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Applying the methods of image evaluation and spatial analysis to study the sound environment of urban street areas

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Abstract

One important aspect of the urban environment is its sound environment, in which the sound environment of street areas plays a significant role. In this research, we employed methods of subjective image evaluation and spatial analysis of soundscape formation, in studying the sound environments of urban street areas. In Saga City, Japan, we analysed the structure and main sound components of urban street areas, as well as the sound pressure levels through on-site investigation. Through image evaluation, we obtained people's ratings of each sound component in terms of "preference" and "congruence". Simultaneously, we interviewed people on site for their evaluation of the sound environment using semantic differential profiles. Lastly, we performed a spatial analysis of the site, identifying the different types of street sound environment and their characteristics using cluster analysis, as well as noting the interaction of auditory image and visual factors. The methods presented by this research can help us understand the sound environment of urban street areas more comprehensively and vividly, and to point out a unique direction in the research of urban sound environment as well as the planning of urban street areas.

1. Background and objectives

Street areas are one of the most basic and important spaces for urban functions and people's daily lives. It is important for them to provide assurance of safe and smooth transportation, comfortable urban open spaces, attractive cityscape, urban infrastructures, as well as proper disaster prevention. As a result the street area can be seen to play a significant role in maintaining the image of a city. Therefore, the development and improvement of street areas has been one of the key issues in city policy and urban planning. However, in the field of urban planning, the development of urban street areas has overwhelmingly concentrated on the functional and visual factors, whilst the auditory and other non-visual factors have been largely ignored. Although functional and visual factors are undeniably important, people perceive and interact with their environment in a multi-sensory manner. Even when we consider the broader functions of urban street areas, we can find that most of them have close relationships with auditory and senses other than the purely visual. Therefore, in order to construct a comfortable, and attractive urban street area, auditory and other sensory factors should also be taken into consideration.

Furthermore, sound is becoming an increasingly important research subject within the field of urban environmental science, as noise is now developing into a serious environmental problem, especially in street areas due to the increasing transportation and construction activities that accompany urbanization. Much research has been performed on the noise control of urban street areas focusing on issues such as, the calculation, simulation, and measurement of street sound environments, the noise control technology of road traffic, the acoustical insulation of buildings, and noise control regulations and so on (Garcia, 2001). The approach of noise study focuses on the elimination of undesirable elements within a sound environment, and treats sound as a signal to be processed instead of meaning to be understood. Despite being undoubtedly important, the elimination of negative factors is merely an elementary requirement, whereas the need to

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actively generate positive factors can be seen to be of much greater importance in the development of pleasant urban street sound environments. It cannot be denied that in our cities, especially in big cities, human beings are faced with the problem of losing the amenity of natural, historical and cultural sound environments, for example, the twittering of birds, the flowing tune of creeks, waterfalls or streams, the chime of old temple bells, the sound of traditional events, as well as sound of children playing. Accordingly, the planning of urban street sound environment should not only focus on the prevention or control of undesirable elements, but should also actively create desirable ones. Moreover, as the perception of sound has strong subjective properties, the meaning of various sounds perceived by people should be significantly valued in the study of the sound environment.

The establishment of the concept of soundscape has brought about the revolution in studying sound environments more positively and comprehensively. Defined as an environment of sound (sonic environment), soundscapes place an emphasis on the way they are perceived and understood by the individual, or by a society (Schafer, 1977a). Inaugurated by Schafer, a sustained contribution has been made by the World Soundscape Project (WSP), which aimed to "discover principles and develop techniques by which the social, psychological, and aesthetic quality of the acoustic environment or soundscape maybe involved" (Truax, 1978). Schafer's pioneering theoretical work into soundscapes provided analytical techniques, applicability in environmental management and a comprehensive theory of acoustic design. For more than a decade, a lot of theoretical and empirical soundscape research and designs have also been done all over the world. Truax (1978) studied the relationship between soundscape and noise. An example of empirical soundscape research can be seen in the work of Schafer (1977b) who studied the soundscapes of five villages with various characteristics in detail. In addition, Schafer (1978) summarized the characteristics and informational value of soundscape components. Porteous and Mastin (1985) explored the concept of soundscape by comparing the very nature of soundscape study and noise study; he then performed both objective (by machine recording and expert listening) and subjective (by means of a survey of residents on the site) studies of a soundscape in the South Fairfield urban neighborhood. Organizations have also been formed, dedicated to the investigating the field of soundscapes, such as CRESSON (Research Center for Sonic Space), which was founded by sociologist and musicologist Jean–Francois Augoyard who has done a lot of work on effects of sound (Augoyard & Torgue, 1995) and acoustic quality of urban space (Augoyard, 1991). The Soundscape Association of Japan (SAJ) started its activities in 1993, from which Torigoe (1999) established the framework of soundscape design in the levels of urban planning, environmental design, architectural acoustics, and equipment design. Namba (2001) concluded and introduced various applicable subjective methods of soundscape surveys.

