Statistical Analyses

All the data from statistical analyses were coded and analysed by the commercial package SPSS, version 23.0 (IBM Corp., Armonk, NY, USA). All statistical tests were two-tailed tests with the significance level of 0.05. The normality of the objective and subjective data was checked for the selection of suitable statistical tests. The nonparametric tests such as Mann-Whitney U tests, Kruskal-Wallis tests, and Spearman's rank correlation tests would be applied for the non-normal distributed data. Mann-Whitney U tests or Kruskal-Wallis tests were applied to test the differences of the acoustic characteristics (or the subjective responses) between the different locations at the park. Spearman's rank correlation tests were applied to test the correlations between the acoustic characteristics and subjective responses, or the correlations between the different subjective responses. Moreover, an principal component analysis (PCA) [46] was used to extract the dominant pattern of the measured variance of the preferences for soundscape elements. If the principal components were successfully extracted, the scores of the corresponding questions would be summed up in a factor scores for further statistical analyses. Furthermore, the stepwise linear regressions were applied for the visitors' general satisfaction and their overall preference for a good soundscape.

3. Results

3.1.Statistical description of subjects

A total of 30 valid questionnaire surveys were collected at each evaluated location. Total 150 completed and valid questionnaires were therefore collected. About one third (28.7%) of the visitors were male (see Fig.3). Nearly half (49.3 %) of the visitors visited Sha Tin Park every day, and nearly one third (35.5%) of them visited the park 3-4 times per week. The percentages of the visitors staying < 30 mins, 30 - 60 mins, 60 - 120 mins, > 120 mins at the park were respectively 19.3%, 53.3%, 16.0%, and 11.4%. The three most popular aims of the visit were playing with children (32.0%), sports (24.7%), and rest (14.6%).

