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Evaluation of soundscape and audio–visual factors in VR environment for quiet urban park

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ABSTRACT

Soundscape was evaluated in a virtual reality environment and audio–visual influences were investigated for a quiet urban park design. First, three urban parks in Paris were selected, and the sound environment was measured using a 360 camera and a sound-field microphone. Based on the measurement data, the VR evaluation environment was simulated by applying a head mounted display device and three-dimensional sound, and HRTF and head movement were applied to reflect the user's movement. We evaluated the dominant sound and visual factors, and examined the perception of soundscape through a semantic expression test. The analysis of the objective landscape factors and human behavior in the space and the relationship with the overall sound environment satisfaction were examined. Consequently, it was found that the satisfaction increased when the visually natural factor increased in the VR environment.

Keywords: Soundscape, Landscape, Audio–visual, Human behavior, Virtual reality
I-INCE Classification of Subject Number: 61

1. INTRODUCTION

Soundscape exhibits a close relationship with landscape; many previous studies have reported that the soundscape perception depends on the landscape composition[1,2]. Furthermore, the effects of audio–visual components on the recognition of soundscape and audio–visual interaction have been studied[3]. In recent years, researchers have attempted to investigate the change in sound environment according to the behavior characteristics of urban users in addition to the simple audio–visual effect investigation[4]. However, little research has been performed on the relationship between the audio–visual components of soundscape perceived in space and the human behavior of urban users. Although a recognition model for soundscape perception has been proposed, further study is required because of the limitations on the consideration of user behavior and the application of visual indicators[5].

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Virtual reality (VR) technology is widely used to reproduce the visual and acoustical conditions of a real environment. In recent years, many studies have been conducted on external noise, and methodological studies on VR environments for soundscape evaluation have been implemented[6,7]. Hong et al.[8] concluded that a headphone-based binaural implementation in a VR environment can provide a realistic feeling in terms of the directionality, width, and distinctiveness of a source. Therefore, field evaluation can be performed in a limited laboratory environment with an immersive sound reproduction.

In this study, we implement the evaluation environment by applying VR technology and evaluate the soundscape of an urban park. First, we examine the audio–visual component of each park's evaluation points, observe the behavioral characteristics of the park users, evaluate the satisfaction, and finally examine the interrelation among audio–visual indicators, human behavioral, and satisfaction.

2. METHOD

2.1 Case study area

For the evaluation of the soundscape, Arènes de Lutèce (A), Jardin des Tuileries (J), and Champ de Mars parks (C), all of which exhibit different acoustic and visual characteristics around the Seine River in Paris, were selected. The Arènes de Lutèce Park, which has a green area, is located near a residential area and is surrounded by buildings. Further, it has a circular square in the center. The Jardin des Tuileries Park, which has a large open space and green area, is surrounded by tall buildings and consists of distinctively different-sized fractions. The Champ de Mars Park houses the landmark Eiffel Tower in Paris and features a large green area. Subjective response and objective measurement results were obtained at 18 points, and each evaluation point is shown in Fig. 1.

