Perception of urban park soundscape

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A number of studies have been initiated to explore how to improve the soundscape quality in urban parks. However, good soundscape quality in parks cannot be provided without a thorough understanding of the complex relationships among sound, environment, and individuals. As acoustic comfort is considered to be an important outcome of soundscape quality, this study investigates the relative impacts of the factors influencing acoustic comfort evaluation by formulating a multivariate ordered logit model. This study also explores the inter-relationships among acoustic comfort evaluation, acceptability of the environment, and preference to stay in a park using a path model. A total of 595 valid responses were obtained from interview surveys administered in four parks in Hong Kong while objective sound measurements were carried out at the survey spots concurrently. The findings unveil that acoustic comfort evaluation, besides visual comfort evaluation of landscape, also plays an important role on users' acceptability of the urban park environment. Compared with all the studied acoustic related factors, acoustic comfort evaluation serves as a better proxy for park users' preference to stay in urban parks. Hearing the breeze will significantly increase the likelihood of individuals in giving high acoustic comfort evaluation. Conversely, hearing the sounds from heavy vehicles or sounds from bikes will significantly reduce the likelihood in giving a high acoustic evaluation. © *2012 Acoustical Society of America*. [http://dx.doi.org/10.1121/1.3693644]

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I. INTRODUCTION

Numerous benefits provided by public parks to ecological environments and public communities have led to an intense interest in understanding how a good urban park design can attract more visitors or make them stay longer. Visual aesthetic quality of landscape, particularly the beauty and exuberance of vegetation, has always been one of the primary focuses in a majority of park designs.[1] Recently, there is a growing body of evidence suggesting that soundscape quality also helps define quality of visitor experiences in parks.[2] Quiet, solitude and natural sounds are important characteristics for defining quality of visitors' experiences in parks,[3] and an intrusion of any unwanted noise is likely to detract from park experiences.[4]

Indeed, the soundscape of urban parks is quite complex as it comprises a mixture of many different types of sounds occurring simultaneously or separately in time. Some of the sounds may be pleasant or unpleasant, and some may have positive or adverse effects on peoples' well-being or health. The complex nature makes its informational content important in perception of soundscape quality.[5]

As there is a lack of comprehensive knowledge on the specific nature or information content of sounds that are directly associated with a good soundscape quality, many recent efforts have been diverted to revealing individuals' preferences for different types of sounds in the foreground.[6–8] Natural sounds like twittering of birds and falling water were more preferred, while mechanical sounds from road traffic were not welcomed in parks.[9,10] The types of sounds favored or disliked are found to be congruent with the context of environments. For instance, park users tended to dislike mechanical or human sounds more in a country park than those in an urban park.

All these attempts aim to reveal individuals' preferences for specific types and information characteristics of sounds that help define good soundscape quality in parks. However, it is still uncertain about what are the final preferred outcomes that can be derived from having a good soundscape in urban parks.[11] Conceivably, acoustic comfort, which is defined here as the state of mind that expresses satisfaction with the acoustic environments, must be one of the outcomes preferred by visitors in an urban park although it may not necessarily be the only preferred one. For instance, a visitor

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may also prefer a sense of naturalness in addition to high acoustic comfort in urban parks.

However, little has been known about what exactly influences individual's acoustic comfort evaluation. So far, acoustic comfort evaluation was only found to be moderately correlated with the noise level subjectively evaluated by an individual, and their inter-relationship was found to be different for different sound source types.[12] Hitherto, there is a lack of a holistic view on how to provide a comfortable soundscape in an urban park. This is of particular significance as it can provide valuable insights in formulating effective strategies for improving the acoustic comfort evaluation of urban parks. Accordingly, this study aims to bridge this gap by formulating a multivariate stochastic model to predict the likelihood of giving a high acoustic comfort evaluation of the soundscape within an urban park environment. Further, this study also aims to reveal whether acoustic perception relates to the acceptability of environment and to identify the major acoustic related parameters that influence visitors' preferences to stay in urban parks.

II. METHODOLOGY

Questionnaire surveys were designed to elicit park users' perception of soundscape and to examine how acoustic comfort evaluation relates to acceptability of the environment and preference to stay within a park due to soundscape quality. Four public parks in Hong Kong were selected as our studied sites. They were selected because traffic noise was expected to be the major sound sources within the park areas. Also they were expected to possess similar landscape features and to be equipped with similar sports and recreational facilities (see Table I). Park users were randomly approached and invited for interviews. To capture the peak flow of visitors, face-to-face interviews were administered in both mornings and afternoons during weekends and holidays but were only administered in mornings during weekdays. Sound recordings and the measurements of the sound levels were carried out at a number of designated spots near to the locations of park visitor interviews during the on-site surveys. These physical sound measurements were carried out using Brüel and Kjær sound analyzer type 2270 held firmly on a tripod as close to the target road segment as practicable and in a direction facing the nearest busiest road. The sound analyzer gave the equivalent sound pressure levels and the A-weighted percentile levels. The simultaneous sound measurement and the questionnaire survey enabled an analysis on the visitors' perceptions of the park soundscape.

A. Questionnaire survey

Our questionnaire survey form comprises four main sections. The first section aims to elicit respondents' awareness and perception of a list of natural sounds (e.g., bird's twittering; see Table II for the full list). Respondents were asked to indicate (1) whether they could hear particular types of natural sounds and (2) whether they preferred or did not prefer to hear particular types of natural sounds. They were also presented with a list of natural sounds to assist them in identifying the types of sound that made up the existing soundscape in the surveyed parks. They were then asked to rate their levels of preference for the natural sounds they heard as a whole on a five-point verbal scale (1–5 graded, "very much dislike," "dislike," "neutral," "like," and "very much like"). Also, they were asked to describe their psychological responses to different types of natural sounds on five-point verbal scales (1–5 graded, "very stressful," "stressful," "neutral," "relaxing," and "very relaxing").