The perceptual characteristics of soundscape interaction between acoustical perceptions and visual cues provided by the environment are emphasized in the research. Urban sound preference is a critical issue in trying to reveal the perceptual nature of the human being. Iwamiya (1999) studied the favorable and unfavorable sound sources in a botanical garden of Fukuoka, Japan, using surveys and interviews over different seasons. The Japanese Soundscape Association and several other organizations have conducted various studies and produced catalogues of soundscape such as, the 100 best soundscapes in Japan, 20 favorable soundscapes in the Fukuoka Prefecture, best soundscapes in Nagasaki City, and so forth. Research conducted on sound preference that concerns the interaction between vision and hearing, demonstrates that the two elements are not independent but rather interact and reinforce each other in complex ways. However, not many of these studies of auditory and visual interactions are conducted in an urban environment setting. In research by Southworth (1969), subjects were asked to describe their impressions of various urban places through which they had walked. Subjects were divided into three groups, which were categorized as auditory only, visual only and auditory/visual. The comparison among the results of the three groups illustrated that the visual experience of cities is not independent of the sound experience, but rather linked to the sounds that accompany it. Anderson, Mulligan, Goodman, and Regen (1983) used three methods: site evaluation, questionnaire, photographs and tape recordings to study the effects of sounds on preferences for various outdoor settings, in which the visual environment varied according to the degree of urban development. The sound environments were represented by a set of sounds heard in various urban and rural settings. They concluded that it is the interaction of both a setting's visual and acoustic characteristics that significantly influence the evaluations of that setting. Sounds affect the environmental quality of a site but this influence depends on the type of site in which they are heard. In response Carles, Bernaldez, and De Lucio (1992) evaluated the influence of audiovisual interactions on preferences for different combinations of soundscapes and landscapes with a pleasant/unpleasant rating scale in a laboratory setting, attempting to deal with the problem of incongruity between vision and audio. Tamura (1997) assessed the capacity of various landscapes to induce feelings of annoyance. Subjects were required to evaluate the image of a district in both laboratory and natural settings. Results indicated that the feeling of annoyance was a combination of both auditory (level of traffic noise) and visual (degree of tree plantations) factors. Viollon, Lavandier, and Drake (2002) examined the influence of visual settings on sound ratings in an urban environment, and again the results showed a significant and many-sided visual influence. Impact of visual settings depended on the urban sound scenes involved in the audio–visual combination. Recently, simulations of urban environments by computer are increasingly utilized in research and application contexts. Rohrmann and Bishop (2002) presented a simulation of a suburban environment to subjects in several variations of lighting, personal shadow and sound, in order to investigate the effects of these factors on the perceived simulation quality. As a result the provision of sound was found to enhance the perceived quality of presentations. In sum, among the studies concerning the interaction of visual and auditory elements of urban environment, some adopted a global strategy by studying the perception of a given situation which results from the interaction between visual and auditory information; whilst others focused on specific influences by examining the effects of audiovisual interactions through the combination of one specific visual environment and one specific auditory environment.

In this paper, urban street areas were selected as research subjects considering their important roles in urban planning, as well as the close relationship between the function of street areas and sound environment. In previous research, open spaces such as parks, residential areas, green fields and so on feature prominently, with very few studies based on street areas. Akiyama and Uno (1997) did analyse the soundscape in an urban downtown area, but focused solely on one type of street area. Considering that urban street areas have quite different characteristics both in sound and spatial viewpoints, this research aims to study the sound environment of street areas in a comprehensive manner by understanding its physical presence and perceptual characteristics under various spatial formations.

