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Multiple regression model for soundscape perception in urban open spaces based on ex-situ experiments with audios from 27 localities

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ABSTRACT

Soundscape is an essential environmental element affecting people's experience in urban open spaces. In the complex mechanism of soundscape perception, the acoustic characteristics of the soundscape are the primary influencing factor. Herein, we used ISO 12913 soundscape indicators to carry out auditory perception experiments on typical soundscape materials recorded from 27 urban open spaces. The principal indicators pleasantness and eventfulness were calculated from the evaluation results of 68 participants. They were then taken individually to perform multiple regression with factors including psychoacoustic, physical acoustics indicators, the significance of various sound source types, and other indicators characterizing the sound composition. The results showed that: 1) The regression model for pleasantness (Ad R^2= 0.703, F=21.48) showed that the significance of bird sounds contributed positively, and the significance of mechanical sounds and the level of S_{95} in the environment have a negative impact. 2) The regression model for eventfulness (Ad R^2=0.676, F=19.05) showed that the number of significant sound sources and the level of F_{50} in the environment contributed positively. Simultaneously, the significance of mechanical sounds has a negative impact.

Keywords: Pleasantness, Eventfulness, Soundscape indicators

1. INTRODUCTION

Today's urban open public space is a system connected by a series of internally associated elements and carries people's daily leisure activities. The internal elements' complexity increasingly grows with the development of cities, especially the acoustic environment aspects. Improving people's sense of experience and promoting public health seem to be the main goals of open space. Multiple perception results of the acoustic environment constitute people's public space experience to a large extent. Therefore, it is crucial to determine the perception influence factors in the environment.

As a momentous environmental element related to people's feelings, soundscape, defined by ISO, is acoustic environment as perceived or experienced and/or understood by a person or people, in context(1). People perceive the acoustic environment in the context and produce various experience results, such as relieving pressure and relaxing mood under the soundscape restorative effect(2). Pleasantness and eventfulness are two commonly used perception dimensions in soundscape study. They originated from a circular model with pleasant on the X-axis and eventful on the Y-axis proposed by Axelson et al. (3). ISO 12913-3 formally adopts this model and gives the definition and calculation method of them(4). Based on these two perceptual dimensions, researchers use this model to explore the influencing factors of soundscape perception widely.

Likewise, it is also indispensable to find a soundscape indicators group suitable for urban open public spaces to predict soundscape perception more accurately and scientifically(5). Researchers consider the input indicators as comprehensively as possible to enhance the model's prediction ability. The sound source temporal dynamic indicators(6), the overall perceptual indicator of the acoustic environment from the subjective evaluation (such as the overall loudness evaluation)(7), the visual

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information(8), environment and context information(9), the demographic information(10).

In this study, the subjects only used auditory perception to experience and evaluate the binaural soundscape materials from 27 urban open public spaces in an ex-situ way. According to the ISO proposed parameter extraction method, extract the physical and psychoacoustic parameters. Establish three sound source relevant indicators to describe their existing characteristics by jury test, including the number of sound source types, the significance of sound sources, and the number of significant sound sources. We use correlation analysis to find the potential influencing factors of pleasantness and eventfulness and put the correlative factors into linear regression with them. Through modeling the soundscape perceptions, we found the comprehensive influence on pleasantness and eventfulness.

2. MATERIALS AND METHOD

2.1 Soundscape materials

The soundscape binaural stimuli materials came from the SSID project (ID: 740696, 20180301-20230228), collected from 27 localities in European cities. Each material lasts for 30 seconds, and it can recognize sounds such as traffic, construction, high-pressure water spray, stream, bird songs, talking, footsteps, children playing, and street performances. These sounds cover the typical sounds that may appear in most public spaces and represent their acoustic environments in different acoustic characteristics. According to all the sound types appearing in the material, the sounds are classified as human sounds (talking, footsteps, and other sounds from human activities), bird sounds, music sounds (performance music), water sounds (stream sounds, fountain sounds, irrigation sounds), and mechanical sounds (traffic sounds, construction sounds).