The structure of the second section is similar to that of the first section, but its main focus is on anthropogenic and mechanical sounds. Table II lists all types of anthropogenic and mechanical sounds studied. Again, a list of sounds was also presented to help respondents to identify the types of sounds heard in the existing soundscape. Respondents were asked to rate their levels of preferences for the anthropogenic and mechanical sounds they heard as a whole and to indicate

TABLE I. Summary of the characteristics of the four studied parks.

	Park A	Park B	Park C	Park D
Area (m^2)	134 700	85 000	156 000	52 000
Location	A busy commercial district in the city center	A developed new town in suburban	A residential and industrial district in the city center	A resident district in the city center
Sports facilities				
· **Swimming pool**	✓			
· **Football fields**	✓		✓	✓
· **Basketball courts**			✓	✓
· **Jogging path**	✓	✓	✓	✓
· **Extreme games**			✓	
· **Tennis**			✓	
· **Bicycle track**				✓
Landscape features				
· **Square**	✓	✓	✓	
· **Garden**	✓	✓	✓	
· **Pond**	✓	✓	✓	
No. of measurement spots	6	7	16	5

TABLE II. Types of sounds studied in the surveys.

Natural sounds		
• Insects	• Fountain	• Tree murmur
• Twittering of birds	• Sea wave	• Running water
• Calling crows	• Barking dogs	• Waterfall
• Wind	• Rain	• Thunder
Anthropogenic and mechanical sounds		
• Car horn	• Car reverse horn	• Heavy vehicles
• Bicycle ring	• Ship siren	• Talking
• Siren from ambulance/ Fire Engine/police vehicles	• Train	• Screaming
	• Airplane	• Footsteps
• Music	• Light vehicles	• Cell phone ring

the type of psychological responses to those sounds on the five-point verbal scales.

The third section asks respondents to rate their perceptions of the existing soundscape in the surveyed spots on five-point verbal scales. The characteristics of the existing soundscape monitored were perceived strength of sound (1–5 graded, "very quiet," "quiet," "adequate," "noisy," and "very noisy") and acoustic comfort (1–5 graded, "very uncomfortable," "uncomfortable," "neutral," "comfortable," and "very comfortable"). In addition, they were asked to indicate their degree of acceptability of the existing park environment as well as their preferences to stay at the current spots in the parks. The final section collects information on individuals' personal characteristics including self-rated auditory capabilities, which are rated on five-point verbal scales (1–5 graded, "very bad," "bad," "neutral," "good," and "very good"). Respondents were also asked to indicate the motivation for their current park visits with reference to four predetermined options, i.e., whether they came for undertaking physical activities, raising kids, resting, or other purposes.

B. Data collection and analysis

A pilot study was carried out in July 2009 with an objective to remove any ambiguities on the content and the method of delivery arisen from the designed survey. After rewording some ambiguous questions, full blown surveys were conducted between August 2009 and April 2010. SPSS version 18.0 (Ref. 13) was applied for performing statistical analysis of the collected responses. NLOGIT 4.0 (Ref. 14) was used for constructing an ordered logit model, while AMOS version 18.0 (Ref. 15) was applied for formulating a path model.

III. RESULTS

A. Respondents' characteristics

In total, 732 interviews were successfully administered via a face-to-face manner in the four parks from August 2009 to April 2010, including interviews with 595 park users and 137 passers-by. As we are only interested in the responses from park users, 137 responses collected from passers-by were excluded from the analysis. The total number of samples drawn for this study is considered to be adequate based on a 95% confident interval and ± 5% precision for unknown population size.[16] The average duration for completing an interview was around 5 to 7 min. Table III shows a statistical summary of the sound pressure levels (L_{eq}) of the surveyed spots in the individual parks. The average noise levels (L_{eq}) of the four individual parks lie in a range between 60 and 64 dB(A).

Table IV shows a summary statistics of personal characteristics for the surveyed respondents. Among the 595 respondents, 54% were females and 44% were over 60 yr old. Seventy-six percent were residents living in vicinity of the parks. A majority rated their auditory capabilities as either "average" (35.0%) or "good" (37.5%). Elderly generally reported a lower auditory capability ($P = 0.00$, Spearman's rho test). Sixty-one percent of the respondents spent less than an hour in the parks. More than half were motivated to visit the parks for undertaking physical activities (63.2%). Around 20% of the visitors came for resting, 7% visited the park for raising their kids, and 9% visited the park for other purposes. Overall, around 55% of the respondents rated the existing acoustic environment in the parks as either comfortable or very comfortable. Nineteen percent of the respondents in Park A and 18% in Park B rated their acoustic comfort as very comfortable, whereas only 3% in Park D rated very comfortable. On the other hand, 81% of the respondents in individual parks considered the park environment as acceptable or very acceptable. Nearly half of the respondents considered staying or continuing to stay in the parks due to the existing soundscape quality. Although only a few respondents rated very unacceptable and very uncomfortable to the overall and acoustic environment, the proportion of respondents who gave negative feedbacks to the park environment is comparable to those studies investigating

TABLE III. A statistical summary of the sound pressure levels (L_{eq}) for the surveyed spots in the individual parks.