This research has three main components. The first component is the sound preference in urban street areas. This pertains to the study of the similarity and differences in people's preferences of each soundscape element (i.e. natural, artificial, living sounds) as compared to different street spatial structures. This could supplement the research on urban sound preference, and could also be useful in the consideration of the design elements of soundscape in different types of urban street areas. The second component of the study concerns the perceptual property of soundscape, wherein the detailed semantic differential profiles of soundscape are studied. Previous studies have dealt mainly with sound preferences such as

	very much	quite	a little	neut-ral	a little	quite	very much	
Adjectives on Left Side	-3	-2	-1	0	1	2	3	Adjectives on Right Side
noisy								quiet
gloomy								sunny
unpleasant								cheerful
warm								cool
inactive								active
inconsistent								unity
oppressive								open
distinctive								indistinctive
artificial								natural
dislike								like
unharmonious								harmonious

Fig. 2. Image evaluation items and evaluation scale.

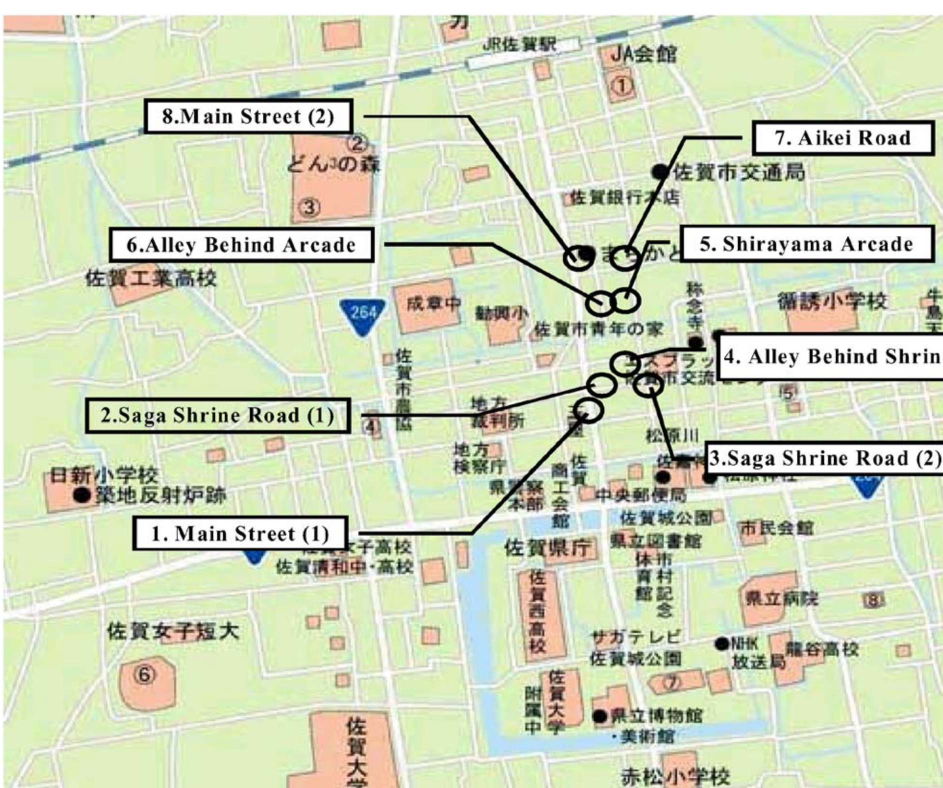


Fig. 1. Study area location points.

"like or dislike", but our study will attempt to delve into more detail about the perceptual properties, including preference (like or dislike). This could enable us to understand the perceptual nature of the soundscape of urban street areas in more depth. Furthermore, the soundscapes of street areas are clustered into several patterns; and the different perceptual properties in different patterns will also be studied. The third component focuses on the interaction between the auditory and visual elements. We study the interaction in an intermediate or meso-level approach, which means it is neither global nor specific compared with previous research. As we have clustered the urban street area into some patterns, the influence of vision on auditory perception is also studied with each pattern. We believe that in the urban street areas, the meso-level strategy (between the global approach and specific approach) can elucidate both similarities within group and the variety among the groups, and therefore can be used to improve and develop sound environment more effectively and efficiently.