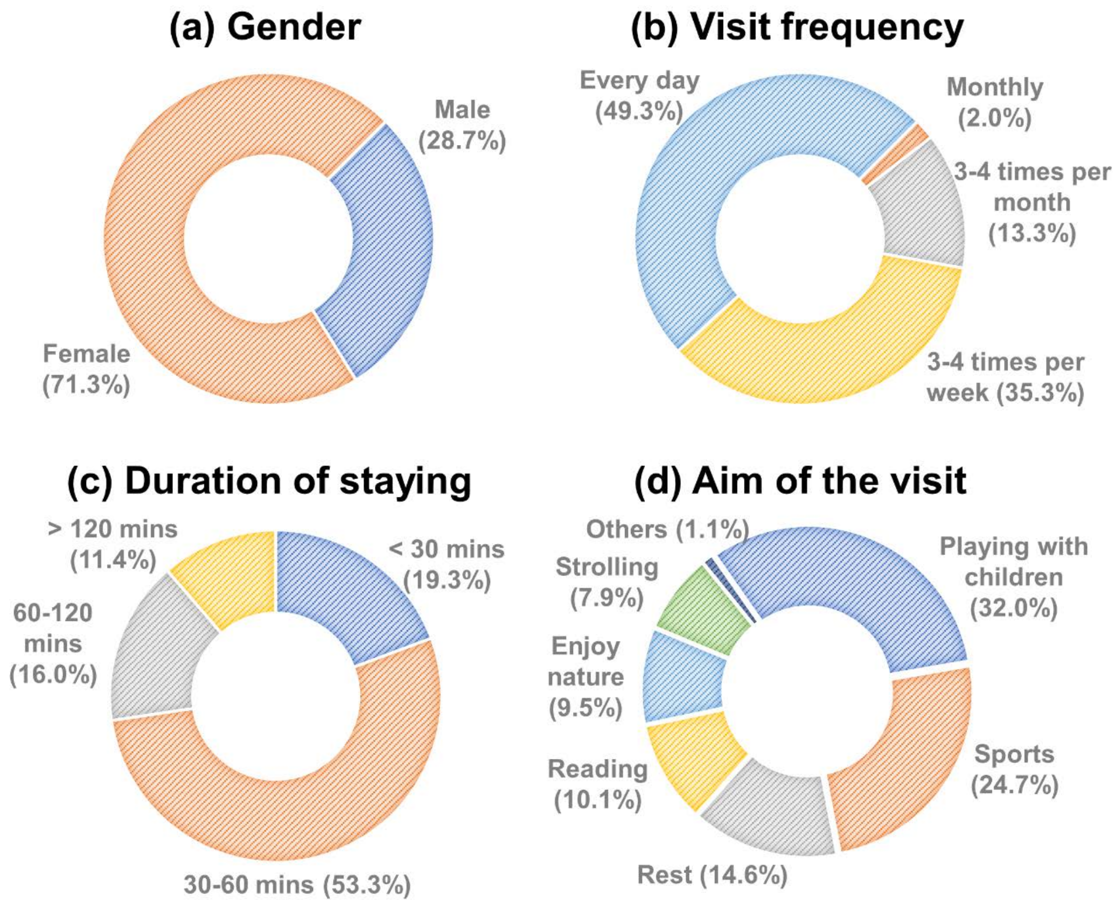

Fig. 3. The distribution of the subjects' characteristics: (a) gender; (b) visit frequency; (c) duration of staying; and (d) aim of the visit.

Characteristics of the acoustic environment

The objective characteristics of the five evaluated locations at Sha Tin Park were recorded in Table 2. The lowest average noise level (in terms of L_{Zeq}, L_{Aeq}, and N_{eq}) was measured at South garden (G2). However, the maximum noise level (in terms of L_{Zmax}, L_{Amax}, and N_{max}) was measured at the North garden children playground (P1). The lowest S_{eq} and the largest L_{A10}-L_{A90} were also recorded at P1.

Table 2

Measured acoustic metrics in the five locations at Sha Tin Park of Hong Kong.

Point	L_{Zeq} [dB]	L_{Aeq} [dBA]	N_{eq} [sone]	S_{eq} [acum]	L_{Zmax} [dB]	L_{Amax} [dBA]	N_{max} [sone]	L_{A10} [dBA]	L_{A50} [dBA]	L_{A90} [dBA]	L_{A10} - L_{A90} [dBA]
G1	63.9	59.5	13.3	1.63	81.7	77.1	44.0	62.3	51.1	45.7	16.6
P1	64.1	61.9	11.6	1.22	82.9	82.1	44.3	65.6	54.2	48.4	17.2
P2	63.1	60.3	11.0	1.29	81.5	80.6	40.3	64.1	52.6	47.8	16.3
G2	60.6	50.8	7.29	1.58	79.8	76.9	37.3	51.4	47.4	46.1	5.3
G3	64.3	61.8	13.2	1.44	78.4	77.6	34.7	65.7	59.3	53.4	12.3

Notes. G1 = North garden, P1 = North garden children playground, P2 = South garden children playground, G2 = South garden, G3 = South garden entrance, L_Z = unweighted sound pressure level, L_A = A-weighted sound pressure level, N = total loudness, S = sharpness, $_{eq}$ = time-equivalent, $_{max}$ = maximum, $_{10/50/90}$ = percentiles of 10/50/90%.

3.2.Soundscape perceptions

In general, the acoustic environment of North garden children playground (P1) was perceived to be the loudest and the least variated (see Table 3). The acoustic environment of North garden (G1) was perceived to be most pleasant and satisfying. After grouping the locations into two major environments (garden and playground), the environment of garden was perceived to be significantly more quiet, pleasant, varying and more satisfying than that of playground ($ps < 0.05$ in Mann-Whitney U tests). The Spearman's rank correlation test results ($ps < 0.05$, see Table 4) showed that the higher the values of L_{Amax}, N_{max}, L_{A10} - L_{A90} the higher degree of loudness perception but lower degree of satisfaction perception was. The L_{Amax} increment would significantly lower the visitors' pleasantness perception. The value of S_{eq} was significantly correlated with the perception of sound variation.