2.2 Experimental design

The experiment is the second stage of SATP(11). A total of 68 subjects participated in the ex-situ experiment. As shown in figure 1, We adopted a within-subjects design during the process in the semi-anechoic chamber. The experimental equipment includes a computer to control the playback of sound clips (Lenovo 310), an external sound card with headphone output function (console 6S), headphones (Sennheiser hd650), and Pads equipped with soundscape evaluation system. The headphones must be calibrated to experience the binaurally recorded soundscapes with the same loudness found in-situ during recording. According to the standard practice recommended by the SSID project, we use the calibration signal SPLcalibration (1 kHz sine signal recorded at SPL 94dB) and multimeter (Fluke15b+digital) to make the headphones reach the same sound pressure level as the calibration signal and complete the headphones' standardization. Besides, during the experiment, we used a sound level meter (Optimus cr:160) to ensure the background noise level could be negligible.

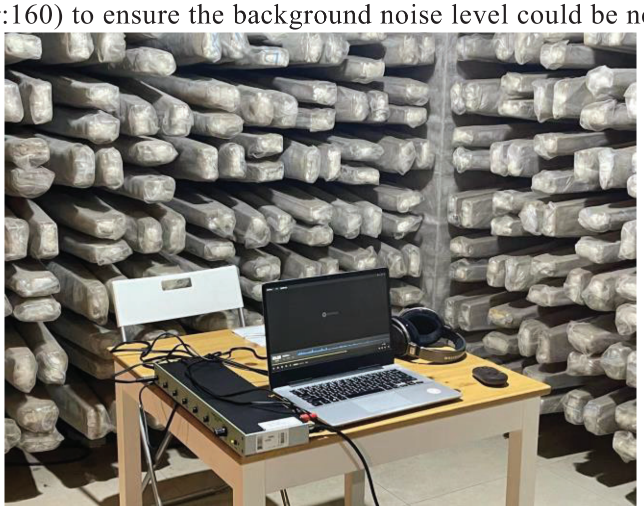

Figure 1 – Soundscape evaluation experiment in the semi-anechoic chamber

Before starting the actual sequence of stimuli of the experiment, arrange a stimulus to conduct an evaluation exercise for each subject. The evaluation exercise stimulus material does not belong to the 27 soundscape materials used in the formal experiment. In the formal experiment, randomize the order of the 27 stimuli for each participant, ask the participants to listen to the audio, and then rate the scales. There were at least 30 seconds between successive stimuli, and each participant was allowed to re-listen to any stimulus as many times as they wished. All questions in the evaluation scale are mandatory and asked as per the ISO recommendations(12): "For each of the eight scales below, to what extent do you agree or disagree that the present surrounding sound environment is...(translated in Chinese)." For each of the eight attributes, use a 100-step slider, ranging from 0 (strongly disagree) to 100 (strongly agree). The default position of the slider for the participant to start is on 50 (neutral assessment).

2.3 Participants

The 68 subjects, all from Shenyang Architecture University, passed three preliminary screening: 1) students and teachers aged 18-55 years old, 2) no hearing impairment, and 3) healthy and able to complete the experiment without affecting the experimental results. Each subject filled out a Weinstein Noise Sensitive Scale (WNSS). As shown in table 1, two participants with lower scores were excluded by cluster analysis (systematic clustering - square Euclidean distance) through SPSS (version26, IBM, USA), so the actual compelling subjects are 66.

Table 1 – The subjects' attributes

Gender		Age			WNSS		
Male	Female	20-30	30-40	40-50	Very low-WNS	Low-WNS	High-WNS
30	38	46	8	14	2	31	35
44.12%	55.88%	67.65%	11.76%	20.59%	2.94%	45.59%	51.47%

2.4 Indicators

Referring to the analysis method of binaural data in ISO 12913-3(4), the acoustical parameters relate to 1) physical acoustic parameter: sound pressure level A-weighted (L_{Aeq}, dB) and the statistical evolution of it (L_5, L_{50}, L_{95}). 2) psychoacoustic parameters: Loudness (sone), sharpness (acum), fluctuation (vacil), roughness (asper), and the statistical evolution of them(N_5, N_{50}, N_{95}, S, S_5, S_{95}, R_{10}, R_{50}, F_{10}, F_{50}). All parameters are calculated by B&K connect software. Loudness and its statistical parameters are calculated according to the method of ISO 532-1(13), the sharpness parameter group's calculation follows the method described in the DIN 45692 standard(14), and the roughness and fluctuation parameter group is calculated based on the method developed by Zwicker and Aurés(15).