2. Methodology

2.1. Study areas

In this research, the chosen area of study is Saga City, Japan. Saga City is the hub of politics, economy, culture and activities in the Saga Prefecture; it is also abundant in garden landscape, with characteristics typical of a city in the prefecture. Accordingly the functions of street areas are abundant and diverse. We selected eight street areas of Saga City with varied characteristics, as shown in Fig. 1. They are: (1) Main Street (I, far from railway station); (2) Saga Shrine Road (I, near to the entrance of Main Street); (3) Saga Shrine Road (II, far from Main Street); (4) Alley behind the Shrine; (5) Shirayama Arcade; (6) Alley behind the Arcade; (7) Aikei Road; (8) Main Street (II, close to railway station). The Main Street of Saga City is wide and straight, with Saga Railway Station located towards the center of the city. Flanked by buildings and shops the flow of pedestrian and vehicle traffic along Main Street is relatively heavy (points (1), (7), and (8)). However, the streets that run along the back of the Main Street are full of quiet alleys, with plenty of natural landscaping and cultural spots (points (3), (4), and (6)). The streets connecting the main street with these alleys have a mix of urban and natural properties (points (2) and (5)). Three surveys were conducted from September 2003 to January 2004, and comprised of on-site investigations, interviews regarding preference of sound components, and image experiments on street sound environments and their spatial analysis.

2.2. On-site investigations

In carrying out the on-site investigation we made a visual inspection of the chosen sites, as well as collecting sound and video data. For 3 days, investigators walked along the research areas, recorded and identified the sounds heard in the streets from 9:00 in the morning to 20:00 in the evening. At the same time, videos of these street areas were also taken by digital camera (SONY DCR-PC300K). Then, a sound level meter ROIN NL-05 was employed to measure the sound pressure levels ($L_{A,eq}$) every hour. We calculated the $L_{A,eq}$ for each area by measuring the $L_{A,eq}$ in 1-min periods five times, and then taking the average value.

Table 1
Sound component of street areas

Artificial sound	Sound of transportation, sound of pedestrian light, guidance of bus, background music of shops
Activity sound	Speaking voices, walking sound, bicycle sound
Natural sound	Insect chirps, sound of animals, murmur of wind in the trees, sound of the wind

Table 2
Sound pressure level ($L_{A,eq}$, dB(A))

Time	Measuring points							
	1	2	3	4	5	6	7	8
9:00	67.44	54.82	52.28	50.26	53.32	44.20	57.74	67.98
10:00	67.64	56.98	56.04	54.02	51.90	46.30	55.52	66.82
11:00	68.46	59.74	58.82	57.70	53.20	50.08	57.70	67.60
12:00	67.90	59.04	60.02	56.78	55.44	49.64	61.06	68.00
13:00	65.98	59.18	56.06	55.00	53.86	46.92	59.68	65.70
14:00	66.24	56.96	55.82	56.18	56.20	45.70	61.38	67.78
15:00	71.26	55.36	62.44	56.18	55.40	49.50	62.40	68.28
16:00	72.50	56.72	58.56	58.26	54.46	48.54	64.28	66.94
17:00	72.40	57.98	60.48	55.68	54.44	51.54	64.80	70.04
18:00	67.64	61.74	55.52	55.30	54.02	47.16	66.82	67.50
19:00	69.06	58.84	60.26	49.76	54.96	48.04	60.40	66.26
20:00	64.64	56.14	52.80	53.16	57.24	51.26	60.70	68.38
Average	68.43	57.79	53.24	50.94	50.73	44.99	56.88	63.02
Std. dev.	2.49	2.00	3.17	2.67	1.44	2.27	3.23	1.12

Furthermore, we also observed and recorded the spatial condition, transportation condition and people's activity on the streets.

2.3. Interview about preference on sound components

Whilst on site, investigators also conducted interviews with the people walking or working in every study point. The investigators asked about people's evaluations on the sound components they heard, in terms of "preference" (whether they like the sound) and "congruence" (whether they feel the sound is appropriate with the overall environment) using a 7-point scale: −3 (strongly disagree); −2 (disagree); −1 (somewhat disagree); 0 (neutral); +1 (somewhat agree); +2 (agree); +3 (strongly agree). In total 75 adults were selected randomly and interviewed, among the 75, 41 of them were men and 34 were women. Through the interviews, people's subjective preferences for different sounds, and the change of preference for the same sound in varied street conditions could be analysed.