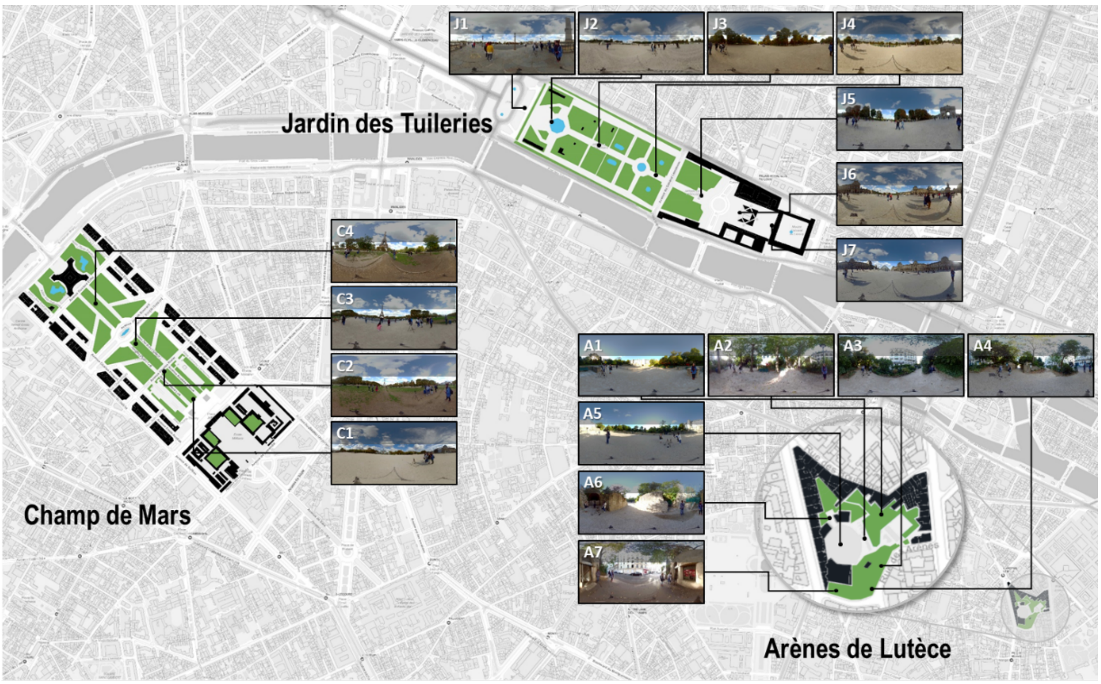

Fig. 1 – Panoramic stills from the spherical videos of selected evaluation locations

2.2 Data collection

2.2.1 Soundscape data

Soundscape data were collected using a questionnaire and observation. The questionnaire consisted of four parts. The dominance of the perceived sound sources was evaluated using a five-point scale: 1 = not heard at all, 2 = heard slightly, 3 = heard moderately, 4 = heard significantly, and 5 = sound dominates completely. The types of sound sources were classified into five categories: traffic noise, sounds from human activities, water sounds, birdsong and music, and other noises such as mechanical noise[8,9]. The dominance of the perceived visual indicators was evaluated using a five-point scale: 1 = not observed at all, 2 = observed slightly, 3 = observed moderately, 4 = observed significantly, and 5 = observation dominates completely, and the types of visual indicators were classified into seven categories: vehicle, road, building, green area, water feature, human activity, and sky. The perceived affective quality at each location was evaluated using eight adjective attributes that were chosen based on previous studies[10]. In the final part, the overall satisfaction, quietness, and comfort were assessed using a five-point scale: 1 = strongly disagree, 2 = slightly disagree, 3 = neither disagree nor agree, 4 = slightly agree, and 5 = strongly agree. Human behavior characteristics were investigated using the observation method. The behavioral characteristics of every 30-s frame of the video captured at each evaluation position were classified into three categories: Activity (chatting, eating, loitering, talking on the phone, stroll with dog, capturing a picture, walking, jogging, riding, stroller), group (alone, group) [11].

2.2.2 Acoustic parameter

The physical acoustic indicators are summarized according to three aspects: sound strength, spectral content, and temporal structure of sounds. The acoustic recording samples at each location were used to calculate the SPLs. A-weighted SPL (L_{Aeq}) was calculated to represent the sound strength of the acoustic environment and $L_{Ceq\text{-}Aeq}$, which represents the low-frequency energy, was calculated to investigate the spectral contents of the acoustic environment. The differences between the 0th and 90th percentile levels were calculated ($L_{10\text{-}90}$) to quantify the temporal variability of the sound environment.

2.3 Stimuli

2.3.1 Audio–visual recording

Audio–visual data were collected at 18 evaluation points to evaluate the auditory sensation in a laboratory VR environment from 10 am to 2 pm in October 2018. An Insta 360 camera was used to capture 360-degree video information, and was recorded at 8k ultrahigh definition, 30 fps resolution, and 95 Mbps bit rate. The acoustic environment data were recorded in a first-order ambisonic format using a soundfield SPS 200 microphone and using a MixPre-6 (Sound devices) recorder. In addition, A-weighted sound pressure levels were measured using a calibrated 1/2-inch microphone (GRAS AE46) and an AS 70 portable sound-level motor (RION) to calibrate the sound pressure level when reproducing recorded sources in a laboratory environment.

