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Soundscape Cognition for User Behavior in Urban Parks

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ABSTRACT

To investigate the cognitive components of urban park soundscape design, we evaluated soundscape preference based on visual object change factors for the background and people within the virtual reality (VR) environment. We investigated the changes in the sound pressure level and frequency characteristics among 18 evaluation points selected from three parks in Paris. For the investigation, sound environments of two minutes and 30 seconds during the daytime (10:00-14:00) were selected from each point using a 360-degree camera (Insta360) and SoundField (SPS200) microphone. To investigate the behavioral characteristics of urban users, the image of each selected point was divided into 30-second segments, and objective characteristics, such as activity, group, posture, and density, were analyzed. We also evaluated subjective responses, such as soundscape evaluation factors, landscape evaluation factors, and overall satisfaction, to investigate the differences in soundscape cognition as behavioral characteristics changed at the same point in the park. To realize an immersive environment, the subjects were allowed to move freely in VR by reflecting the direction of the sound source and head rotations. Assessments of the level of immersion and sense of reality were used to verify the experimental environment.

Keywords: Soundscape, human behavior, soundscape quality

1. INTRODUCTION

Soundscape has a close relationship with the landscape, and there are many previous studies that the perception of the soundscape perception depends on the composition of the landscape (1, 2). Furthermore, the effects of audio-visual components on recognition of soundscape and audio-visual interaction have been studied (3). In recent years, there has been an attempt to investigate the change of the sound environment according to the behavioral characteristics of the urban users in addition to the simple audio-visual effect investigation (4). However, there is little research on the relationship between the soundscape quality in a space and the human behavior of urban users. Although a recognition model for soundscape perception has been proposed, further study is needed because there are limitations on the consideration of user behavior and application of visual indicators (5).

Virtual reality technology is widely used to reproduce the visual and acoustical conditions of a real environment. In recent years, there have been a lot of applied studies on indoor and outdoor noise, and methodological researches on the implementation of VR environment for soundscape evaluation have been made (6 - 8). Therefore, it is possible to implement similar conditions in the laboratory environment through the VR technology in a situation where control of the experimental conditions is required, and the results of the previous studies show that the subjective evaluation results in the VR environment are similar to the actual ones, so they need to be practically used (9, 10)

In this study, we implement the evaluation environment by applying the virtual reality technology and evaluate the soundscape of the urban park. First, we examine the perceived sound sources of each park's evaluation points, observe the behavioral characteristics of the park users, evaluate the soundscape quality, and finally examine the relationship between human behavioral characteristics

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and soundscape recognition.

2. METHODS

2.1 Site Selection

To investigate the effect of human behavior characteristics on soundscape recognition in urban parks, Arènes de Lutèce (A), Jardin des Tuileries (J), and Champ de Mars parks (C), which have different acoustic and visual characteristics around the Seine River in Paris, were selected. The Arènes de Lutèce park is located near the residential area and is surrounded by buildings and has a green area. And it has a circular square in the center. The Jardin des Tuileries park has a large open space and a green area, surrounded by tall buildings, and there are distinctively different sized fractions. The Champ de Mars park also houses the landmark Eiffel Tower in Paris and features a large green area. Subjective response and objective measurement results were obtained at 12 points in total, and each evaluation points is shown in Fig. 1.

The A-weighted sound pressure level (L_{Aeq}) was calculated to determine the sound strength characteristics. $L_{Ceq-Aeq}$ was calculated to investigate the relative low-frequency characteristics with respect to the sound spectral contents. Finally, $L_{A10-A90}$ was calculated to investigate the temporal variability of the sound environment (See the table 1).