2.4. Image experiment on street sound environment

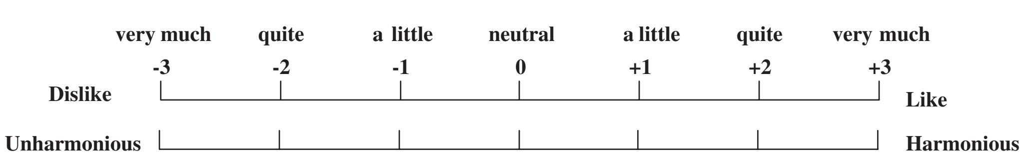
We showed the videos of all of the 8 locations taken during the on-site investigation to 45 experimental subjects who are students from Saga University. The experiment was performed in two steps: (a) let them listen to the sound only; (b) let them watch the video together with sound; the order of presentation of the two kinds of stimuli was randomized. We asked them to evaluate the semantic differential profiles of the two stimuli respectively, in 11 pairs of adjectives describing the sound sense of street areas on a 7-point scale, shown in Fig. 2. These 11 pairs of evaluation terms are selected from the 32 pairs of adjectives in the research of "Verbal expression of emotional impression of sound" conducted by Namba et al. (1991), which are considered to be most suitable for the emotional impression of sound environment in open space. Through the experiment, we can grasp the subjective senses of people to the sound environment of street areas, as well as clarifying the influence of visual information on auditory sense in the urban open space.

2.5. Spatial analysis of the street sound environment

We conducted a cluster analysis of the image evaluation results with both video and audio to identify the spatial formation of sound environments of urban street areas and their characteristics. Considering that soundscape is one of the inevitable elements of the overall environment, we want

Table 3
Evaluation on preference and congruence of sound components in different areas

Sound components	Evaluation items	Evaluation areas							
		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Sound of transportation	Preference	−1.00	−1.27	−1.53	−0.67	—	—	−0.13	−1.07
	Harmoniousness	0.33	−1.53	−1.67	0.20	—	—	0.33	0.33
Sound of pedestrian light	Preference	0.47	−0.93	—	—	—	—	—	0.00
	Harmoniousness	0.80	−0.67	—	—	—	—	—	0.60
Guidance of buses	Preference	0.27	—	—	—	—	—	—	—
	Harmoniousness	0.60	—	—	—	—	—	—	—
Background music from shops	Preference	—	—	—	—	1.00	—	—	−0.53
	Harmoniousness	—	—	—	—	0.87	—	—	−0.73
Speaking voices	Preference	—	0.47	0.33	0.20	0.53	—	0.27	0.27
	Harmoniousness	—	0.33	0.53	0.40	0.73	—	0.20	0.60
Walking sound	Preference	—	—	0.13	0.20	0.07	—	—	—
	Harmoniousness	—	—	0.40	0.47	0.20	—	—	—
Bicycle sound	Preference	0.40	0.13	0.07	0.27	0.00	—	0.33	0.27
	Harmoniousness	0.47	0.47	0.33	0.47	0.20	—	0.27	0.47
Worm chirps	Preference	—	—	—	—	—	—	—	—
	Harmonious	—	—	—	—	—	—	—	—
Sound of animals	Preference	—	—	1.40	0.40	—	—	—	—
	Harmoniousness	—	—	1.33	−0.27	—	—	—	—
Murmur of the wind in the trees	Preference	—	—	0.80	—	—	—	—	—
	Harmoniousness	—	—	0.93	—	—	—	—	—
Sound of wind	Preference	—	—	—	—	—	—	—	—
	Harmoniousness	—	—	—	—	—	—	—	—



to understand the sound environment in the background of visual environment, instead of perceiving it separately. Therefore, we used the image evaluation results of sound environment with both video and audio stimuli to perform the spatial analysis of sound environment.

3. Analysis and discussion

3.1. Sound components of street areas

Through the on-site investigation, 11 sound components were recorded and identified. These 11 sound components could be divided into three types, namely artificial sounds, activity sounds and natural sounds as shown in Table 1. Although the results are for Saga City, they can be considered to contribute to the understanding of sound environment structures of urban street areas, and also can serve as the basic data for the other surveys.

3.2. Sound pressure level

The results of sound pressure level $L_{A,eq}$ measured are listed in Table 2. $L_{A,eq}$ is the A-weighted equivalent decibel, an expression of the relative loudness of sounds in air as perceived by the human ear. In the A-weighted system, the decibel values of sounds at low frequencies are reduced compared with non-weighted decibels. This correction is made because the human ear is less sensitive at low audio frequencies, especially below 1000 Hz, than at high audio frequencies. We found that among the eight areas, the differences of sound pressure level are quite apparent. (1) Main Street has the highest average $L_{A,eq}$ ((1) 68.43 dB (A); (8) 63.02 dB (A)); whilst the Alley behind the Arcade (6) has the lowest (44.99 dB (A)). Generally, in the noise regulation of urban street areas, 60 dB (A) is the limitation during daylight hours and 50 dB (A) at night. We can find that in the main streets of the city, this regulation is hard to achieve, while in the backside alleys, it seemed to be being realized.