2.3.2 Reproduction method

The video captured by the six-channel 360-degree camera was edited with the Insta360stitcher to be compatible with the VR HMD device (VIVE Pro 2), and the A-format sound source recorded in four channels was converted to B-format first-order ambisonics down-mixed[7] and reproduced using an open-type headphone (Sennheiser HD-650). In addition, the Unity 3D engine was used to implement the VR image and spatial audio. For the immersion of the participants in the sound environment, the directional implementation according to the head movement was reflected in real time by reflecting the head-rotation tracking technique. The ambisonic audio and video synchronizations were adjusted based on the clapper sound at each evaluation point. The length of the evaluation source was set to 30 s, which was 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 150 s ($L_{Aeq,150-sec}$).

2.4 Procedure

Thirty subjects (20 males, 10 females) participated in the evaluation of the soundscape, and all participants had normal auditory capabilities. The test participants were between 20 and 29 years old (mean age = 24.8, standard deviation = 1.98). The evaluation was conducted in a semi-anechoic room and the background noise was sufficiently low at 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 s for each evaluation point, and each sound source was divided into five sections in 30-s intervals. The participants were asked to answer the same questionnaire for 90 sound sources (18 points × 5 sound sources). To minimize physical fatigue during the evaluation period, the participants were allowed a sufficient resting time of approximately 10 min for every 30 min.

3. RESULTS

3.1 Acoustical parameters

The calculated acoustic parameters in park A-J are listed in Table 1. In terms of the sound strength, Park C indicated the highest sound pressure level at 72.1 dBA and Park J indicated the second highest sound pressure level at 56.1–66.1 dBA. Meanwhile, the sound pressure level of part A was 42.5–60.4 dBA, which was lower than those of other parks. $L_{Ceq-Aeq}$, representing temporal variability and L_{A10}-A90, representing spectral characteristics, varied from Park A to J.

3.2 Perceived sound sources

The percentage of responses recorded as "heard significantly" or "dominated completely" for a given source type were calculated to explore the dominant sound sources for the different locations, as shown in Fig. 2. In Park A, birdsongs were dominant because of the high distribution of trees and relatively low background noise. In Park C, human, traffic, and birdsongs occurred. Park C is a landmark element of France and the sound from it more dominant than other sound sources because of the large number of tourists and population. Regarding Park J, similar to Park C, the sound of people is predominant, and water sound is always recognized.

Table 1 – Mean value of acoustic parameters of the three sampling periods

Sites	L_{Aeq}	L_{A10}	L_{A50}	L_{A90}	$L_{A10-A90}$	$L_{Ceq-Aeq}$
A1	**54.5**	52.4	41.1	40.0	**12.4**	**21.8**
A2	**42.5**	44.2	40.6	39.2	**5.0**	**28.4**
A3	**47.3**	48.9	44.7	41.2	**7.8**	**10.9**
A4	**54.8**	59.2	45.2	37.1	**22.1**	**22.4**
A5	**60.4**	64.0	45.0	40.2	**23.9**	**20.7**
A6	**51.7**	55.5	47.4	41.6	**13.9**	**18.7**
A7	**53.9**	57.7	50.4	45.4	**12.3**	**18.6**
C1	**67.6**	71.6	60.3	49.7	**21.9**	**17.8**
C2	**72.1**	76.4	68.8	54.0	**22.4**	**16.1**
C3	**69.6**	74.3	65.7	54.6	**19.7**	**17.5**
C4	**67.9**	71.9	64.5	49.9	**22.1**	**18.4**
J1	**64.0**	66.9	63.1	56.9	**10.0**	**18.6**
J2	**65.0**	70.4	51.2	46.0	**24.4**	**18.5**
J3	**66.1**	70.5	61.0	50.8	**19.7**	**18.7**
J4	**64.2**	69.4	54.4	50.5	**18.9**	**19.3**
J5	**56.1**	58.8	49.8	46.7	**12.1**	**21.9**
J6	**66.0**	70.5	62.6	53.1	**17.5**	**19.6**
J7	**56.4**	58.7	50.7	48.5	**10.2**	**20.6**