Table 3

Subjects' soundscape perceptions in the five evaluated locations of Sha Tin Park of Hong Kong.

Location (Point)	**Mean (Standard deviation)**			
	Pleasantness	**Loudness**	**Sound variation**	**Satisfaction**
North garden (G1)	4.77 (0.43)	2.37 (0.77)	2.47 (0.97)	4.60 (0.56)
North garden children playground (P1)	3.33 (0.96)	3.40 (0.97)	1.80 (1.06)	2.73 (0.79)
South garden children playground (P2)	3.67 (1.03)	3.07 (1.05)	2.17 (1.23)	3.37 (1.07)
South garden (G2)	3.63 (0.85)	2.57 (0.63)	2.30 (0.95)	3.60 (0.93)
South garden entrance (G3)	4.40 (0.72)	1.90 (0.66)	2.50 (0.82)	4.40 (0.68)
Garden (G1 - G3)	4.27 (0.83)	2.28 (0.74)	2.42 (0.91)	4.20 (0.85)
Playground (P1 & P2)	3.50 (1.00)	3.23 (1.02)	1.98 (1.16)	3.05 (0.98)
Mann-Whitney U test (G vs P)	***	***	0.015	***
Kruskal–Wallis test (G1 vs G2 vs P1 vs P2 vs P3)	***	***	0.004	***
Post-hoc tests	G1 > G3 > G2 = P1= P2	G3 < G1 = G2 < P1 = P2	G1 = G2 = G3 = P2 > P1	G1 = G3 > G2 > P2 > P1

Notes. ****p* < 0.001 in a Kruskal–Wallis test or a Mann-Whitney U test of a soundscape perception in different locations or in different environments of the park.

Table 4

Spearman's rank correlation coefficients between the acoustic characteristics and the subjects' soundscape perceptions.

Variable	Pleasantness	Loudness	Sound variation	Satisfaction
S_{eq}	0.41***	-0.37***	0.22**	0.54***
L_{Amax}	-0.24**	0.34***	-0.20*	-0.40***
N_{max}	-	0.40***	-1.83**	-0.31***
L_{A10} - L_{A90}	-	0.30***	-	-0.20*

Notes. *p < 0.05; **p < 0.01; ***p < 0.001 in a Spearman's rank correlation test.

In the stepwise linear regression of satisfaction perception, the loudness and pleasantness perceptions were remained in the model (see Table 5). Four independent variables (gender, visit frequency, duration of staying, sound variation perception) were excluded as their *ps* ≥ 0.05. The visitors' satisfaction perception was predicted to be increased by 0.54 unit for each unit-increment of pleasantness perception and to be decreased by 0.39 unit for each unit-increment of loudness perception.

Table 5

Stepwise linear regression of subjects' satisfaction from other soundscape perceptions.

Dependent variable (y)	Predictor variable	B (SEB)	95% CI	β	P
Satisfaction	**Pleasantness**	0.59 (0.06)	[0.47, 0.71]	0. 54	< 0.001
	Loudness	-0.43 (0.06)	[-0.55, -0.31]	-0.39	< 0.001
	y-intercept	2.5 (0.35)	[1.84, 3.24]		< 0.001

Notes. B = unstandardized coefficient, SEB = standard error of B, CI = confidence interval for B, β = standardized coefficient. R^2 = 0.67, F (2,147) = 149.8, p < 0.001.