	Park A	Park B	Park C	Park D
Number of sound measurement spots taken in the park area	6	7	16	5
Total no. of sound measurements taken	56	64	117	48
L_{eq} (dB(A))				
Maximum	70.8	70.8	65.8	69.1
Minimum	59.4	55.6	55.6	58.7
Average	62.8	61.2	59.5	64.2
Standard deviation	2.75	3.12	1.98	2.81

TABLE IV. A summary statistics of personal characteristics of the respondents.

	Park A	Park B	Park C	Park D	Total	Percentage of Total
Gender						
Male	55 (51.4)[a]	57 (41.3)	125 (50.2)	37 (36.6)	274	(46.1)
Female	52 (48.6)	81 (58.7)	124 (49.8)	64 (63.3)	321	(53.9)
	107 (100)	**138 (100)**	**249 (100)**	**101 (100)**	**595**	**(100)**
Age (yr)						
Under 15	13 (12.1)	1 (0.7)	6 (2.4)	16 (15.9)	36	(6.1)
16–25	13 (12.1)	1 (0.7)	8 (3.2)	8 (7.9)	30	(5.0)
26–40	19 (17.8)	4 (2.9)	28 (11.3)	27 (26.7)	78	(12.9)
41–60	30 (28.1)	54 (39.2)	77 (30.9)	27 (26.7)	188	(31.6)
Over 60	32 (29.9)	78 (56.5)	130 (52.2)	23 (22.8)	263	(44.2)
	107 (100)	**138 (100)**	**249 (100)**	**101 (100)**	**595**	**(100)**
Purpose of visiting the park						
Resting	29 (27.1)	16 (11.6)	42 (16.9)	35 (34.7)	122	(20.5)
Undertaking physical activities	36 (33.6)	120 (87.0)	188 (75.5)	32 (31.7)	376	(63.2)
Raising kids	8 (7.5)	1 (0.7)	4 (1.6)	31 (30.7)	44	(7.4)
Other purposes	34 (31.8)	1 (0.7)	15 (6.0)	3 (2.9)	53	(8.9)
	107 (100)	**138 (100)**	**249 (100)**	**101 (100)**	**595**	**(100)**
Duration of stay (min)						
Less than 30	22 (20.6)	24 (17.4)	63 (25.3)	22 (21.8)	131	(22.0)
30–59	32 (29.9)	51 (37.0)	112 (45.0)	37 (36.6)	232	(39.0)
60–89	4 (3.7)	31 (22.5)	44 (17.7)	15 (14.9)	94	(15.8)
90–119	20 (18.7)	18 (13.0)	24 (9.6)	18 (17.8)	80	(13.4)
More than 120	29 (27.1)	14 (10.1)	6 (2.4)	9 (8.9)	58	(9.7)
	107 (100)	**138 (100)**	**249 (100)**	**101 (100)**	**595**	**(100)**
Local residents						
Yes	42 (39.3)	130 (94.2)	212 (85.1)	65 (64.4)	449	(75.5)
No	65 (60.7)	8 (5.8)	37 (14.9)	36 (35.6)	146	(24.5)
	107 (100)	**138 (100)**	**249 (100)**	**101 (100)**	**595**	**(100)**
Self-rated auditory capability						
Very poor	0 (0)	1 (0.7)	1 (0.4)	1 (1.0)	3	(0.5)
Poor	2 (1.9)	11 (8.0)	20 (8.0)	4 (4.0)	37	(6.2)
Average	29 (27.1)	54 (39.1)	99 (39.8)	26 (25.7)	208	(35.0)
Good	39 (36.4)	44 (31.9)	87 (34.9)	53 (52.5)	223	(37.5)
Very good	37 (34.6)	28 (20.3)	42 (16.9)	17 (16.8)	124	(20.8)
	107 (100)	**138 (100)**	**249 (100)**	**101 (100)**	**595**	**(100)**

[a]Percentages are in parentheses.

perception of acoustic environment in parks or urban spaces.[9,12]

Figure 1 shows a breakdown by the number of respondents who had heard different types of natural sounds. Twittering of birds was heard by a majority of the respondents in all the parks ($N = 540$, 90.7%), and tree murmur was the second most frequently heard sound ($N = 109$, 18.3%). Sound from water related sources were heard by only a few respondents as water features were only found in some areas within Parks A, B, and C. Figure 2 shows a breakdown by the number of the respondents who had heard different types of anthropogenic and mechanical sounds. Conversely, sounds from talking were the most frequently heard sound attributed to human activities ($N = 334$, 56.1%). Sounds from heavy vehicles ($N = 282$, 47.4%) were also heard by a majority of the respondents; this is considered to be reasonable as all the studied parks were located in proximity to roads and highways.

Generally, natural sounds were considered to be relaxing in parks (average = 4.16, SD = 0.68) as a majority of the respondents rated their psychological responses as relaxing or very relaxing. On the contrary, anthropogenic and mechanical sounds were considered to be slightly stressful (average = 2.34, SD = 0.86) as a majority rated their psychological responses as either neutral or stressful.

B. Multivariate analysis

The collected responses were analyzed by two different methods of multivariate analysis to accomplish the two different objectives. First, an ordered logit model was formulated for establishing a stochastic relationship between acoustic comfort evaluation and its influencing factors. Second, path analysis was applied to explore the inter-relationships among physical sound characteristics, acoustic comfort evaluation, acceptability of environment, and preference to stay in the park area due to soundscape quality.