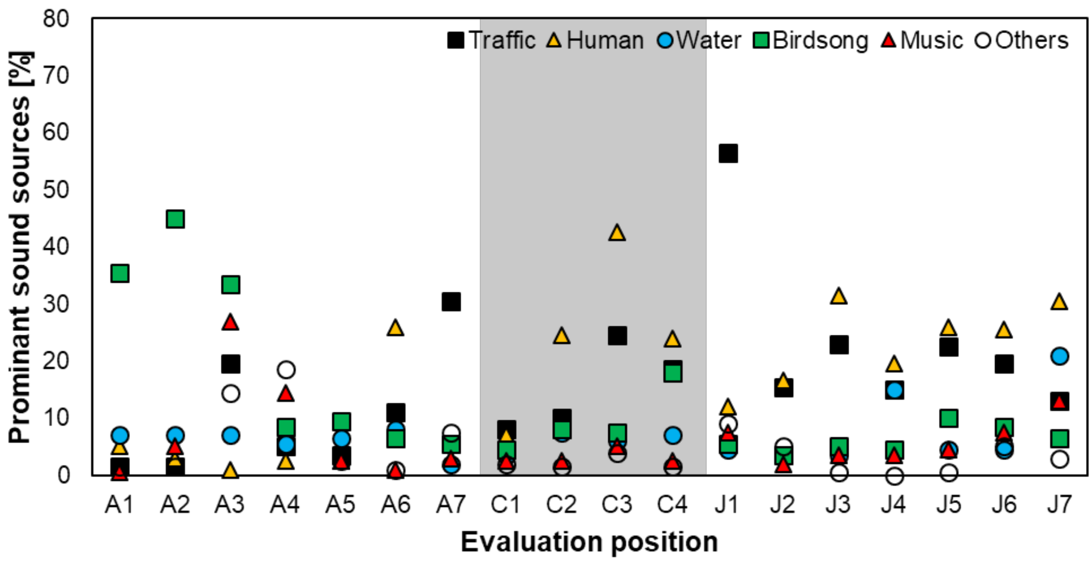

Fig. 2 – Dominant sound sources types for different evaluation positions

3.3 Perceived visual indicates

The percentage of response recorded as "observed significantly" or "dominated completely" was calculated for the given dominant visuals for the different locations, as shown in Fig. 3. In Park A, the green area was dominant, and it was related with birdsongs being dominant, as shown in Fig. 2. In Park C, the visual elements of open space and human were extremely high, and Park J demonstrated a similar tendency. Water features were characterized only in Park J, and building, road, and traffic were similar in the three parks.