3.3.Soundscape preferences

The most preferable soundscape element was the bird sound (M = 4.55, SD = 0.67; see Fig. 4) in the environment. The most undesirable element was the construction sound (M = 1.43, SD =

0.72) in the environment. High degree of overall preference for a good soundscape (*M* = 4.49, *SD* = 0.78) was also recorded. Two third (66%) of the visitors strongly preferred for a good general soundscape. In order to have a better illustration of the variance pattern, the Spearman's rank correlation test results of the soundscape elements were plotted in Fig. 5. The numbers in Fig.5. were the Spearman's rank correlation coefficients of the row and column elements. The dominate pattern of the soundscape preferences was investigated by the PCA that run on the 11 elements. The overall Kaiser-Meyer-Olkin (KMO) was measured to be 0.65 which indicated the sampling is mediocre adequacy [47]. Bartlett's test of sphericity was statistically significant ($p < 0.001$), indicating the sufficiently large correlations between the elements in the components. A varimax rotation was applied for a better interpretation of the PCA result (see Table 6). The eigenvalues of the three components were found to be greater than 1. The three-component solution explained 52.8% of the total variance. The 1st component, named as "*Natural sounds"*, was formed by four soundscape elements "Bird", "Water", "Wind", and "Insect". The 2nd component, named as "*Human-made sounds"* was formed by five soundscape elements "Human activity", "Music", "Pet", "Chatting" and "children playing". The remained two elements "Traffic" and "Construction" were grouped into the 3rd component "*Mechanical sounds*". The means of the preference scores of *Natural sounds*, *human-made sounds* and *Mechanical sounds* were 17.0 units (*SD* = 2.63) out of 20 units, 14.2 units (*SD* = 3.08) out of 25 units, and 3.39 units (*SD* = 3.39) out of 10 units, respectively.

	Mean (*SD*)	Strongly not to be preferred (1)	Not to be preferred (2)	Neutral (3)	To be preferred (4)	Strongly to be prefered (5)
Bird	4.55 (0.67)	0.67%	0.67%	4.00%	32.67%	62.00%
Water	4.16 (0.79)	1.33%	1.33%	12.67%	49.33%	35.33%
Wind	4.16 (0.92)	1.34%	5.37%	11.41%	39.60%	42.28%
Insect	4.13 (1.09)	2.01%	10.07%	11.41%	25.50%	51.01%
Activity	2.77 (0.93)	5.33%	38.67%	32.67%	20.67%	2.67%
Music	3.03 (1.10)	3.33%	36.00%	26.67%	22.00%	12.00%
Pet	3.35 (1.00)	2.67%	16.67%	37.33%	30.00%	13.33%
Chatting	2.50 (0.96)	10.00%	49.33%	25.33%	11.33%	4.00%
Children playing	2.55 (0.97)	7.33%	52.00%	24.67%	10.67%	5.33%
Traffic	1.96 (0.74)	23.33%	62.00%	11.33%	2.00%	1.33%
Construction	1.43 (0.72)	66.00%	28.67%	3.33%	0.67%	1.33%
A good soundscape	4.49 (0.78)	0.00%	1.33%	14.00%	18.67%	66.00%

Percent: 100, 75, 50, 25, 0

Fig. 4. Subjects' preferences for the different soundscape elements and a good overall soundscape of urban parks.