Referring to the previous study that extracted and tested the indicators by jury test(9), we obtained the sound source characteristics indicators. Including the significance degree of five sound source types, the number of sound sources in each material, and the number of significant sound sources. The Jury members are composed of 4 graduate students (two male and two female). The members need to answer the following questions for the five sound source types with each soundscape material: "please rate the significance of the five sound sources according to the audio you hear. "The answer options are set at 0-3 points (0 point, do not hear at all. 1 point, heat a little but not dominant. 2 points, dominates moderately. 3 points, dominates completely). The consistency test shows that there are three sound sources' Kendall harmony coefficient W>0.8, conclude the human sounds, bird sounds, and music sounds, which were 0.886 ($p=0.000<0.01$), 0.806 ($p=0.000<0.01$), and 0.891 ($p=0.000<0.01$), respectively. Besides, The W of the mechanical sounds and water sounds was 0.784 ($p=0.000<0.01$) and 0.738 ($p=0.000<0.01$), respectively. It shows consistency among the jury member's evaluation results. Then calculate the mean value of the evaluation results from the four jury members to express the significance of each sound source type. In addition, according to the number of sound source evaluation scores, the number of sound sources (from the number of sound sources with scores of 1, 2 and 3 in each material) and the number of significant sound sources(from the number of sound sources with a score of 3 in each material) are calculated.

As shown in figure 2, the eight evaluation questions asked to the subjects are set according to the Chinese translation of the eight soundscape attributes in ISO 12913-2(12). Meanwhile, the evaluation results are simplified into pleasantness and eventfulness following the calculation method from ISO12913-3(4)for subsequent analysis.

Furthermore, in view of the differences in age and occupation of the subjects, conduct a consistency test of evaluation results among 66 subjects to ensure that the statistical analysis would not be affected by individual differences. The results showed that for pleasantness, Kendall harmony coefficient $W=0.699$, $p=0.000<0.001$. For eventfulness, $W=0.433$, $p=0.000<0.001$. 66 subjects were consistent in the evaluation of pleasantness and eventfulness. It also means that the impact of individual differences will be lower than that of the soundscape material itself.

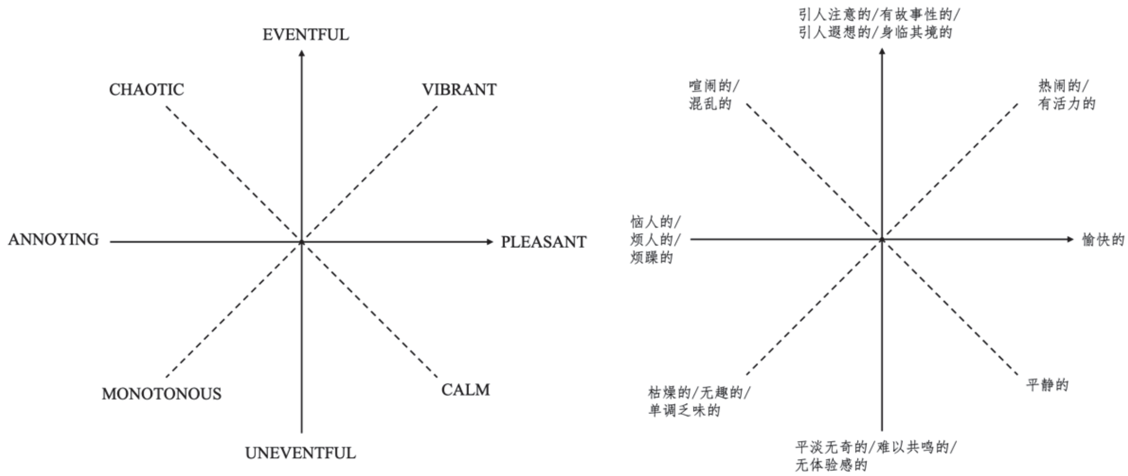

Figure 2 – Eight attributes from ISO in English and Chinese

2.5 Statistical analysis

This section has two parts. The first part is to conduct a correlation between the two perception dimensions and all indicators of the soundscape characteristics to find out the potential influencing factors related to soundscape perception. The second part establishes two regression models to find the comprehensive influence on pleasantness and eventfulness. All statistical analyses were performed using the software SPSS (version 26, IBM, USA). The description indicators and their symbols as shown in table 2.