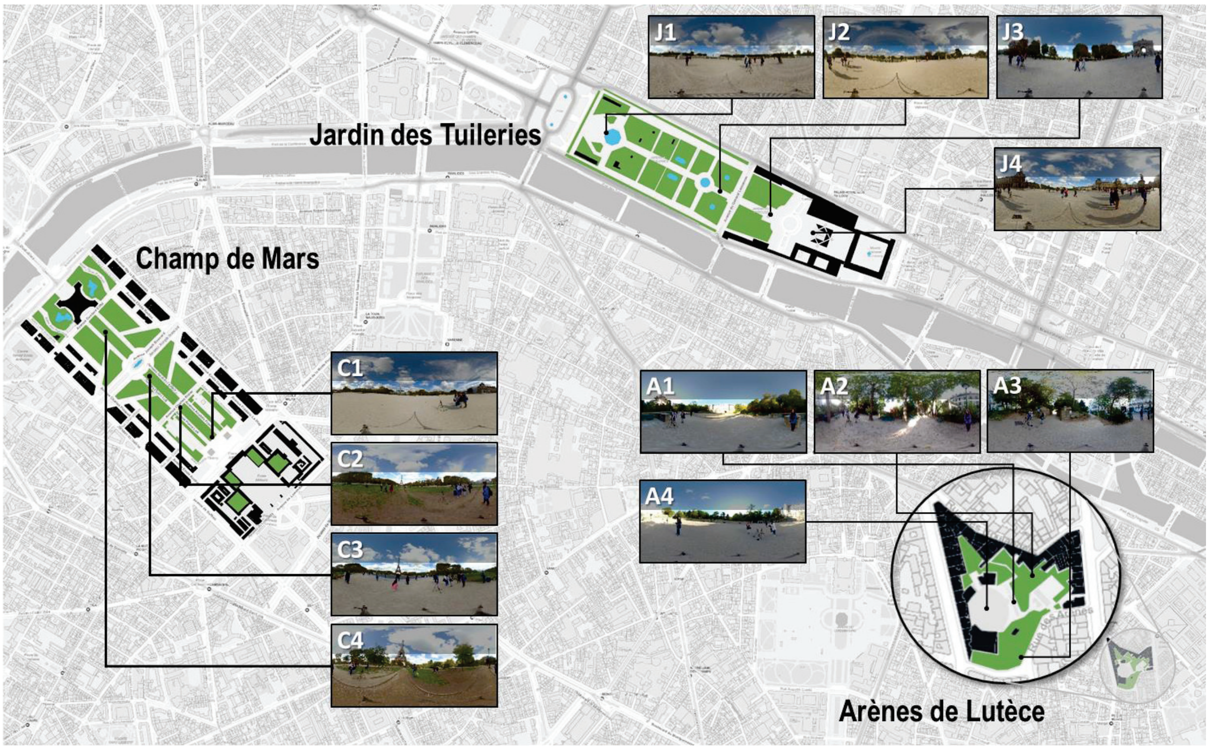

Figure 1 – Panoramic view of selected evaluation locations

Table 1 – Mean value of acoustic parameter of each evaluation locations

Sites	L_{Aeq}	$L_{A10-A90}$	$L_{Ceq-Aeq}$	Sites	L_{Aeq}	$L_{A10-A90}$	$L_{Ceq-Aeq}$	Sites	L_{Aeq}	$L_{A10-A90}$	$L_{Ceq-Aeq}$
A1	54.5	12.4	21.8	**C1**	67.6	21.9	17.8	**J1**	65.0	24.4	18.5
A2	42.5	5.0	28.4	**C2**	72.1	22.4	16.1	**J2**	64.2	18.9	19.3
A3	54.8	22.1	22.4	**C3**	69.6	19.7	17.5	**J3**	56.1	12.1	21.9
A4	60.4	23.9	20.7	**C4**	67.9	22.1	18.4	**J4**	66.0	17.5	19.6

2.2 VR soundscape recording and reproduction

Soundscape data were recorded at 12 points at 10 am – 2 pm in October 2018. A spherical panoramic camera (Insta 360 camera), an ambisonic microphone (Soundfield SPS 200 microphone), and portable recording device (MixPre-6) were used to measure the audio-visual environment data. The recordings were recorded in A-format first-order ambisonic (FOA). A-weighted sound pressure levels were measured using a calibrated 1/2-inch microphone (G.R.A.S AE46) to calibrate the sound pressure level when reproducing recorded sources in a laboratory environment.

A 360° camera image recorded with six channels was implemented with a head-mounted display (HMD). For the implementation of headphone-based 3D stereo sound, the sound source recorded with the A-format FOA was converted into B-format FOA using Unity software and down-mixed with a binaural track and reproduced using and open-type headphone (Sennhiser HD-650). The length of the evaluation source was set to 30 seconds, which is sufficient to answer the question through the pilot test. The sound pressure level of the recorded ambisonic audio at each evaluation point was calibrated using a head and torso simulator (Brüel & Kjær 4100) based on the value of the A-weighted equivalent continuity sound level of the 150 sec (LAeq,150-sec).