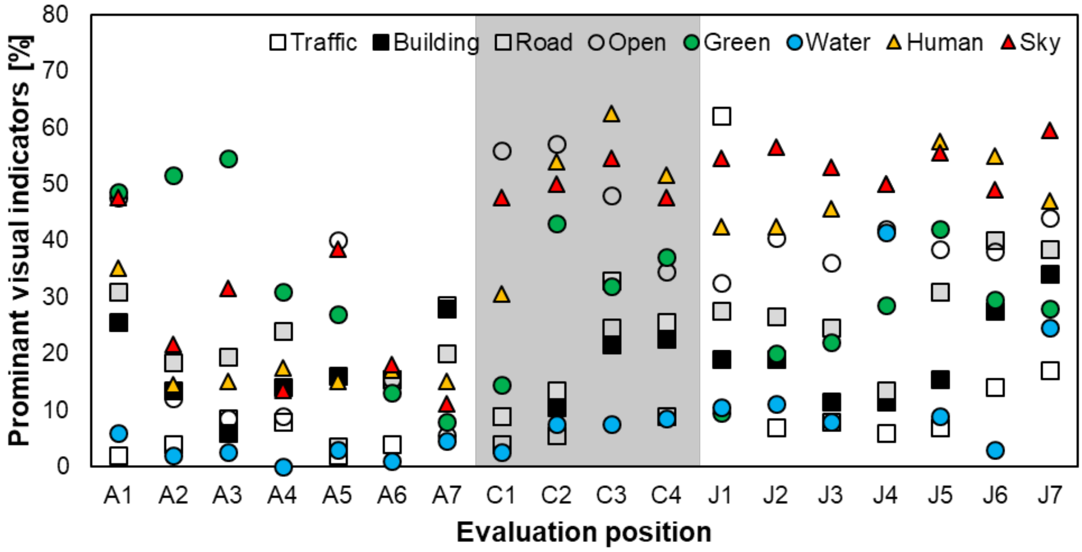

Fig. 3 – Dominant visual indicators for different evaluation positions

3.4 Perceived affective quality

To investigate the perceived affective quality of the soundscape, the mean rating scores of the four attributes: (a) pleasant, (b) eventful, (c) calm, and (d) exciting, are plotted in Fig. 4. Park A was rated as exciting only where birds could be heard and was generally evaluated as negative in other qualities, whereas Park C was rated as eventful as more people appeared and more human sound was perceptible. However, the exciting value in affective quality is not necessarily determined by the presence of human sounds or birds.

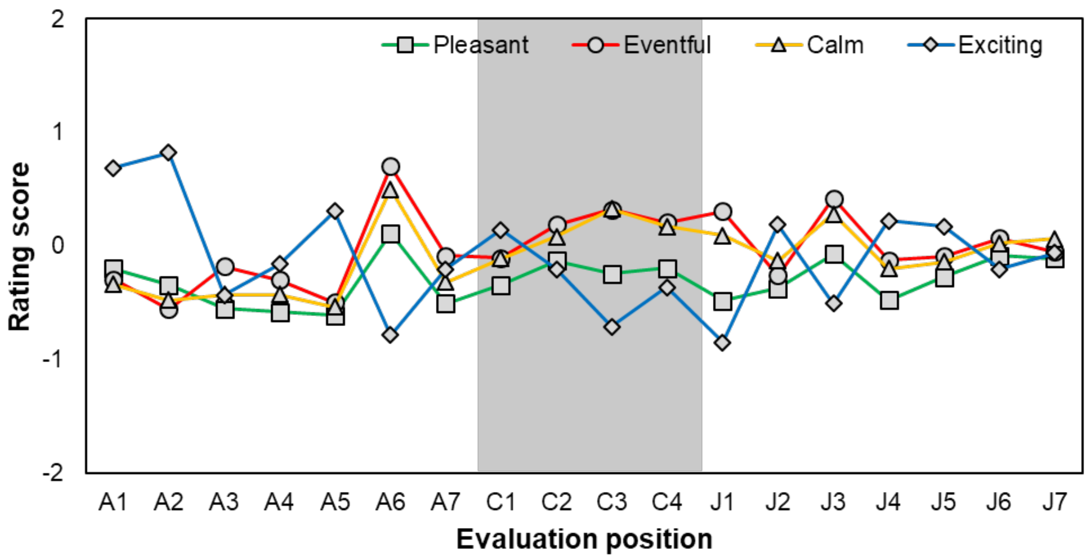

Fig. 4 – Mean rating scores of the perceived affective quality attributes

3.5 Human behavior

The behavioral characteristics of park users were analyzed according to activity type and group type, as shown in Figs. 5 (a) and (b), respectively. First, as shown in Fig. 5 (a), the number of users of Park J was the largest and the number of users of Park A was the smallest. The users of Park A were the most likely to remain silent without any action, followed by walking or loitering. In Park C, chatting occurred more frequently than park A, and many people were performing dynamic behaviors such as riding a bicycle or capturing a picture rather than sitting alone. Finally, Park J exhibits the characteristics of Parks A and C, and many chatting people and people remaining quiet exist. In terms of group, as shown in Fig. 5 (b), Park A users primarily came alone, Park C users were primarily in groups, and Park J has an equal ratio of alone and group users.