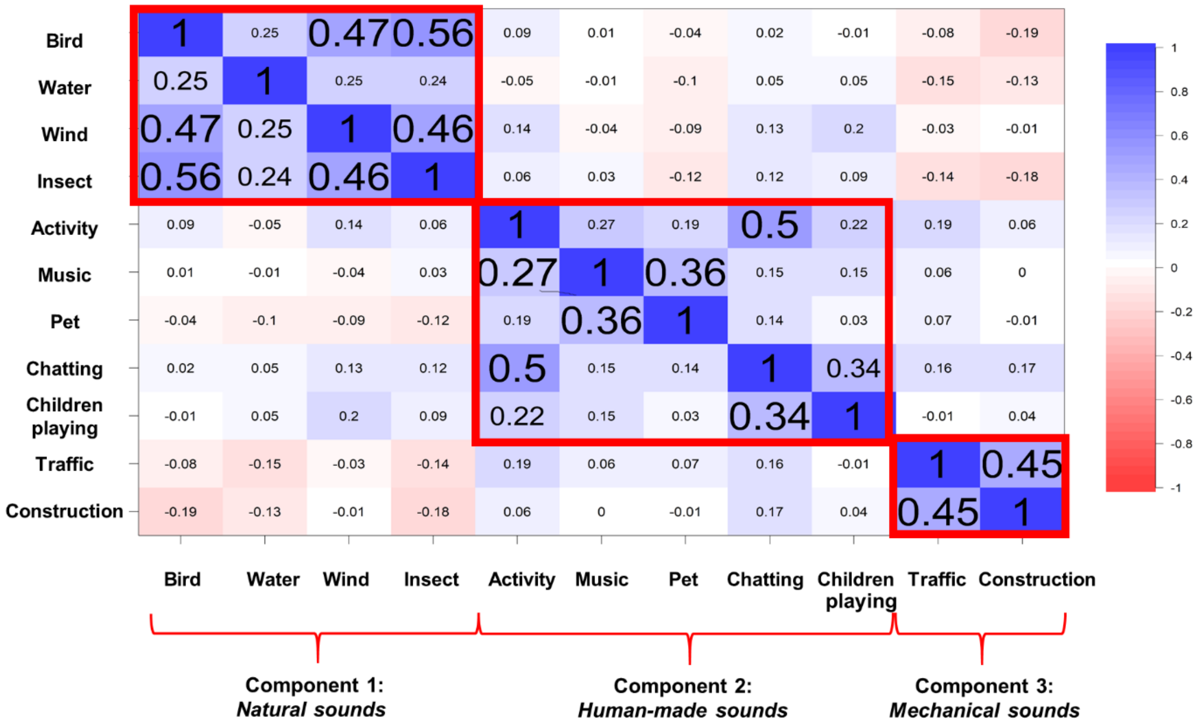

Fig. 5. A heatmap of the correlations between the preferences for the 11 soundscape elements according to the magnitude of Spearman's rank correlation coefficients.

Table 6

Results of the principal component analysis of the subjects' preferences for the 11 soundscape elements.

***Principal* component (*PC*)**	**Variable**	***PC1***	***PC2***	***PC3***
Natural sounds	**Bird**	0.79	-	-
	Water	0.77	-	-
	Wind	0.75	-	-
	Insect	0.50	-	-
Human sounds	**Activity**	-	0.69	-
	Music	-	0.69	-
	Pet	-	0.62	-
	Chatting	-	0.61	-
	Children playing	-	0.45	-

Mechanical sounds	**Traffic**	-	-	0.79
	Construction	-	-	0.73
Eigenvalue		2.28	1.94	1.58
% of variance explained		20.7	17.7	14.4
Cumulative % of variance explained		20.7	38.4	52.8

Notes. Extraction method: principal component analysis (PCA). Rotation method: varimax with Kaiser normalization. Rotation converged in 7 iterations. Kaiser-Meyer-Olkin measure of sampling adequacy = 0.65. Bartlett's test of sphericity χ^2 = 288.3; df = 55; p < 0.001. Factor loading of an absolute value < 0.04 were suppressed.

In the stepwise linear regression of the visitors' overall preference for a good soundscape, 10 independent variables (background information: gender, visit frequency, and duration of staying; soundscape perceptions: pleasantness perception, loudness perception, sound variation perception, and satisfaction perception; preferences for soundscape elements: *natural sounds*, *human-made sounds*, and *mechanical sounds*) were input into the model. Three variables (pleasantness perception, preference score for *natural sounds*, and visit frequency) were finally remained in the final model (see Table 7) with *ps* < 0.05. For the visitors who perceived a more pleasant acoustic environment, had a higher degree of the preference for natural sounds, and higher visit frequency, they would have a significantly higher overall preference for a good soundscape of the park.

