PROCEEDINGS of the
23rd International Congress on Acoustics

9 to 13 September 2019 in Aachen, Germany

VR Environment-based Evaluation of Impact Factors on the Urban Soundscape Recognition

Rosa SEO[1]; Hyun In JO[1]; Jin Yong JEON[1]

[1] Hanyang University, South Korea

ABSTRACT

To investigate the impact of soundscape spatial change factors in a pleasant urban environment, we evaluated a soundscape in a virtual reality (VR) environment and investigated the audiovisual impact factors on the soundscape. First, nine evaluation points were selected around Area A, and three-minute sound environments were selected at each point using a 360-degree camera (Insta360) and a SoundField (SPS200) microphone to investigate changes in the sound pressure level and frequency characteristics. Subjective responses, such as overall satisfaction, soundscape evaluation factors, and landscape evaluation factors, were evaluated in three environments (audio, visual, and audio with visual) based on the sound environment measurement data. To realize the 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. The experiment results showed that, in terms of the soundscape evaluation factors, overall satisfaction decreased as traffic noise increased and human sounds decreased. As for the landscape evaluation factors, the vegetation factor was the most dominant; as the green area increased, the overall satisfaction increased despite the noise factor. As a result, as the visual factors related to natural element, such as green area, increased, the auditory complaint factor was controlled and satisfaction towards the urban soundscape improved.

Keywords: Soundscape, Landscape, Audio-visual interaction, Expectation, Soundscape design quality

1. INTRODUCTION

With the negative effects of urban noise on health emerging as a social issue, the urban acoustic environment has begun to be considered an important factor for sustainable and healthy urban life. In this context, the concept of the soundscape has emerged. It focuses on the actual human perception of the acoustic environment (1, 2). ISO 1291-1 defines soundscape as the "acoustic environment as perceived or experience and / or understood by a person or people, in context." In this context, many studies have investigated the correlations between acoustic indicators and soundscape descriptors in various urban spaces (parks, squares, and streets) (3, 4).

It is important to investigate the contexts formed by various complex factors, including such nonacoustic factors as the function of the space, types of environment, and social background to interpret the soundscape. Context also includes factors that, in a broad sense, could affect the perception of soundscapes. Therefore, psychological factors, such as expectations—as well as physical factors constituting space, such as visual factors and auditory factors—and social backgrounds should be examined (5, 6).

There are many studies on soundscape quality and audio-visual interaction based on the fact that the early concept of soundscape originated from the landscape and is closely related to the visual. As a result, recognition models considering audio-visual interaction have been proposed to interpret the urban soundscape. However, until now, most of them have focused on the auditory property, and the detailed analysis model considering the detailed factors of the landscape is insufficient (7, 8).

[1] rosa824@hanyang.ac.kr
[1] best2012@hanyang.ac.kr
[1] jyjeon@hanyang.ac.kr

Assessment methodology soundscape research is mostly based on fieldwork methods, such as soundwalk and narrative interviews, for reasons of high ecological validity. When the surrounding environment needs to be controlled, 2D photos and Photoshop techniques are used in the laboratory environment (9, 10). However, this method of providing visual stimuli has the limitation that it does not sufficiently reflect the real sense of space and the actual field. To solve this problem, virtual reality (VR) technology has recently been introduced (11-13). It has been confirmed that the similarity is high when the subjective evaluation test results are compared with the actual field in the soundscape evaluation in an environment implemented with VR. Therefore, it is necessary to develop more-practical research on audio-visual interaction by applying this VR technique. (8, 14)

Therefore, in this study, audiovisual interaction was investigated for soundscape and landscape perception in urban environments by applying VR technology, and the relationship between soundscape quality and the urban environment was examined. In conclusion, an analytical model for overall satisfaction is newly proposed.

2. MANUSCRIPT FORMAT

2.1 Case study area

To investigate audio-visual influences through auditory evaluation in a laboratory environment, nine evaluation sites located in Seoul were selected, including various urban contexts (see Figure 1). The points where various noise sources such as traffic, people, and birds exist, including open space, green space, and a waterfront space (river), far away, were visually selected. A route was set up from a point where the traffic was densely close to the road, where the noise was the highest, to a point surrounded by a building and relatively quiet.