1. Model for predicting acoustic comfort evaluation

Data collected from the 595 interviews were used to formulate an ordered logit model. Given that one of our

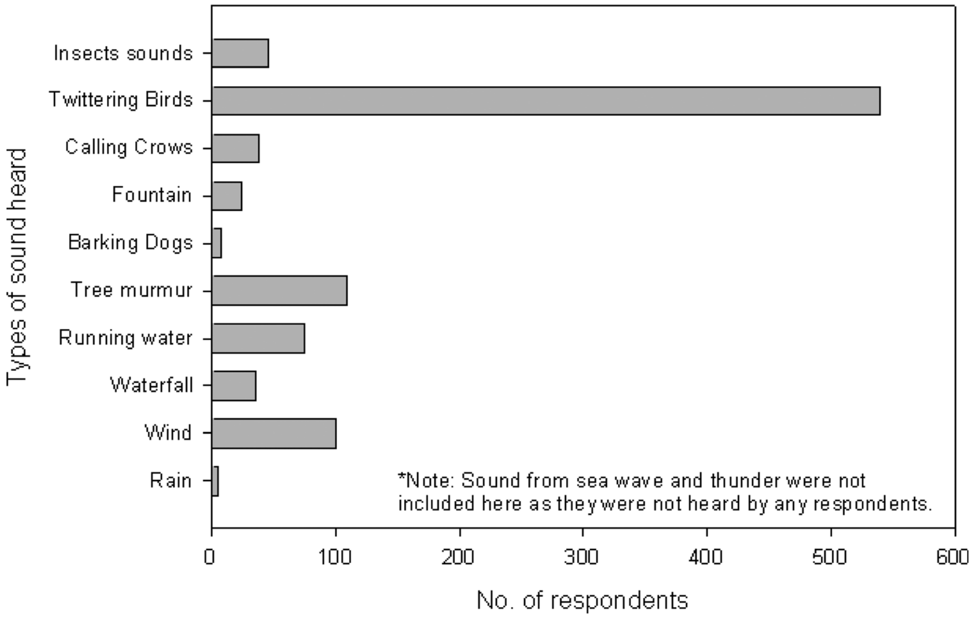


FIG. 1. A breakdown by number of the respondents hearing different types of natural sounds in their survey spots.

objectives is to identify the major acoustic and environmental factors that affect a high acoustic comfort evaluation, the acoustic comfort evaluations originally rated on a five-point verbal scale were dichotomized into either "low acoustic comfort evaluation" or "high acoustic comfort evaluation" in final model development (Table V). High acoustic comfort evaluation refers to a rated response of comfortable or very comfortable but excludes a neutral response. Low acoustic comfort evaluation refers to a rated response of very uncomfortable, uncomfortable, or neutral. This dichotomization method is considered to be logical as we aim to predict the likelihood of giving positive responses, i.e., comfortable or very comfortable ratings. As a result, the total numbers of responses falling into two groups are comparable (i.e., 55.3% for high acoustic comfort evaluation and 44.7% for low acoustic comfort evaluation).

Other factors, with an exception of sound pressure level, were also dichotomized in the same manner in the final model development. With such dichotomization, the final model becomes:

$$\begin{aligned} Y_i^* = {} & \beta_{LEQ} LEQ + \beta_{SUB} SUB + \beta_{INSECT} INSECT + \beta_{BIRD} BIRD + \beta_{TREE} TREE + \beta_{FLOW} FLOW + \beta_{WIND} WIND + \beta_{BIKE} BIKE \\ & + \beta_{LIGHT} LIGHT + \beta_{HEAVY} HEAVY + \beta_{TALK} TALK + \beta_{SCREAM} SCREAM + \beta_{AGE} AGE + \beta_{GEDER} GENDER \\ & + \beta_{RESI} RESI + \beta_{DUR} DUR + \beta_{PK1} PK1 + \beta_{PK2} PK2 + \beta_{PK3} PK3 + \beta_{PREFH} PREFH + \beta_{PREFN} PREFN \\ & + \beta_{AUDIT} AUDIT + \beta_{LAND} LAND + \varepsilon_i \end{aligned} \quad (1)$$

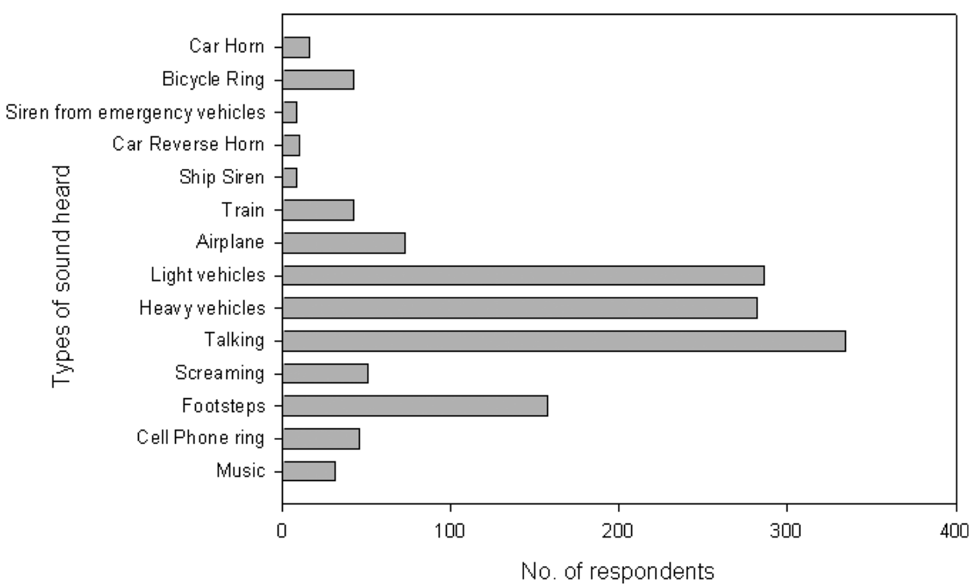


FIG. 2. A breakdown by the number of respondents hearing different types of anthropogenic and mechanical sounds in their survey spots.