Table 7

Stepwise linear regression of subjects' overall preference for a good soundscape.

Dependent variable (y)	**Predictor variable**	**B (SEB)**	**95% CI**	***β***	***p***
Overall preference for a good soundscape	**Pleasantness**	0.26 (0.60)	[0.15, 0.38]	0.33	< 0.001

Preference score of *Natural sounds*	0.07 (0.02)	[0.03, 0.12]	0.25	0.001
Visit frequency⁺	0.17 (0.07)	[0.03, 0.32]	0.18	0.017
y-intercept	1.44 (0.51)	[0.42, 2.45]		0.006

Note. B = unstandardized coefficient, SEB = standard error of B, CI = confidence interval for B, β = standardized coefficient. $R^2 = 0.22$, F (3,146) = 13.9, $p < 0.001$. ⁺ The response to the question of visit frequency was coded into an ordinal variable (1 = Monthly, 2 = 3-4 times per month, 3= 3-4 times per week, 4 = every day).

4. Discussion

4.1.Principal results

The time-equivalent sound levels of the five locations were more or less the same. The relatively higher value of L_{Amax} and lower value of S_{eq} in the playground environment (P1 and P2) illustrated that acoustic environment was influenced by human activities at the locations. Since the critical-band-rate dependent in S calculation increases the weighing for the frequency component > 1 kHz, in other words, the S decrement means that more low-frequency noise is added to the environment. For this case, human voice, as a low-frequency sound source [48], could account for the L_{Amax} increment but S decrement at the locations P1 and P2. More importantly, the results showed that the objective characterization was not enough to rank the environmental sound quality without the support of subjective data. The analysis of the visitors' perceptions provided the additional evidence that the environmental sound quality can affect the perceptual responses of people. The Mann-Whitney U test results showed that the perceived environment of playground was significantly worse than that of garden. The correlation analysis between the objective characteristics and perceptual responses gave an insight into the proper selection of environmental indicators. The significant correlations of the metrics L_{Zmax}, L_{Amax}, and N_{max} and the loudness perception illustrated that the monitoring of the maximum noise level from the significant noise sources was more important than that of the time-equivalent noise level that applied in traditional environmental monitoring. The visitors were more sensitive to the relative changes in acoustic environment rather than the absolute background noise level. It is interesting that the visitors' perception of sound variation was negatively correlated with L_{Amax}, and N_{max} increments but positively correlated with the S_{eq} increment. The psychoacoustic metric S is sensitive to the spectral content of sounds, in some extent the results reflected that the perception of sound variation was affected by the spectral content more than the energy content of sounds. The requisite for the evaluation on the three fundamental perceptual dimensions of sounds was also demonstrated. Not only the drop of loudness perception but also the growth of pleasantness perception was associated with the drop of L_{Amax}. The regression result of the satisfaction perception further emphasized the needs of a more quiet and pleasant environment for improving the visitors' environmental satisfaction in their visit experience.

If the perceptual responses of the soundscape were the short-term environmental influence on visitors, the responses of the preferences could be regards as the long-term influence combining the daily experience of the visit. Nearly 85% visitors showed their overall preference for a good soundscape. The demand for the pleasant acoustic environment was hence demonstrated. It was clear that the majority of the visitors had a high preference for the natural sounds in their environment. It explained why the preference score of natural sounds was one of the significant predictors of the overall preference of a good soundscape. For the preference of human-made sounds, the responses were slightly distributed towards "Not to be preferred". Although human-made sounds were the significant noise sources in the environment of the park, the existence of the sounds were somehow understandable and acceptable. Nonetheless, mechanical sounds were definitely undesired in the park environment. Apart from the preferences for soundscape elements, the visitors' behavior in respect of visit frequency also affected their expectation on the general soundscape. The daily user of the park revealed their strong preference for a pleasant acoustic environment. The results of the study were consistent with the other studies that there were the mutual interactions between subjects' behavior, soundscape expectation, and soundscape perceptions [49, 50].