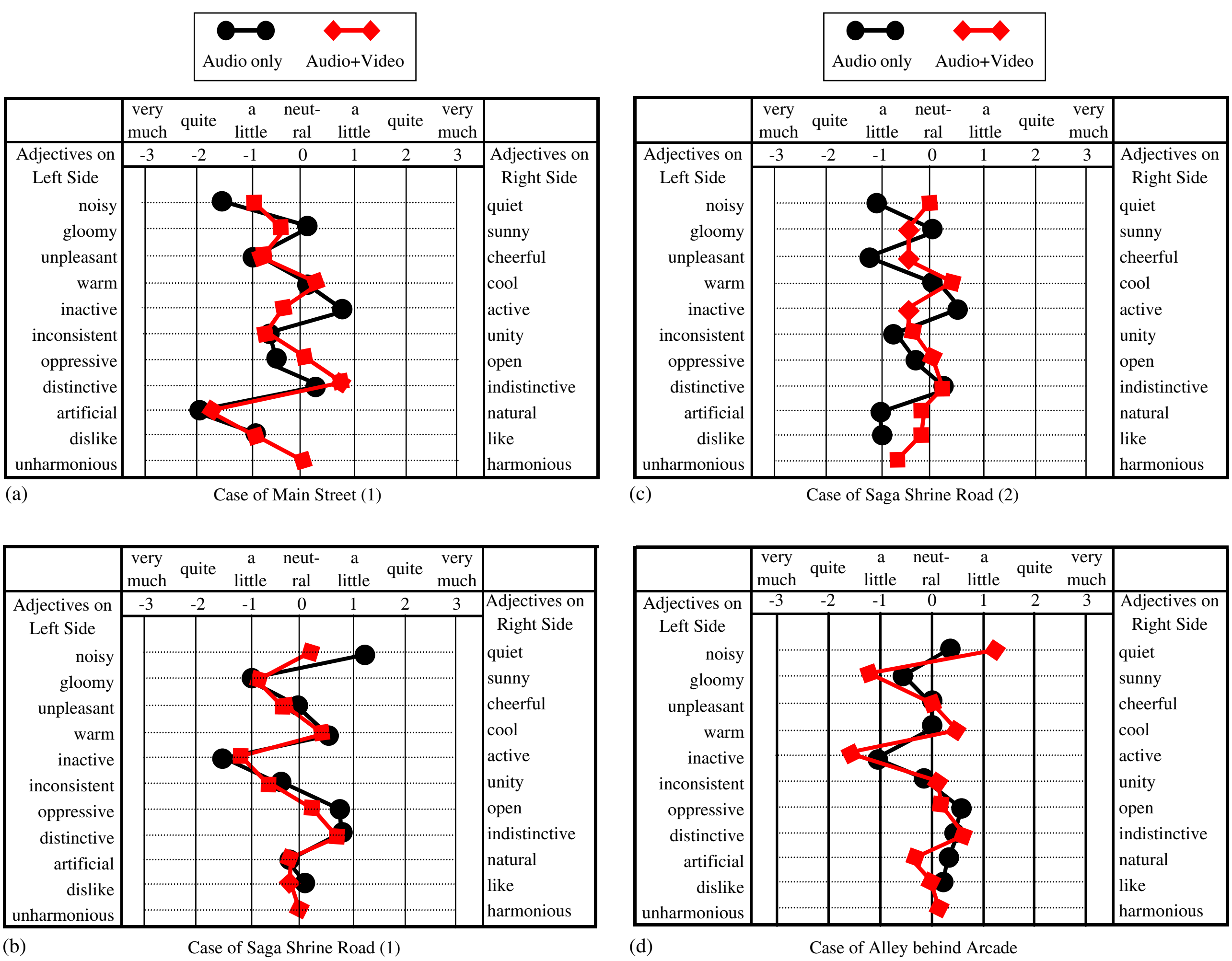


Fig. 3. Semantic differential profiles of sound environment. (a) Case of Main Street (1), (b) case of Saga Shrine Road (1), (c) case of Saga Shrine Road (2), (d) case of Alley behind Arcade, (e) case of Shirayama Arcade, (f) case of Alley behind Arcade, (g) case of Aikei Road and (h) case of Main Street (2).