The A-weighted sound pressure level (L_{Aeq}) was calculated to determine the sound strength characteristics of each evaluation point. $L_{Ceq-Aeq}$, which is calculated as the difference between the A-weighted and the C-weighted SPL, is presented, showing the relative low-frequency characteristics with respect to the sound spectral contents. $L_{A10-A90}$ was calculated to investigate the temporal variability of the sound environment. The L_{Aeq} mean value of the evaluation points was very widely distributed in the range of 57.2–79.4 dBA. In addition, the difference between the maximum and minimum values of $L_{A10-A90}$ and $L_{Ceq-Aeq}$ exceeded 10 dB, respectively, which includes the variation range of the sound environment that can occur in a typical urban area.

Figure 1. Pictures of the nine evaluation locations for the experiment

2.2 VR soundscape environment

The measurements were conducted during the daytime (10 a.m. to 2 p.m.) in September 2018 to implement the VR evaluation environment in the laboratory environment. A spherical panoramic camera (Insta 360 camera) was used for recording for 3 min at each evaluation point. At the same time, an ambisonic microphone (Soundfield SPS 200) and a portable sound recorder (Mixpre-6, Sounddevices) were used for measuring the audio environment data and recorded with A-format first-order ambisonic (FOA). Both the spherical camera and the ambisonic microphone were measured at a height of 1.6 m. A-weighted sound pressure levels (LAeq) were measured using a 1/2-inch microphone (G.R.A.S AE46) and an AS-70 portable sound level meter (RION) to calibrate the sound pressure level.

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. Then, the head tracker mounted on the VR device was used to reflect the real-time direction of the sound source according to the head rotation of the subject. To calibrate the sound pressure level at each evaluation point, nine sound sources generated from the VR were recorded in a semianechoic chamber using a head and torso simulator (Brüel & Kjær 4100) and adjusted using Adobe Audition software version 1.5.

2.3 Experimental design

To evaluate the audio-visual environment interaction, the soundscape in three evaluation environments was evaluated: (1) only audio environment, (2) only visual environment, and (3) audio-visual environment. Experiments were conducted in a semianechoic chamber where background noise was approximately 25 dBA. Open-type headphones (Sennheiser HD-650) were used for evaluation, and VIVE Pro 2 (HMD) was used for visual information.

The questionnaire for the evaluation of the audiovisual interaction of the soundscape was composed of five parts. At each evaluation point, dominant sound sources (traffic, humans, birdsongs, music, and wind), dominant visual elements (vehicles, buildings, roads, open, green, people, and sky), soundscape quality (pleasant, unpleasant, eventful, uneventful, exciting, monotonous, calm, and chaotic), landscape quality (comfortable, uncomfortable, harmonious, disharmonious, natural, artificial, open, closed, wide, narrow, orderly, and disorderly), and overall satisfaction were evaluated on a five-point Likert scale.

2.4 Procedure

Each subject underwent soundscape evaluation in three different evaluation environments, and the order of evaluation environment was presented as only audio, only visual, and audio-visual environment. Each participant participated in one evaluation environment per day and was evaluated for a total of three days. To facilitate the response to the questionnaire, Unity software was used to select the response directly in the VR with the VIVE controller. The order of the evaluation sound sources was sequentially evaluated for nine stimuli from H1 to H9 along the path, and intervals between evaluation sound sources were 10 s. To solve the physical discomfort of the subjects due to wearing the HMD for a long time, the experiment time of each evaluation environment was not exceeded for 30 min, and the rest time was provided at the request of the subject.

3. RESULTS

3.1 Perception of audio-visual indicator

Figure 2 shows the dominant and audible preference for each evaluation point in only audio and audio-visual environments. Overall, traffic sound was dominant, and human sound was high in the road, around the building, and in the moving route. Bird sound was also high in a well-organized green area, such as a promenade and a park. As a result of two-way analysis of variance (ANOVA) analysis, there was a significant difference of sound and presence according to the presence or absence of visual information for traffic, humans, birds, and wind. It was shown that humans, birds, and wind are better recognized, but not traffic, in an audio and visual environment.