TABLE V. A summary statistics of responses in relation to acoustic comfort, acceptability to the environment and preference to stay.

	Park A	Park B	Park C	Park D	Total	Percentage of total
Acoustic comfort						
Very uncomfortable	0 (0.0)[a]	3 (2.2)	6 (2.4)	5 (5.0)	14	(2.4)
Uncomfortable	5 (4.7)	11 (8.0)	32 (12.9)	12 (11.9)	60	(10.0)
Neutral	44 (41.1)	33 (23.9)	60 (24.1)	55 (54.5)	192	(32.3)
Comfortable	38 (35.5)	66 (47.8)	132 (53.0)	26 (25.7)	262	(44.0)
Very comfortable	20 (18.7)	25 (18.1)	19 (7.6)	3 (3.0)	67	(11.3)
	107 (100)	**138 (100)**	**249 (100)**	**101 (100)**	**595**	**(100)**
Acceptability of the environment						
Very unacceptable	1 (0.9)	2 (1.4)	2 (0.8)	0 (0.0)	5	(0.8)
Unacceptable	3 (2.8)	9 (6.5)	11 (4.4)	8 (7.9)	31	(5.2)
Neutral	31 (29.0)	8 (5.8)	11 (4.4)	21 (20.8)	71	(11.9)
Acceptable	42 (39.3)	72 (52.2)	154 (61.7)	55 (54.5)	323	(54.3)
Very acceptable	30 (28.0)	47 (34.1)	71 (28.5)	17 (16.8)	165	(27.7)
	107 (100)	**138 (100)**	**249 (100)**	**101 (100)**	**595**	**(100)**
Preference to stay due to soundscape quality						
Leave right away	2 (1.9)	3 (2.2)	7 (2.8)	3 (3.0)	15	(2.5)
Consider leaving	2 (1.9)	5 (3.6)	13 (5.2)	11 (10.9)	31	(5.2)
Neutral	38 (35.5)	49 (35.5)	127 (51.0)	49 (48.5)	263	(44.2)
Consider staying	32 (29.9)	40 (29.0)	54 (21.7)	27 (26.7)	153	(25.7)
Continue to stay	33 (30.8)	41 (29.7)	48 (19.3)	11 (10.9)	133	(22.4)
	107 (100)	**138 (100)**	**249 (100)**	**101 (100)**	**595**	**(100)**

[a]Percentages in parentheses.

where Y_i^* is the acoustic comfort evaluation. The studied acoustic related factors include subjectively evaluated sound level, sound pressure level expressed in terms of L_{eq} dB(A) (LEQ), subjective evaluation of sound level (SUB), types of sounds heard, including sounds from insects (INSECT), bird (BIRD), tree (TREE), water flow (FLOW), wind (WIND), bike (BIKE), light vehicles (LIGHT), heavy vehicles (HEAVY), talking (TALK), screaming (SCREAM), preferences for natural sounds (PREFN), and preferences for anthropogenic and mechanical sounds (PREFH). Meanwhile, the studied respondents' characteristics include age (AGE), gender (GENDER), self-rated auditory sensitivity (AUDIT), residency status (RESI), and duration of stay in a park (DUR). Visual comfort evaluation of landscape (LAND*),* which is defined as the state of mind that expresses satisfaction with the visual environments, is included to study the potential impact of visual on acoustic perception. Park-specific dummy factors, PK1, PK2 and PK3, have also been incorporated to account for any unobserved park characteristics. β_k represents the coefficient estimate for an individual factor X_{ki}.

Because the software can only handle a maximum of 25 dependent variables at one time, the analysis has to be carried out in a sequential manner, i.e., by first including 25 variables and subsequently replacing the insignificant variables with new variables. As a result, some of the variables were dropped from the model as they were determined to be insignificantly related to acoustic comfort evaluation. For instance, the variable "motivation of visiting the parks" was not included in the final model as its coefficient was determined to be statistically insignificant ($P < 0.05$).

The constructed ordered logit model can fit the response data extremely well and therefore can be used to portray the acoustic comfort evaluation relationships (i.e., with a McFadden's ρ^2 value of 0.26). McFadden's ρ^2 statistics have always been recommended for evaluating the goodness of fit for probability models. The McFadden's ρ^2 is analogous to R-square commonly applied in linear regression in that the log likelihood of the intercept model can be regarded as the total sum of squares while the log likelihood of the full model can be regarded as the sum of square errors. The log likelihood of the full model will be relatively small in case this model is more likely to occur, and therefore a small ratio of log likelihoods indicates that the full model is better fit than the intercept model.[17]

The McFadden's ρ^2 measures the relative power of the model while the R^2 for linear models measures the absolute power.[18] In fact the McFadden's ρ^2 at 0.3 can be translated to be equivalent to an R^2 of around 0.6 for the linear model equivalent.[19] Table VI lists the estimated coefficient values for various factors. A positive sign implies the likelihood in giving a high acoustic comfort evaluation increase with the value of the studied factor while a negative sign implies the likelihood decreases as the value of the studied factor increases. For example, a positive sign for WIND indicates the likelihood of giving a high acoustic comfort evaluation increase when hearing the breeze. Conversely, a negative sign for L_{eq} indicates the likelihood in giving a high acoustic comfort evaluation decreases as L_{eq} increases. As a consistency check, the obtained signs of the variables are aligned with our prior expectation on their relationships with acoustic comfort evaluation.