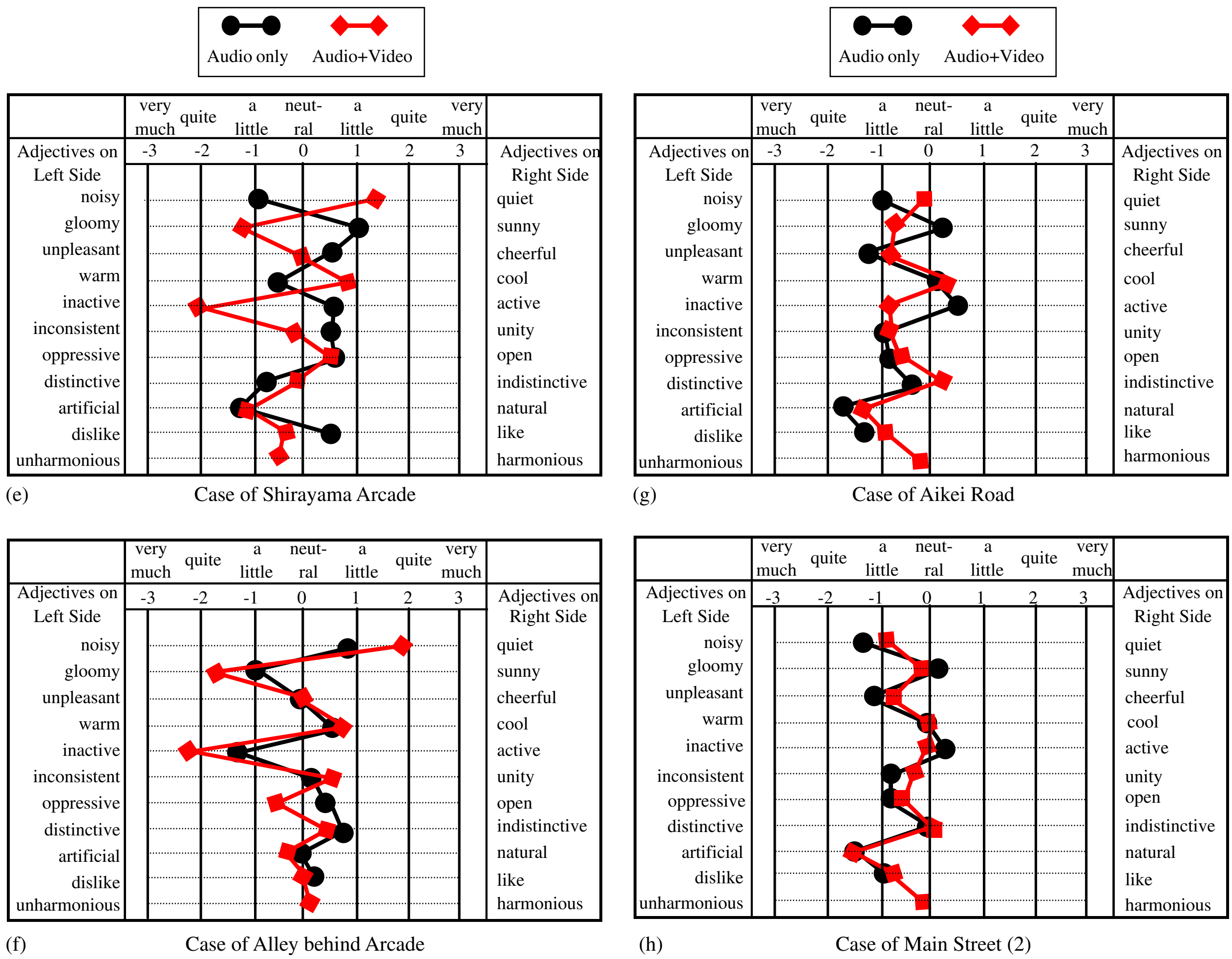


Fig. 3. (*Continued*)

Conversely, it could be seen from the standard deviation (std. dev.) of the $L_{A,eq}$ based on measurements taken every 1 h from morning to evening, that sound levels in some places fluctuated greatly (points (3) and (7)), while others kept steady (points (5) and (8)). This could be explained mainly by the change of transportation and people flow throughout the course of the day.