2.3 Questionnaire

Soundscape data were collected using a questionnaire and observation, and the questionnaire consists of 3 parts. The dominance of the perceived sound sources was evaluated using a 5-point likert scale, and the types of sound sources were classified into four categories: traffic noise, sounds from human activities, water sounds, and birdsong. The perceived affective quality at each location was also evaluated using eight adjective attributes. Human behaviour characteristics were investigated using observation method. The behavioural characteristics of every 30 seconds frame of the video taken at each evaluation positon were classified into three categorize: Activity (chatting, eating, loitering, talking on the phone, stroll with dog, talking a picture, walking, jogging, riding, stroller), group (alone, group) (11).

2.4 Procedure

A total of 30 subjects (20 males, 10 females) participated in the evaluation of the soundscape, and all subjects had normal auditory capabilities. The test subjects were aged between 20 and 29 (mean age = 24.8, standard deviation = 1.98). The evaluation was conducted in the semi-anechoic room and the background noise was sufficiently low to be 30 dBA. The order placement of the evaluation points in the same park was set to coincide with the actual walking path, and the order of the park was set to be random. The length of the sound source was set to 150 seconds for each evaluation point, and each sound source was divided into 5 sections in 30 second intervals. Subjects were asked to answer the same questionnaire for a total of 60 sound sources (12 points × 5 sound sources). To minimize the physical fatigue during the evaluation period, the subjects were allowed to have a sufficient resting time of about 10 minutes every 30 minutes.

3. RESULTS

3.1 Perceived sound sources

The sound sources prominent at each evaluation point are shown in Figure 2. Percentage is the percentage of people who answered "heard a lot" or "dominated completely" out of the 5-point scale. First, Park A is dominated by birds, because it is quiet and well-organized compared to other parks. In the case of Park C, the sound of people was predominant, which is considered to be due to the flow of people because Park C is a sightseeing spot and plays a landmark role in Paris. Park J showed that traffic, human, water, birdsongs can be heard well. Thus, it can be seen that the three parks have different acoustic characteristics.

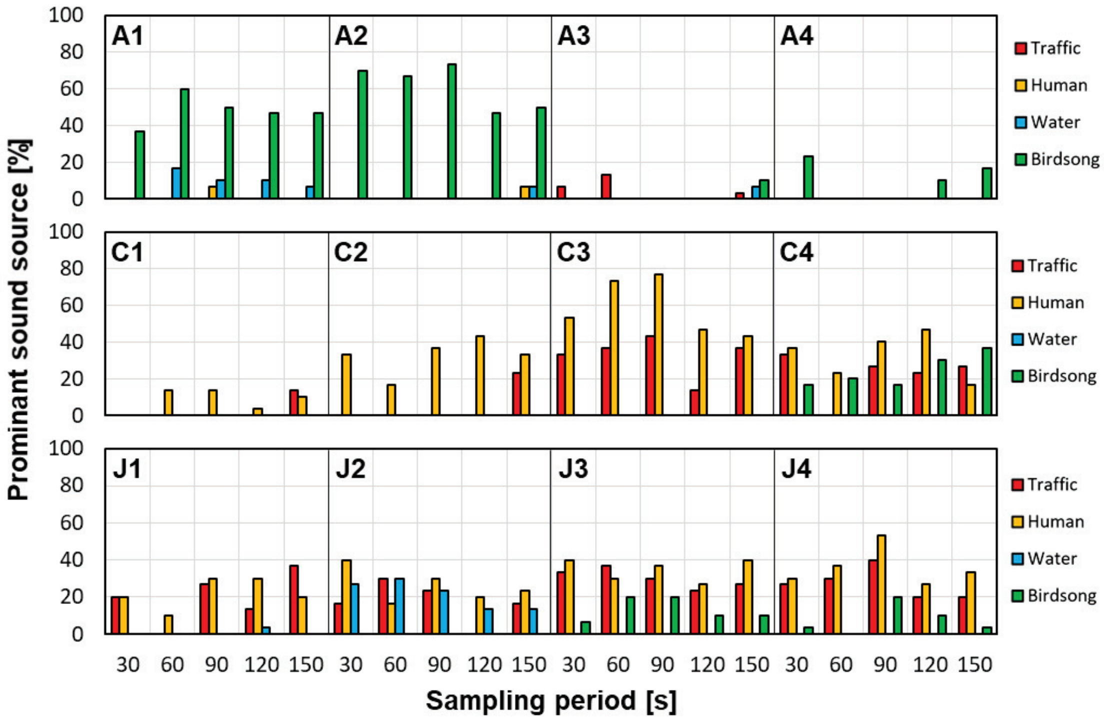

Figure 2– Temporal variation in the dominant sound sources types for 5 different sampling period