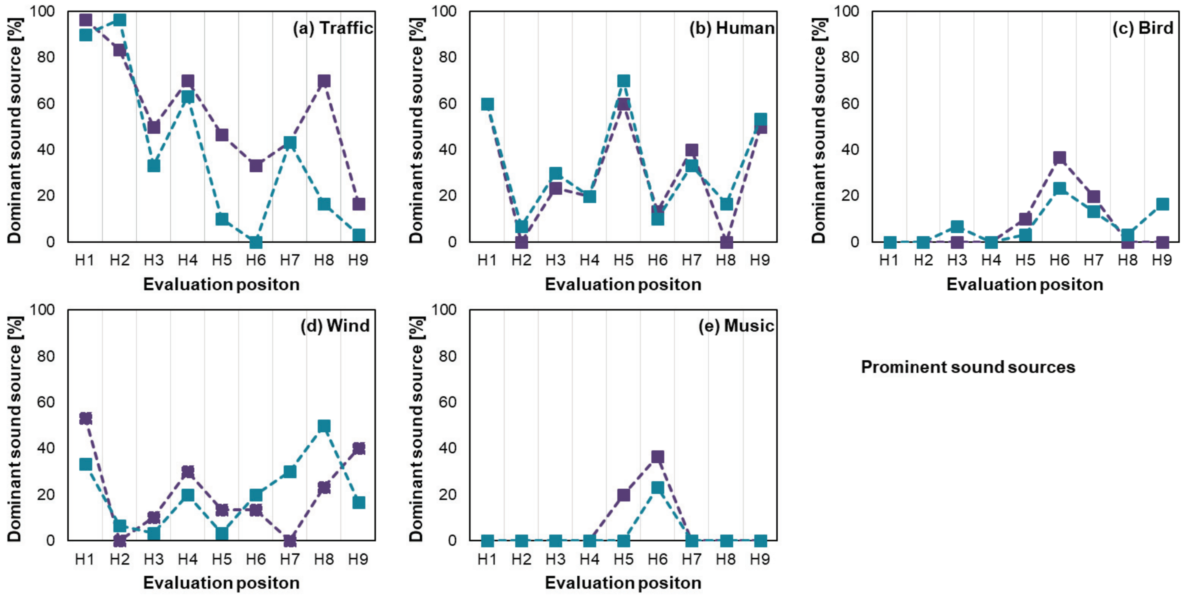

Figure 2. Dominant sound sources of each location

Figure 3 shows the dominant visual factors and the preference for each visual factor in each of the evaluation points in the only visual and the audio-visual environment. The distance from the road was the most influential factor. The closer to the big road, the higher the awareness of vehicles. The two-way ANOVA analysis and the simple main analysis of the interaction between the visual information and the audio information showed significant differences for the building, green, people, and sky elements ($p < 0.01$). In the audio-visual environment, the perception of building, green, and sky elements was lower, and for green it increased.