2. Acoustic related factors

Acoustic comfort evaluation is influenced by both objective and subjective acoustic factors. Both sound pressure level and subjectively evaluated sound level are found

TABLE VI. Coefficient estimates for the ordered logit model portraying the acoustic comfort relationship.

Model fitting information			
Number of observations			595
Log likelihood function			– 409.081
McFadden's ρ^2			0.26
Attribute	**Coefficient (β)**	***P* value**	**Odds ratio**
Index function for probability			
Constant	10.034	0.001	N.A.
Acoustic factors			
LEQ	– 0.190	0.000[a]	1.209[b]
SUB (Subjectively evaluated sound level)	– 1.410	0.000[a]	4.096[c]
INSECT	0.401	0.312	N.A.
BIRDCALL	– 0.137	0.696	N.A.
TREE	– 0.394	0.172	N.A.
FLOW (Water flow)	– 0.349	0.304	N.A.
WIND	0.925	0.003[a]	2.522[d]
BIKE	– 1.098	0.032[a]	2.998[e]
LIGHT	– 0.062	0.784	N.A.
HEAVY	– 0.586	0.012[a]	1.797[f]
TALK	– 0.065	0.758	N.A.
SCREAM	0.093	0.821	N.A.
Environmental factors			
LAND (Visual comfort of landscape)	2.213	0.000[a]	9.143[g]
PK1	– 0.398	0.382	N.A
PK2	– 0.127	0.753	N.A
PK3	0.591	0.148	N.A
Receptors' characteristics			
AGE	– 0.262	0.371	N.A.
GENDER	0.070	0.737	N.A.
AUDIT (Self-rated auditory capacity)	0.130	0.542	N.A.
RESI (Residency in the park district)	– 0.811	0.008[a]	2.250[h]
DUR (Duration of stay)	– 0.053	0.835	N.A.
PREFN (Preference for natural sounds)	0.842	0.037[a]	2.321[i]
PREFH (Preference for anthropogenic and mechanical sounds)	0.964	0.001[a]	2.622[j]

[a]Significant at 0.05 level.
[b]Increase in chance of giving a high acoustic comfort valuation if L_{eq} is increased by 1 dB(A).
[c]Increase in chance of giving a high acoustic comfort valuation if subjectively evaluated sound level is considered to be "very quiet," "quiet," or "neither quiet nor noisy."
[d]Increase in chance of giving a high acoustic comfort valuation if a respondent hears the breeze.
[e]Increase in chance of giving a high acoustic comfort valuation if a respondent does not hear the sound from bikes.
[f]Increase in chance of giving a high acoustic comfort valuation if a respondent does not hear the sound from heavy vehicles.
[g]Increase in chance of giving a high acoustic comfort valuation if a respondent rates the visual comfort of landscape as "comfortable" or "very comfortable."
[h]Increase in chance of giving a high acoustic comfort valuation if a respondent is not living within the vicinity of the park.
[i]Increase in chance of giving a high acoustic comfort valuation if a respondent rates their preferences for natural sounds as ""very much prefer."
[j]Increase in chance of giving a high acoustic comfort valuation if a respondent rates their preferences for anthropogenic and mechanical sounds as "prefer" or "very much prefer."

to influence individuals' acoustic comfort evaluations in the parks. In addition, types of sounds heard also influence individuals' acoustic evaluations. Among different types of sounds, only the breeze and sounds from bikes and heavy vehicles influence individuals' acoustic comfort evaluations. Individuals hearing the breeze are 2.5 times more likely to give high acoustic comfort evaluations (odds ratio = 2.52). In contrast, hearing sounds from bikes significantly lowers the likelihood in giving high acoustic comfort evaluation. Individuals not hearing sounds from bikes are 3.0 times more likely to give high acoustic comfort evaluations (odds ratio = 3.00). Also individuals not hearing sounds from heavy vehicles are 1.8 times more likely to give high acoustic comfort evaluations (odds ratio = 1.8).

3. *Environmental factors*

Individuals rating visual landscapes of the parks to be comfortable or very comfortable are 9.1 times more likely to give high acoustic comfort evaluations than those rating uncomfortable, very uncomfortable, or neutral. Further, there are no hidden characteristics in the four individual parks that will contribute to significant differences in acoustic comfort evaluation as no significant differences in values are observed among the dummies PK1, PK2, and PK3.

4. *Receptors' characteristics*

Among all the studied receptors' characteristics, only the individuals' residency status affects their acoustic comfort evaluations. Individuals not living in the vicinity of the parks are 2.3 times more likely to give high acoustic comfort evaluations (odds ratio = 2.25). Other personal characteristics such as age, gender, self-rated auditory capacity, and duration of stay in the park are not found to influence individuals' acoustic comfort evaluations. Conversely, individuals' preferences for natural sounds, or preferences for anthropogenic and mechanical sounds, are found to affect the acoustic comfort evaluations of the parks. Individuals who have indicated higher preferences for natural sounds and individuals who have indicated higher preferences for anthropogenic and mechanical sounds are 2.6 and 2.3 times more likely to give high acoustic comfort evaluations, respectively (odds ratio = 2.62 and 2.32).