Table 2 – Descriptors and symbols

Symbol	Descriptors
PL	Pleasantness
EV	Eventfulness
LAeq	SPL（A-weighted, dB）
N/S/R/F	Loudness(sone)/Sharpness(acum)/Roughness(asper)/Fluctuation(vacil)
HS	Significance of Human sounds
BS	Significance of Bird sounds
MuS	Significance of Music sounds
WS	Significance of Water sounds
MS	Significance of Mechanical sounds
Num	Number of sound sources
NumS	Number of significant sound sources

3. RESULTS

3.1 Correlated factors of soundscape perception

To identify which soundscape characteristics are related to pleasantness and eventfulness, a Pearson correlation analysis was carried out. As shown in table 3, in terms of acoustic parameters, pleasantness is correlated with L_{Aeq} and L_x, N and N_x, and S_{95}. However, for eventfulness, there is a positive correlation only with F, and F_{50} shows the strongest correlation ($r=0.757^{**}$, $p=0.000$).

More sound source characteristic indicators show the correlation with pleasantness. Except for the WS, all other sound source types' significance is related to pleasantness. WS shows irrelevant result due to the diversity of the water sounds in the soundscape materials. From the materials, subjects can receive not only natural water sounds but also the high-pressure spray sounds, fountain water sounds, and irrigation sounds, which could bring several perceptions and are not always pleasant. For the eventfulness, HS, MuS, and MS show the correlation. And the HS take the strongest positive correlation ($r=0.622^{**}$, $p=0.001$). It may be because the human sounds are mostly produced during activities (footsteps, conversation, children playing), which are distinguished from the non-living bodies' sounds and easier to identify. The MS shows the weakest negative correlation ($r=-0.525^{**}$, $p=0.005$). It is likely because the mechanical sounds mainly come from the traffic and construction machinery. Moreover, the traffic sounds are relatively muffled. When other sound sources are more significant, the traffic sounds will not feel prominent and probably be regarded as the background sound of the environment by the listener. In the meantime, the construction equipment sounds always make people feel annoying(16). Besides, the Num positively correlates with pleasantness ($r=0.455^{*}$, $p=0.017^{*}$), and the NumS show a positive correlation with eventfulness ($r=0.635^{**}$, $p=0.000$).

Table 3 – Correlation analysis for soundscape perception

Indicators	PL		EV	
	Pearson's r	p	Pearson's r	p
L_{Aeq}	-0.591^{**}	0.001	0.124	0.538
L_5	-0.517^{**}	0.006	0.195	0.329
L_{50}	-0.573^{**}	0.002	0.113	0.574
L_{95}	-0.662^{**}	0.000	0.002	0.990
N	-0.593^{**}	0.001	-0.025	0.903
N_5	-0.555^{**}	0.003	0.156	0.439
N_{50}	-0.627^{**}	0.000	0.074	0.714
N_{95}	-0.652^{**}	0.000	0.025	0.902
S	-0.262	0.187	-0.102	0.611
S_5	-0.168	0.402	0.027	0.894
S_{95}	-0.540^{**}	0.004	-0.326	0.097
R	-0.203	0.311	-0.075	0.711
R_{10}	0.053	0.794	0.307	0.119
R_{50}	-0.224	0.262	0.009	0.966
F	-0.023	0.908	0.468^{*}	0.014
F_{10}	0.191	0.339	0.711^{**}	0.000
F_{50}	0.216	0.279	0.757^{**}	0.000
Num	0.455^{*}	0.017	0.293	0.138
NumS	0.096	0.633	0.635^{**}	0.000
HS	0.487^{**}	0.010	0.622^{**}	0.001
BS	0.481^{*}	0.011	0.076	0.706
MuS	0.453^{*}	0.018	0.597^{**}	0.001
WS	0.162	0.420	0.127	0.529
MS	-0.695^{**}	0.000	-0.525^{**}	0.005