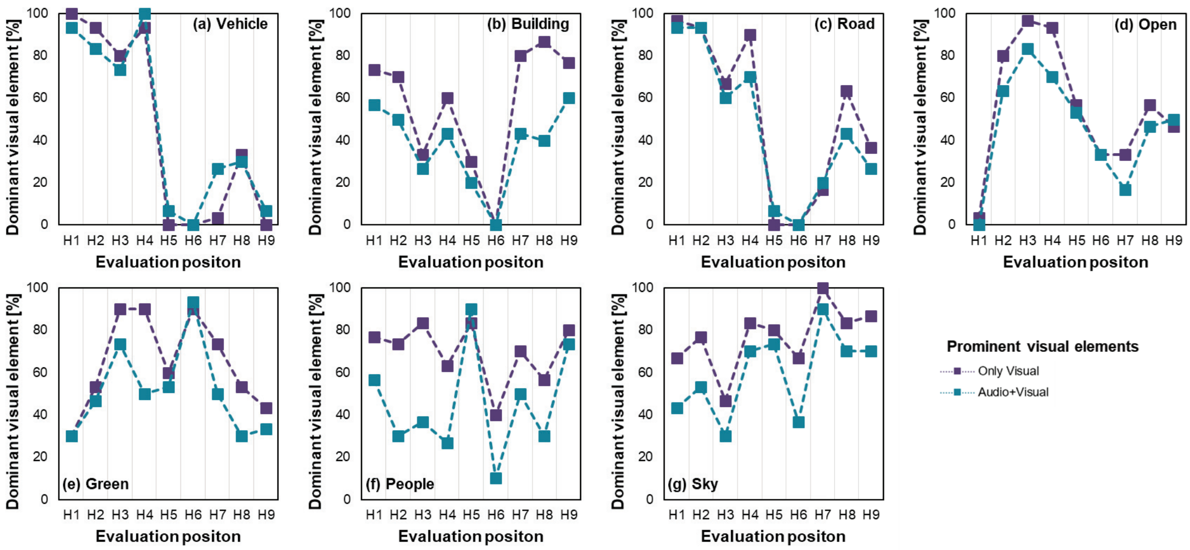

Figure 3. Dominant visual elements of each location

3.2 Semantic differential test

Principal components analysis was performed on eight semantic expression words for soundscape and 12 semantic expression words for landscape in all evaluation environments. The Kaiser–Meyer–Olkin measure of sampling adequacy was adequate, and Bartlett's test of sphericity was evident in all evaluation settings ($p < 0.01$). First, soundscape quality was classified as pleasantness and eventfulness in the only-audio and audio-visual environments. In the case of landscape quality, overall quality, regularity, and spatial impression were observed in the only-visual environment, and naturalness was found to be a new factor in the audio-visual environment.

3.3 Overall satisfaction

Figure 4 shows the overall satisfaction with audio information and visual information in different evaluation environments. There was a difference in satisfaction according to the evaluation environment, and the difference was statistically significant ($F(2,807) = 61.401$, $p < 0.01$). Overall satisfaction was the highest in the visual-only environment, and satisfaction was low in the case of additional audio.

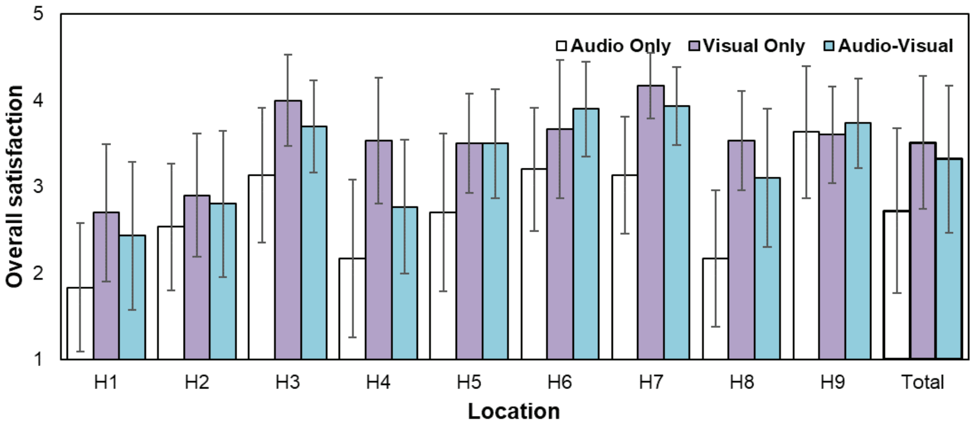

Figure 4. Picture of the nine evaluation locations for the experiment

4. DISCUSSION

4.1 Audio-visual interaction

Table 1 shows the correlation between perceived sound, perceived visual component, and soundscape and landscape components derived from PCA analysis to examine the interaction between perceived soundscape and landscape in urban space.