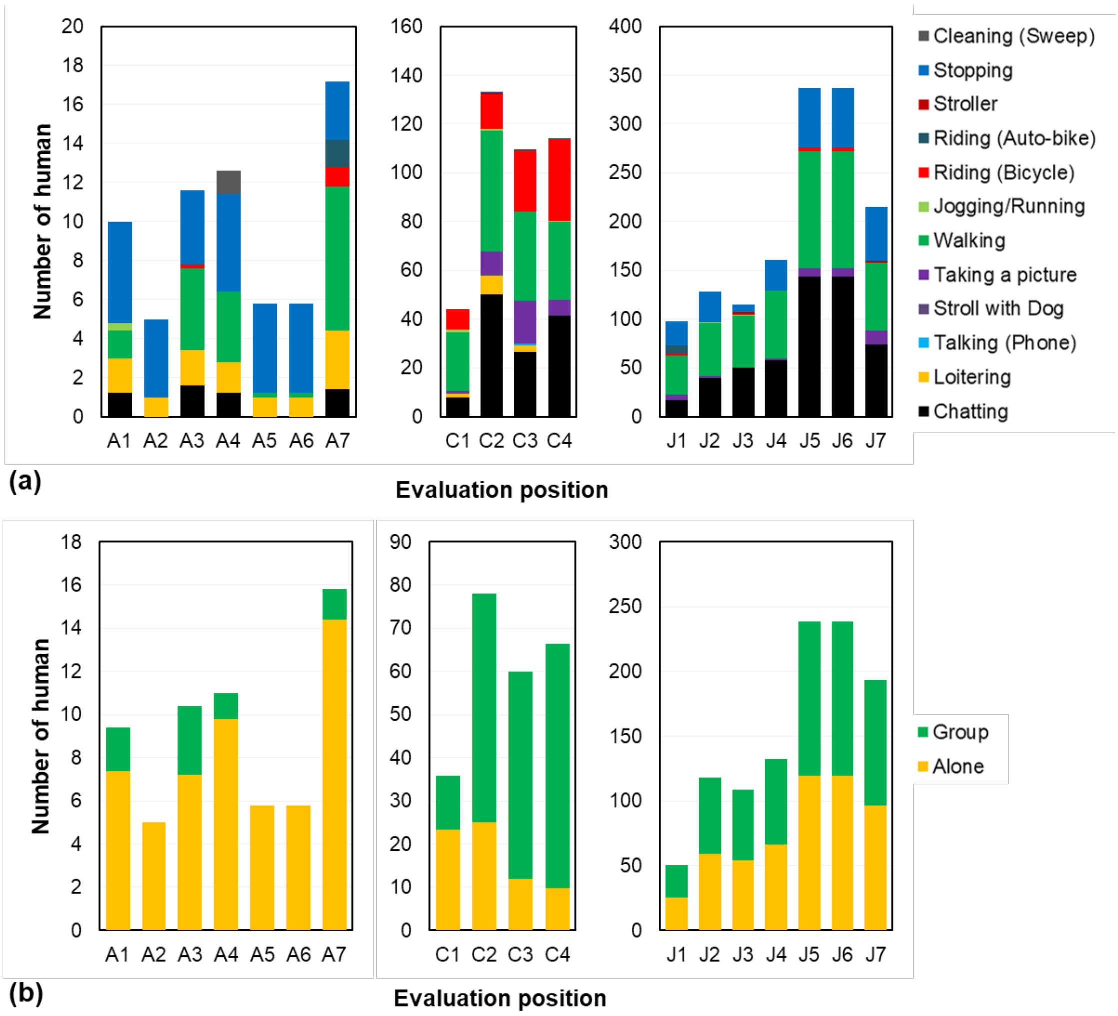

Fig. 5 – Number of humans depending on different criteria (a) Activity, (b) Group

3.6 Overall satisfaction

The average rating score for the overall satisfaction at each evaluation point is shown in Fig. 6. The tendency of satisfaction and quietness was similar, and it was found to change dominantly according to the change in sound pressure level.