** and * respectively indicate correlation is significant at the 0.01 level and 0.05 level (2-tailed)

3.2 Modeling soundscape perception

This section established two multiple linear regression models to find the comprehensive influence on soundscape perception. The significant correlation variables obtained from correlation analysis were put into regression model with pleasantness and eventfulness by stepwise regression. L_{95}, S_{95}, Num, HS, BS, MuS, and MS are the independent input variables for the pleasantness model by the stepwise modeling method. The backward modeling method takes F_{50}, Nums, HS, MuS, and MS as the independent input variables for the eventfulness model. Finally, two meaningful regression models were obtained.

As shown in table 4, the most influential factor for the perception of pleasantness is MS (β=-0.540, t=-4.663, p=0.000<0.05), with a negative effect. In addition, there are two factors that possess the negative impact, BS (β=0.408, t=3.800, p=0.001<0.05) and S_{95} (β=- 0.307, t=-2.660, p=0.014<0.05), the three output factors explained 70.3% of pleasantness (F=21.510, p=0.000<0.05). In the dimension of eventfulness, the model outputs three positive factors. F_{50} shows the most prominent impact (β=0.514, t=2.893, p=0.008<0.05), followed by MS (β=-0.351, t=-2.971, p=0.007<0.05) and the NumS (β=0.289, t=1.913, p=0.068<0.1), which jointly explained 67.6% of the eventfulness (F=19.047, p=0.000<0.05).

Table 4 – Regression model of two perceptual dimensions

DV	IV	β	P	R^2	F	D-W
PL	MS	-0.540	0.000	0.703	21.510	2.042
	BS	0.408	0.001			
	S_{95}	-0.307	0.014			
EV	NumS	0.289	0.068	0.676	19.047	2.312
	MS	-0.351	0.007			
	F_{50}	0.456	0.008			

4. CONCLUSION AND DISCUSSION

1) The L_{Aeq}, loudness, human sounds, bird sounds, mechanical sounds, music sounds, and the number of sound sources are significantly correlated with pleasantness. However, water sounds have an irrelevant relationship due to the diversity of underwater sounds in the soundscape materials. The sounds of water that can be heard in urban Spaces are not always natural, which could bring several perceptions and are not always pleasant. In addition, fluctuation, the significance of human sounds, mechanical sounds, music sounds, and the number of significant sound sources correlate significantly to the eventfulness. Most mechanical sounds in urban open spaces originate from the muffled sound of traffic. Traffic sounds are not prominent compared with other types of sound sources. Listeners probably regard them as the background sound of the environment.

2) This study's 27 binaural soundscape materials' L_{Aeq} ave=56.94dB, std=12.87. Include common urban open spaces such as parks, green spaces, squares, and streets. Most materials' overall acoustic environment is quiet. In such general quiet city spaces, we established two meaningful perception models: for the pleasantness dimension, the significance of bird sounds possesses a positive impact. The significance of mechanical sounds and the level of S_{95} in the environment has a negative impact. For eventfulness, the number of significant sound sources and the level of F_{50} in the environment have a positive impact, while the significance of mechanical sounds will bring a negative impact. The mechanical sounds showed a considerable influence in both models, and both are negative effects. Besides, the model's statistical evolution of psychoacoustic indicators represents the special acoustic representation of one or some sound sources in the environment. When performing soundscape perception prediction, this particular acoustic representation is usually recognized as background sound, not a sound event, which appears in the form of acoustic parameters in the perception model.

3) Under two perception dimensions, the acoustic parameters and sound source characteristics have a particular influence. These soundscape characteristics root in the information released by the sound source, which are the physical clues provided by the environment when people perceive. The acoustic indicators reflect the energy and frequency of the environment through numbers. People's subjective recognition describes the sound source characteristics and delineates the acoustic environment content. In a period acoustic environment, combining the two physical cues facilitates acoustic environment characteristics and changes to be wholly constructed in the form of indicators and make a marvelous soundscape perception prediction.

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