First, traffic has a negative effect on landscape components, and birds have a positive effect on the overall impressions. Pleasantness showed a positive correlation with the overall impression of the landscape and how well the city is organized and visually organized, and how many natural elements are provided. Eventfulness showed a negative correlation with regularity. Therefore, the more the city is visually congested, the more the sound event is recognized in the space.

Table 1. Correlation coefficients between perceived soundscape indicators and perceived landscape indicators (**Bold** $p < 0.01$, underscore $p < 0.05$)

		Sound sources					Soundscape component	
		Traffic	Human	Bird	Wind	Music	Pleasantness	Eventfulness
Visual elements	Vehicle	**0.72**	0.07	**-0.22**	0.05	-0.12	**-0.56**	0.05
	Building	**0.29**	**0.16**	-0.04	0.13	-0.04	**-0.21**	0.08
	Road	**0.63**	0.06	**-0.19**	0.06	-0.04	**-0.53**	-0.03
	Open	-0.04	0.04	**0.18**	0.01	-0.06	0.02	-0.12
	Green	-0.07	0.05	**0.25**	0.15	**0.17**	0.08	-0.11
	People	0.09	**0.43**	0.04	**0.18**	-0.01	-0.01	0.05
	Sky	0.01	**0.22**	-0.05	**0.22**	-0.14	-0.01	**0.24**
Landscape component	Overall quality	**-0.28**	0.05	**0.30**	0.11	0.01	**0.50**	**0.17**
	Regularity	**-0.22**	0.01	**0.17**	0.12	0.03	**0.30**	**-0.24**
	Spatial impression	0.09	0.10	-0.01	0.12	-0.03	-0.06	0.11
	Naturalness	**-0.32**	-0.09	**0.23**	0.08	**0.12**	**0.26**	-0.11

4.2 Soundscape recognition model

To evaluate the contribution of audio-visual information to overall satisfaction and the contribution of soundscape and landscape components, multiple linear regression analysis was performed in each evaluation environment, and the results are shown in Tables 2 and 3. R2 of the total regression model was statistically significant ($p < 0.05$).

First, the interesting thing about audio-visual information is that the subjects focus more on the characteristic information of the space in the environment provided with both visual and auditory information than the environment provided with only visual or auditory information.

Also interesting in terms of the soundscape and landscape component is that the new factor of naturalness is more influential in the environment where audio information is added. This means that when the subjects are added with a sound element in recognizing the landscape of the city, they consider how natural and artificial the space is rather than the recognition of the spatial feeling of the city. In addition, overall, the landscape element has a higher contribution than the soundscape element, and it can be seen that the subjects are more influenced by the visual parts when they evaluate the satisfaction of the city.

Table 2. Standardized regression coefficients from multiple linear regression analysis for overall satisfaction using sound and visual elements in different experimental setups

(**Bold** $p < 0.01$, underscore $p < 0.05$)

	Visual effect		**Audio effect**		**Interaction**
	Only Audio	Audio+Visual	Only Visual	Audio+Visual	Audio+Visual
R^2	0.14	0.25	0.15	0.21	0.31
Traffic	**-0.27**	**-0.29**	-	-	-0.02
Human	0.12	0.03	-	-	0.05
Bird	0.12	**0.31**	-	-	**0.29**
Wind	-0.14	-0.01	-	-	0.02
Music	0.02	0.07	-	-	0.04
Vehicle	-	-	**-0.28**	**-0.36**	**-0.30**
Vehicle	-	-	0.06	-0.02	-0.03
Building	-	-	-0.05	-0.1	-0.07
Road	-	-	0.17	0.07	0.03
Open	-	-	0.12	0.11	0.04
Green	-	-	-0.08	0.02	-0.01
People	-	-	0.05	-0.06	-0.04

Table 3. Standardized regression coefficients from multiple linear regression analysis for overall satisfaction using soundscape and landscape components in different experimental setups (**Bold** $p < 0.01$, underscore $p < 0.05$)