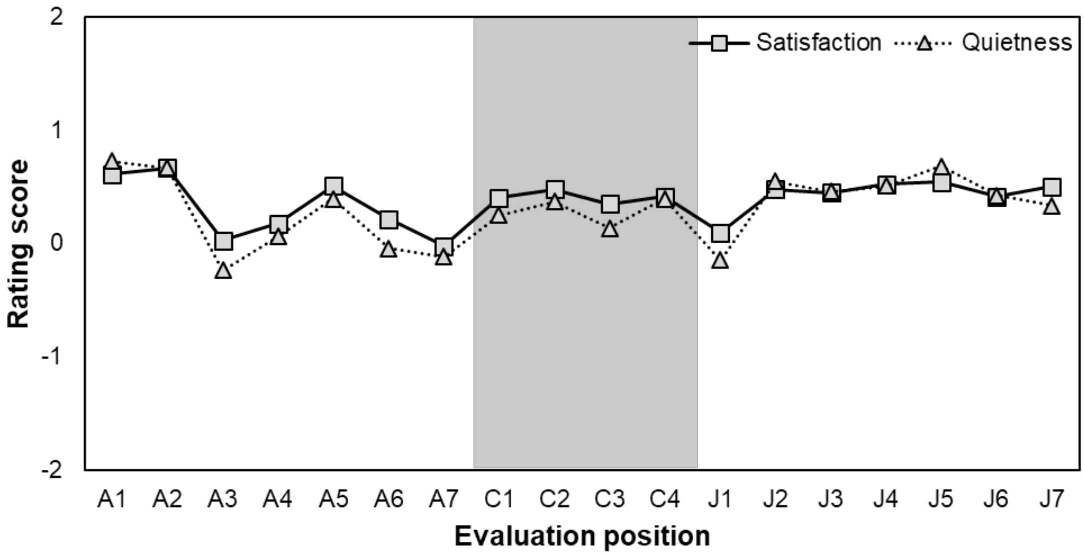

Fig. 6 – Rating score of overall satisfaction in different positions

4. CONCLUSIONS

In this study, the soundscape evaluation of three parks in Paris was conducted, and audio–visual factors for the soundscape design of urban parks were investigated. In addition, statistical tests were conducted to examine the relationships among acoustical parameters, audio–visual indicators, perceived affective quality, human behavior, and overall satisfaction. The results indicated that exciting emotions were changed by auditory/visual factors of birdsongs and human, and perceived affective quality tendency varied according to the composition of human activity. The overall satisfaction was dominantly determined by the sound pressure level. In the future, a park design guideline will be proposed by presenting the structure equation model of the soundscape including the human behavior response to an urban park.

5. ACKNOWLEDGEMENTS

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6. REFERNCES

1. J. Liu, J. Kang, T. Luo, H. Behm, *"Landscape effects on soundscape experience in city parks"*, Science of the Total Environment, 454-455 (2013) 474-481.

2. R. Pheasant, K. Horoshenkov, G. Watts, *"The acoustic and visual factors influencing the construction of tranquil space in urban and rural environments tranquil spaces-quiet places?"*, The Journal of the Acoustical Society of America, 123(3) (2008) 1446-1457.

3. J. Y. Hong, J. Y. Jeon, *"Designing sound and visual components for enhancement of urban soundscapes"*, The Journal of the Acoustical Society of America, 134 (3) (2013) 2026-2036.

4. Q. Meng, J. Kang, *"The influence of crowd density on the sound environment of commercial pedestrian streets"*, Science of the Total Environment, 511 (2015) 249-258.

5. J. Y. Hong, J. Y. Jeon, *"Influence of urban contexts on soundscape perceptions: A structural equation modelling approach"*, Landscape and Urban Planning, 141 (2015) 78-87.
6. L. Savioja, J. Huopaniemi, T. Lokki, R. Väänänen, *"Creating Interactive Virtual Acoustic Environments"*, J. Audio Eng. Soc. 47, 675 – 705, (1999).
7. J. Y. Hong, B. Lam, Z. Ong, K. Ooi, W. Gan, J. Kang, J. Feng, S. Tan, *"Quality assessment of acoustic environment reproduction methods for cinematic virtual reality in soundscape application"*, Building and Environment, 149 (2019) 1-14.
8. J. Y. Hong, J. Y. Jeon, *"Influence of urban context on soundscape perceptions: a structural equation modelling approach"*, Landscape and Urban Planning 141 (2015) 78-87.
9. J. Liu, J. Kang, T. Luo, H. Behm, T. Coppack, *"Spatiotemporal variability of soundscapes in a multiple functional urban area"*, Landscape and Urban Planning 115 (2013) 1-9.
10. Ö. Axelsson, M. E. Nilsson, B. Berglund, *"A principal components model of soundscape perception"*, The Journal of the Acoustical Society of America, 128(5) (2010) 2836-2846.
11. F. Aletta, F. Lepore, E. Kostara-Konstantinou, J. Kang, *"An experimental study on the influence of soundscapes on people's behaviour in an open public space"*, Applied sciences, 6 (2016) 276.