C. Path analysis

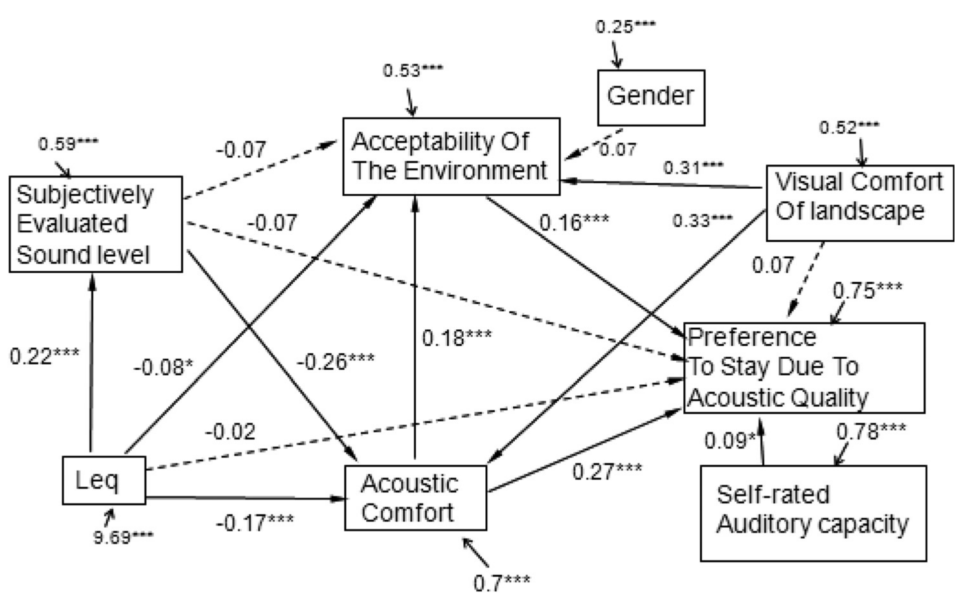
Given the ordered logit model is not suitable for exploring the multi-lateral relationships among factors, path analysis is introduced for this purpose. Path analysis, which is a subset of structural equation modeling (SEM), is a powerful tool for revealing casual relationships among dependent variables, and between dependent and independent variables.[20] Path analysis can give coefficients for estimating direct, indirect and total (direct plus indirect) effects of variables on each other.[21,22]

Path analysis has been widely applied in not only social psychology and sociology[23] but also a number of acoustic studies to investigate the relationships among noise level, human perception, personal characteristics, and noise annoyance.[24–26]

A number of major assumptions were made in formulating the path model. First, acoustic comfort evaluation exerted an influence on an individual's acceptability of the environment. Second, individual's preference to stay was affected by acoustic comfort evaluation, sound pressure level (L_{eq}), and subjectively evaluated sound level. Third, both acoustic comfort evaluation and visual comfort of landscape influenced an individual's acceptability of the environment.

Before constructing a path model to verify these three major assumptions, all the factors relating to personal characteristics were input into an ordered logit model for identifying the factors that significantly influence the acceptability of the environment and preference to stay. Significant factors ($P < 0.05$) were subsequently used as input variables for the path model. Figure 3 shows all the paths in the model together with their estimated correlation values. The coefficient values shown were normalized to facilitate easier comparison with each other. A high coefficient value indicates a strong causal relationship between the dependent and independent variables, while a low coefficient value indicates a weak relationship. A positive coefficient sign implies the value of the independent variable increases with the value of the dependent variable. Conversely, a negative coefficient implies the value of the independent variable increases as the value of the dependent variable decreases.

The path model shown in Fig. 3 unveils the interrelationships among acoustic comfort evaluation, acceptability of the environment, and preference to stay as well as other factors. The formulated path model is considered to be a reasonably good representation of the interrelationships as



Model fit index: $\chi^2/df =$ 2.94 (Criteria: $2<\chi^2/df<5$);[30,31]

RMSEA = 0.057 (Criteria<0.08)[30,32]

Note: Insignificant paths are shown in dotted lines;

***-Significant at a 99.999% confidence level;

**-Significant at a 99% confidence level;

*- Significant at a 95% confidence level

FIG. 3. The path model with standardized path coefficients.

its goodness of fit meets with the requirements laid down for χ^2/df and the root mean square error of approximation (RMSEA) commonly upheld for evaluating the goodness of fit for path models (i.e., the model value of χ^2/df is 2.94, which is $2 < \chi^2/\mathrm{df} < 5$ and the model value of RMSEA is $0.057 < 0.08$).[27–29]

In addition, the ranges of coefficient values obtained for the path model are comparable with other openly reported path models focusing on acoustics, transportation and medicine.[22,30,31] Similar to the results obtained from the ordered logit model, both subjectively evaluated sound level ($r = -0.26$, $P < 0.001$) and sound pressure level ($r = -0.17$, $P < 0.001$) are found to be valid predictors for acoustic comfort evaluation even though the influence from the subjectively evaluated sound level is relatively stronger. The subjectively evaluated sound level and the sound pressure level decreases as acoustic comfort increases and vice versa. On the other hand, sound pressure level (L_{eq}) also exerts a moderate influence on the subjectively evaluated sound level ($r = 0.22$, $P < 0.001$).