	Visual effect		Audio effect		Interaction
	Only Audio	Audio+Visual	Only Visual	Audio+Visual	Audio+Visual
R^2	0.45	0.32	0.49	0.49	0.51
Pleasantness	**0.66**	**0.56**	-	-	**0.21**
Eventfulness	**0.12**	**-0.05**	-	-	-0.05
Overall quality	-	-	**0.62**	**0.55**	**0.45**
Regularity	-	-	**0.28**	**0.29**	**0.22**
Spatial impression	-	-	**0.16**	0.05	0.06
Naturalness	-	-	-	**0.32**	**0.25**

5. CONCLUSIONS

In this study, audio-visual interaction of soundscape and landscape was investigated through a VR environment in the laboratory to improve user satisfaction through the sound and visual environment of urban space. A regression model was proposed based on audio-visual elements — soundscape and landscape components — and it was confirmed that satisfaction prediction through a combination of soundscape and landscape can be used to design and improve the urban space. The model using audio-visual elements showed a somewhat lower explanatory power, but it was found that the bird's sound and the visual part of the vehicle were the main factors of urban design that had a significant effect on satisfaction. The model 51% using the soundscape and landscape component shows a high explanatory power. At the same time, for the overall satisfaction of the city, the model seeks to improve the naturalness and overall quality by adding appropriate vegetation elements while visually adjusting it, and improving pleasantness was effective. The audio-visual interaction of the soundscape and landscape evaluation found in this study and the overall satisfaction model based on it are presented as guidelines for improving the satisfaction of the new design of the city and can be used effectively.

ACKNOWLEDGEMENTS

This work was supported by a grant the Science and Technology Amicable Relationship (STAR) program, from the National Research Foundation of Korea (NRF) grant funded by the Korea government (MSIT) (2018K1A3A1A21043775)

REFERENCES

1. Corburn J. Toward the healthy city: people, places, and the politics of urban planning. Mit Press. 2009.
2. Kang J, Schulte-Fortkamp B. (Eds.). Soundscape and the built environment. CRC press. 2018.
3. Kang J. Zhang M. Semantic differential analysis of the soundscape in urban open public spaces. Build Environ. 2010;45(1):150–157.
4. Meng Q, Sun Y, Kang J. Effect of temporary open-air markets on the sound environment and acoustic perception based on the crowd density characteristics. Sci Total Environ. 2017;601:1488-1495.
5. Botteldooren D, De Coensel B, Van Renterghem T, Dekoninck L, Gillis D. The urban soundscape–a different perspective. Sustainable mobility in Flanders: The livable city, 2008. p. 177-204.
6. Herranz-Pascual K, Aspuru I, García I. Proposed conceptual model of environmental experience as framework to study the soundscape. In Proceedings of INTERNOISE. 2010. p. 2904-2912
7. Joynt JL, Kang J. The influence of preconceptions on perceived sound reduction by environmental noise barriers. Sci Total Environ. 2010;408(20):4368-4375.
8. Liu J, Kang J, Behm H. Birdsong as an element of the urban sound environment: A case study concerning

the area of Warnemünde in Germany. Acta Acust United Acust, 2014;100(3):458-466.
9. Lange E. The limits of realism: Perceptions of virtual landscapes. Landsc Urban Plan. 2001;54(1):163–182.
10. Daniel TC. Whither scenic beauty? Visual landscape quality assessment in the 21st century. Landsc Urban Plan, 2001;54(1):267–281.
11. Sanchez GME, Van Renterghem T, Sun K, De Coensel B, Botteldooren D. Using Virtual Reality for assessing the role of noise in the audio-visual design of an urban public space. Landsc Urban Plan, 2017;167:98-107.
12. Jo, HI, Jeon JY. Downstairs resident classification characteristics for upstairs walking vibration noise in an apartment building under virtual reality environment. Build Environ. 2019;150:21-32.
13. Jeon JY, Jo HI. Three-dimensional virtual reality-based subjective evaluation of road traffic noise heard in urban high-rise residential buildings. Build Environ, 2019;148:468-477.
14. Yu T, Behm H, Bill R, Kang J. Audio-visual perception of new wind parks. Landsc Urban Plan, 2017;165:1-10.