3.2 Human behavior

The results of the observation of human behavior are analyzed and the overall characteristics are shown in Figure 3 and the specific activity types are shown in Figure 4. First, Figure 3 (a) shows that Park A has a higher percentage of people staying in the space, and (b) shows that many people are coming alone. Park C had a higher percentage of passers, as it was one of the tour courses, because of the high percentage of people who came and went for a while, most of them coming to the group. Park J showed the characteristics of Park A and C. The ratio of passer to stopper was similar. However, considering the size of the park, similar to Park C, the proportion of people coming to the group is higher than that coming alone.

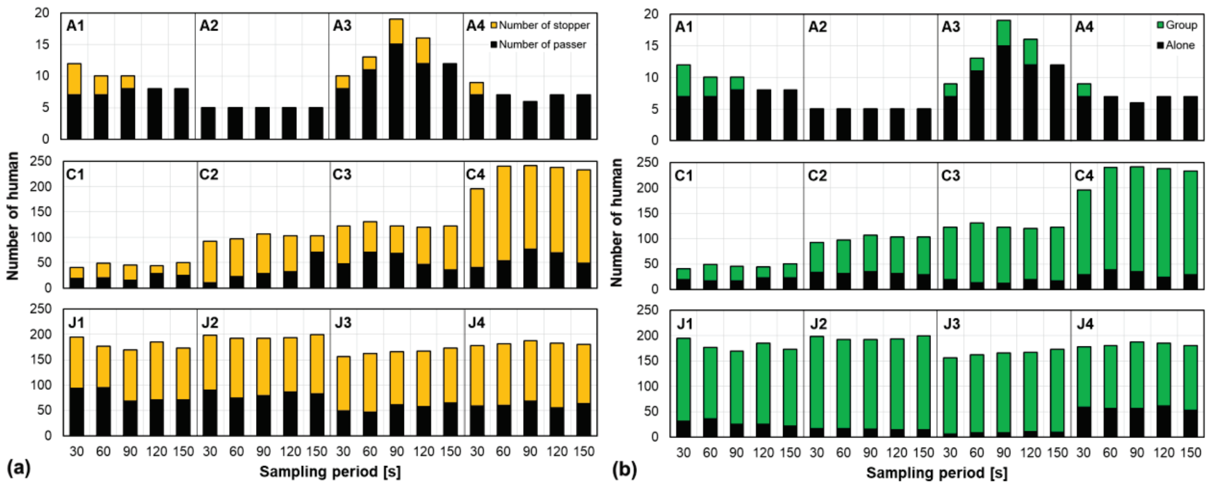

Figure 3 – Overall human behavior characteristics in different sampling periods

As shown in Figure 4, there were many people who went to Park A without taking any special action. In Park C, the closer to the Eiffel Tower, the higher the percentage of people walking and taking photos and staying in the space. In Park J, the percentage of people who walked in the park was high regardless of the location.