4.2.Limitations and future work

Although the soundscape evaluations were conducted in the different locations at the park, the spectral variation of the sounds in the similar acoustic environment may be inadequate to detect the effects of spectral variation on the visitors' perceptions such as pleasantness and satisfaction. More soundscape evaluations should be conducted at the different urban parks that contain different soundscape elements. The comparison of the visitors' soundscape perceptions in different environments will strengthen and clarify the findings of this studies. Moreover, the inclusion of other acoustic metrics in temporal and spatial aspects [51] and other psychoacoustic metrics such as annoyance, roughness and pleasantness [29] may help to account for the soundscape perceptions other than loudness.

One of the difficulties in managing outdoor environment is that noise controls cannot be simply done by the reduction of noise level. Unlike fixed mechanical noise sources [52-58] in indoor environment, outdoor environment is full random noise sources. The occurrence of the combined sounds such as bird, wind, people chatting, and traffic sounds occurred at a time is uncontrollable. Therefore, the maximum noise level of the environment is hard to be predicted. However, the study results found that the maximum noise level had the higher degree of influence on the visitors' perceptions. Extra environmental monitoring about the maximum noise level or temporal variation of the noise level is required for the noise management of outdoor environment. Moreover, the improvement of the soundscape environment will increase the number of visitors [59] and hence the human-made sounds will be produced. Reduction of public utilization for soundscape improvement is put the cart before the horse. That is why the differentiation of the preferences for different soundscape element is important. Even though less effort can be put into the unavoidable sounds, noise masking with the preferable sounds is a possible solution to modify the built public environments. The study result agreed with the other studies finding that the increased opportunities to expose to natural sounds [60] especially water sound [61-63] can promote the users' experience of visit.

This study only focused on the subjective responses of soundscape perceptions and preferences, the effects of noise on health quality such as physiological [64] and psychological responses [65, 66] were not included. A more complicated designs is needed for the integrated analyses of the relationships between the subjective responses of sound quality and other variable such as health quality [67], age, education levels [43], gender [64], and nationality [68].

5. Conclusion

The sound quality of playground environment was found to be significantly different from that of garden environment in Sha Tin Park of Hong Kong. In spite of the similar time-equivalent environmental noise levels, the garden environment was perceived to be more quiet, pleasant, and satisfying than the playground environment. The differences between the soundscape perceptions in the two environments were explained by acoustic characteristics L_{Amax}, N_{max}, and L_{A10} - L_{A90} about the maximum noise levels. Also, the perception of sound variation was more related to the variation of spectral content instead of energy content of sounds. Principally, the traditional L_{Aeq} monitoring is insufficient in predicting the perceptual influence of soundscape on visitors. The monitoring of maximum noise level and other metrics about the spectral and temporal content of acoustic environment is recommended. In addition, the analyses of the soundscape preferences from the visit experience provided an insight into the balance between the environmental improvement and the public utilization of urban parks. High, medium, and low preferences were found for natural sounds, human-made sounds, and mechanical sounds in the environment, respectively. Insertion of natural sounds and elimination of mechanical sounds will be the two main directions of the soundscape development. Better allocation of public spaces to effectively spread out people will also be a solution to reduce the level of human-made sounds. In general, high proportion (85%) of the visitors preferred for a good soundscape. The higher the visit frequency of the visitors, the great degree of their general preference for a good soundscape was. These user experience from the daily visitors is the most valuable information for the noise management of the park. The knowledge on successful urban public space designs will be reinforced with the found associations between objective characteristics and subjective responses of environmental sound quality.

Funding

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

Declarations of interest

None.

Acknowledgements

The master student Yin Park Lui as well as the undergraduate student Po Yee Tam from The Hong Kong Polytechnic University are acknowledged for their assistance in questionnaire design, on-site measurements and data collection.

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