The results shown in Fig. 4 basically confirm our hypothesis that acceptability of the environment and preference to stay due to acoustic quality are influenced by the acoustic comfort evaluated by park users. Nevertheless, an individual's acceptability of the environment is influenced more by visual comfort evaluation of landscape than by acoustic comfort evaluation ($r = 0.31$ for visual comfort evaluation of landscape vs. $r = 0.18$ for acoustic comfort evaluation).

On the other hand, an individual's preference to stay is influenced by acceptability of the environment, acoustic comfort evaluation, and self-rated auditory capacity. Acoustic comfort evaluation has a stronger total influence ($r = 0.31$, $P < 0.001$) on an individual's preference to stay than acceptability of the environment ($r = 0.16$, $P < 0.001$). In contrast, an individual's self-rated auditory capacity only exerts a very weak influence ($r = 0.09$, $P = 0.016$), and visual comfort evaluation of landscape ($r = 0.15$) and L_{eq} ($r = -0.10$) are found to play only indirect roles on individual's preferences to stay.

IV. DISCUSSIONS AND CONCLUSIONS

This study has successfully formulated a multivariate probabilistic model for predicting acoustic comfort evaluation in an urban park from a multitude of factors like sound characteristics, park environment characteristics, and personal characteristics. To our knowledge, this is the first multivariate model developed that allows the influences of different factors relating to acoustic comfort evaluation of urban parks to be compared in a holistic manner. This in turn can help identify the factors that deserve more attention in providing comfortable soundscape in urban parks. Of equal importance is that this study has also successfully revealed the interrelationships among acoustic comfort evaluation, acceptability of environment, and preference to stay in a park. In particular, our study gives the following valuable insights in relation to the provision of a comfortable soundscape in urban parks.

First, our findings generally confirm that acoustic related factors, park environment factors as well as individual receptors' characteristics also influence the acoustic comfort evaluations of urban parks. This is in line with our expectations as soundscape is thought to be interplay among sound, environment, and receptors.

Second, it is found that the acoustic related factors that influence acoustic comfort evaluation include not only the sound pressure level (L_{EQ}) and subjective sound evaluation but also specific types of sounds like the breeze, sounds from bike and heavy vehicles. However, not all the preferred or unflavored sounds heard in urban parks affect an individual's acoustic comfort evaluation despite natural sounds are more preferred while anthropogenic and mechanical sounds are less welcomed. Sounds from birds and water do not exert any significant influence on individuals' acoustic comfort evaluations, even though they are preferred by park visitors (66% for bird call and 50% for water). The breeze significantly increases the likelihood in giving a high acoustic comfort evaluation, while sounds from bikes or heavy vehicles significantly lower the likelihood. Accordingly, park locations and orientations should be carefully planned to mitigate the impacts of sounds from bikes and heavy vehicles.

Third, besides acoustic related factors, visual comfort evaluation of landscape also plays an important role on influencing the likelihood in giving a high acoustic comfort evaluation. Interestingly, a high visual comfort evaluation of landscape is found to be 2.2 times more likely to attract a high acoustic comfort evaluation than a low subjectively evaluated sound level, and 7.6 times more likely than one dB(A) reduction in sound pressure level. This is in line with the finding reported by Pedersen *et al*. (2008)[32] that noise annoyance or discomfort can be affected by visual cues. The impact of visual cues on audio responses can be explained by resorting to some psychology and acoustic related literatures that visual conditions can modify the auditory perception of subjects.[33,34]

Fourth, an individual's residency status, and individual's preference for natural or anthropogenic and mechanical sounds are the only receptor characteristics that are found to significantly influence the likelihood in giving a high acoustic comfort evaluation. In contrast with the result reported by Marin *et al*. (2011),[35] the motivation of visiting a park was not shown to affect an individual's acoustic comfort evaluation. Further studies are needed to explore whether cultural differences account for the differences in the role of motivation being played in the acoustic comfort evaluation. Also, it would be of great interest to examine whether motivation is a strong predictor of preference in areas that are quieter and where visitors can truly expect natural quiet as opposed to urban parks where "quiet" is not even an option.

Last, our findings also help depict a more holistic picture on the inter-relationships existing among acoustic comfort evaluation, acceptability of the environment, and preference to stay. Among all the acoustic related factors, acoustic comfort evaluation serves as a better proxy for individual's preference to stay in a park than sound pressure level (L_{eq}) or subjectively evaluated sound level. On the other hand, acceptability of the environment is found to be mainly influenced by visual comfort evaluation of the landscape. Among all the studied acoustic related factors, acoustic comfort evaluation has the strongest impact on acceptability of the environment. This suggests that the acceptability of the park environment can also be improved by improving acoustic comfort evaluation of urban parks.

Nevertheless, it is worthwhile pointing out that our findings may suffer from some potential errors that may undermine the representativeness of our samples and results. Although our findings are only derived from 595 respondents drawn from four urban parks, the number of samples drawn is considered to be comparable with other socio-acoustic surveys.[7,36–38] However, it would be even better if more samples can be drawn from more urban parks to confirm the wider application of our findings. Also, the validity of our findings may not be able to extend to the younger population group as a majority of our respondents aged above 60, which is the largest group of our park users. Meanwhile, there are also some limitations inherent in our model development. Because the path model developed in this study is confirmatory in nature, the factors are structured in a way that only enable us to acquire a better understanding on the interrelationships among acoustic comfort evaluation, acceptability of the environment, and preference to stay in a park due to soundscape quality. Future studies should be directed toward revealing the influences of other environmental factors on acceptability of the environment and preference to stay.

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