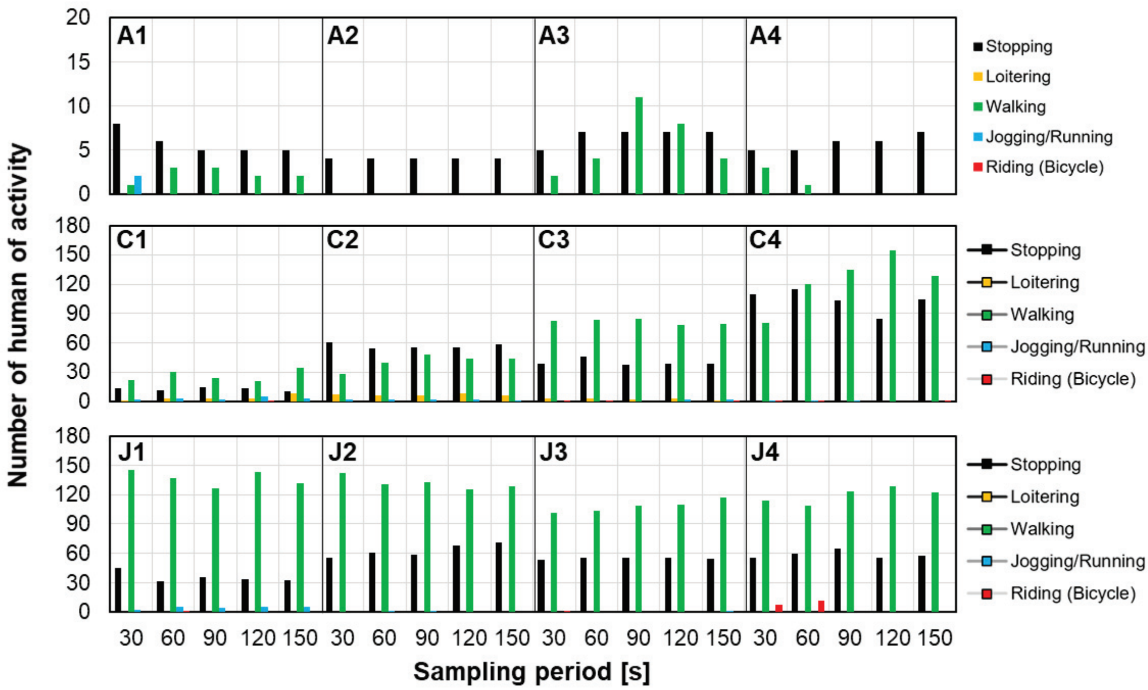

Figure 4 – Specific human behavior characteristics in different sampling periods

3.3 Soundscape quality

Table 2 shows the results of the principle component analysis for eight soundscape attributes. The Kaiser-Meyer-Olkin (KMO) measures of sampling adequacy was 0.71, respectively, indicating optimum levels. The Bartlett's test of sphericity was clear ($p<0.01$). The soundscape quality of the park is expressed by three factors (Tranquil/Peaceful, Dynamic/Lively, Confusing/Uncomfortable).

Table 2 – Rotated component matrices of the PCA using semantic attributes response

Attributes	Tranquil/Peaceful	Dynamic/Lively	Confusing/Uncomfortable
Explained variance	26.30	24.00	18.48
Pleasant	0.23	**0.75**	0.14
Unpleasant	0.01	0.12	**0.84**
Eventful	-0.32	**0.78**	0.12
Uneventful	**0.74**	-0.28	0.19
Exciting	-0.22	**0.78**	0.15
Monotonous	**0.82**	-0.10	-0.07
Calm	**0.83**	0.08	-0.20
Chaotic	-0.10	0.19	**0.80**

The factor scores for each evaluation point are shown in Figure 5. Park A was relatively tranquil and peaceful, and in the case of A3, it was found to be negative in the vicinity of the road. Park C showed a high percentage of people and was rated as dynamic. In the case of Park J, there was no significant difference between factor factors. All three parks showed no significant difference with time.

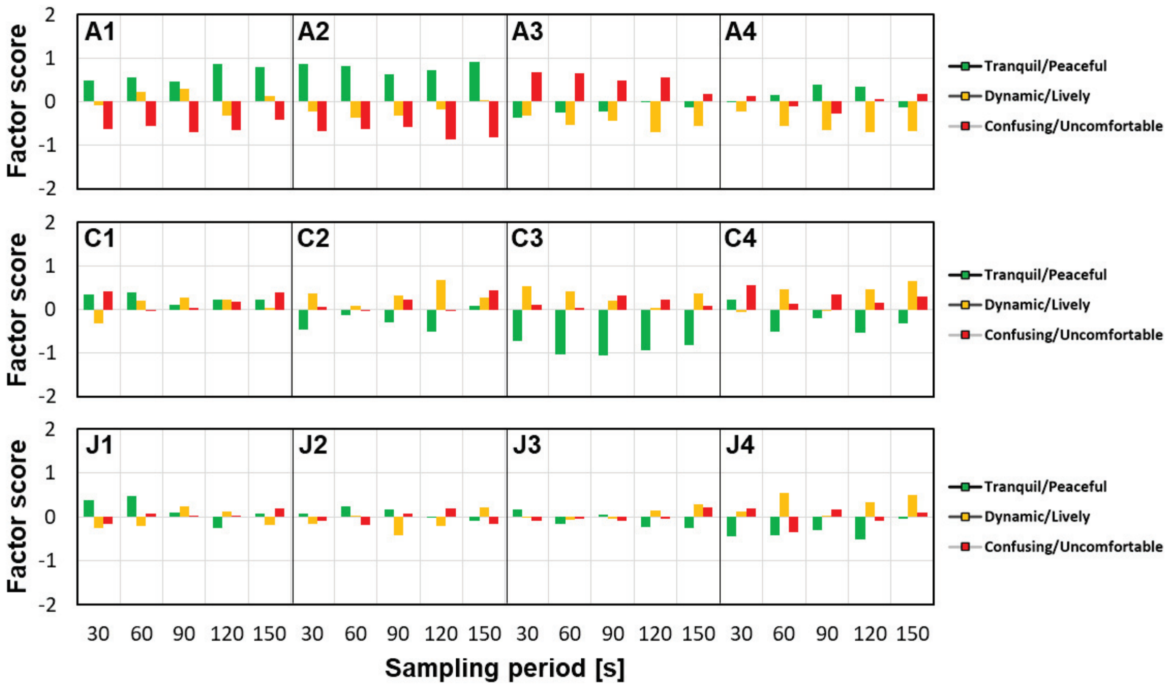

Figure 5 – Temporal variation of the mean PCA component scores

4. DISCUSSION

4.1 Relationship between sound-sources and soundscape quality

Table 3 shows the results of the spearman rho's correlation between the soundscape component results derived from PCA and the sound-sources perceived in the park. Traffic and human sounds were positively correlated with Dynamic / Lively, but they were found to be somewhat confusing. On the other hand, natural sounds (birdsongs, water) showed a positive relationship with Tranquil / Peaceful and showed positive contribution to soundscape evaluation. This is in agreement with the results of previous studies (3, 9)

Table 3 – Spearman rho' correlation between perceived sound sources and perceptual components of soundscapes (**Bold** < 0.01, <u>underscore</u> < 0.05)

Attributes	Tranquil/Peaceful	Dynamic/Lively	Confusing/Uncomfortable
Traffic	**-0.57**	**0.41**	**0.39**
Human	**-0.69**	**0.68**	<u>0.30</u>
Birdsongs	**0.56**	-0.02	**-0.71**
Water	<u>0.29</u>	-0.08	<u>-0.31</u>

4.2 The influence of human behavior characteristics on soundscape recognition

Table 4 shows the correlation between human behavior and soundscape quality. When we look at each group first, it shows that Tranquil / Peaceful is more influential when several people are in group. In the case of Stay, it was found that the higher the ratio of stopper, the more dynamic and lively the person staying in the space is. In the case of specific activities, the degree of walking or staying lightly rather than jogging / running or riding has a greater effect on Dynamic / Lively.

Table 4 – Spearman rho' correlation between perceptual components of soundscapes for different human behavior characteristics (**Bold** < 0.01, underscore < 0.05)

	Criteria	Tranquil/Peaceful	Dynamic/Lively	Confusing/Uncomfortable
Group	Alone	**-0.39**	**0.48**	0.28
	Group	**-0.44**	**0.45**	0.28
Stay	Passer	**-0.39**	**0.35**	0.28
	Stopper	**-0.48**	**0.53**	0.29
Activity	Stopping	**-0.48**	**0.54**	**0.33**
	Loitering	-0.26	**0.39**	0.22
	Walking	**-0.43**	**0.43**	0.25
	Jogging/Running	0.03	0.17	0.18
	Riding (Bicycle)	-0.21	0.25	-0.03

5. CONCLUSIONS

In this study, the effect of human behavior characteristics on soundscape recognition was investigated through a VR environment in the laboratory to improve soundscape quality through inducing the human behavior in the urban parks. As a result, we identified three factors for soundscape quality and identified the relationship with human behavior. However, there is a need to investigate the differences in behavioral changes with time, and it would be more meaningful to study the effect of noise level or psychological density, such as perceived loudness or perceived crowd density. The results of this study can be effectively and practically used from the viewpoint of human behavior in designing and improving the city park.

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