3.3. *Preference of sound components in different areas*

Having obtained the $L_{A,eq}$ data by physical measurement, the next stage was to find out how people felt about each sound component, and how different the sound sensations in different street areas are. The results of the on-site interview on this point are shown in Table 3, which are illustrated in terms of arithmetic average of all respondents. Blanks in the table indicate that the component was not heard at that place.

Artificial Sounds: As regards artificial sounds, our findings established that the sound of transportation is disliked regardless of the location. However, it is disliked most (−1.53) in the (3) Saga Shrine Road where there are plenty of peaceful natural and cultural landscape elements. While in (7) Aikei Road which is full of vehicles and people, the evaluation is −0.13, nearer to neutral. The evaluation of congruency shows a similar trend, confirming that in silent natural areas, the sound of transportation is the most incongruous with the overall environment, whereas in noisy urbanized areas, it is evaluated nearer to neutral or congruous to the environment to some extent.

Other artificial sounds such as sound of pedestrian crossings, guidance of buses, the background music of shops, are evaluated as neutral in almost all research areas. However, the background music in (5) Shirayama Arcade has gained the score of 1.0 in preference and 0.87 in congruence. Shirayama Arcade is a commercial street located in calm natural surroundings, and some people commented that the background music can help to mask the lack of activeness in this arcade to some extent.

Activity Sounds: Among the activity sounds, the evaluations are around 0.5 in almost all the areas, which suggests that these kinds of sounds in the street areas are not noticeable.

Natural Sounds: We can find from Table 3 that natural sounds are rarely heard or noticed in most of the research areas. Only in area (3), (4), could some of the natural sounds be noticed. We found that the sound of animals in (3) Saga Shrine Road gained high evaluation in both preference (1.40) and congruency (1.33), but in (4) Alley behind shrine, it is not evaluated highly (0.40, −0.27 respectively). This can also help to explain the relationship between sound sensations and nearby comprehensive environment. Area (3) is a well-developed street with plenty of natural elements, while site (4) is surrounded by buildings. From the comments of the people interviewed, we understood that the insect chirps could sometimes be heard in the places where there are a lot of plants and green spaces. The visual lack of natural elements of urban street areas has brought about the deficiency of natural sound components which people are partial to.

3.4. Image evaluation of street sound environment

The image evaluation results of semantic differential profiles on sound environments are shown in Fig. 3(a)–(h) and Table 4. The evaluation results express the semantic differential profiles of sound environment of different areas clearly. For instance, in the case of Main Street (1) shown in Fig. 3(a), the image of being noisy and artificial are very strong, while in the case of Alley behind Arcade shown in Fig. 3(d), the sensation of being quiet, inactive and gloomy is apparent.

3.5. Spatial analysis about the street sound environment

We conducted a cluster analysis on the image evaluation results to clarify the spatial formation of sound environment of street areas; the method of clustering used is the

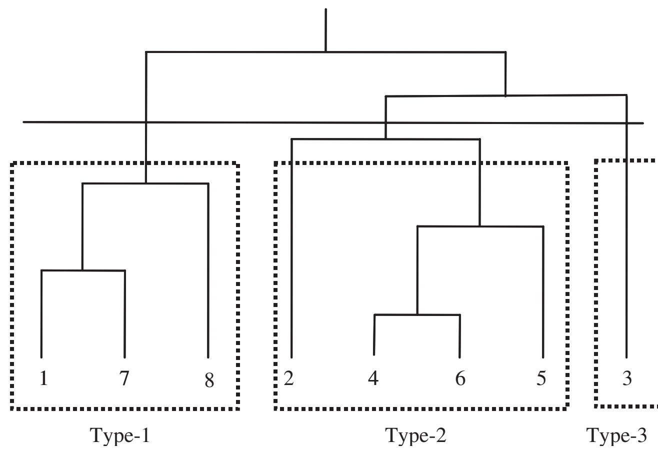


Fig. 4. Tree plot of cluster analysis.

Table 4
Image evaluation results

Evaluation items	Evaluation area											
	1			2			3			4		
	①	②	②–①	①	②	②–①	①	②	②–①	①	②	②–①
Noisy–quiet	−1.5	−1.0	0.5	1.1	0.2	−0.9	−1.1	0.0	1.1	0.3	1.1	0.8
Gloomy–sunny	0.2	−0.4	−0.6	−1.0	−0.9	0.1	0.0	−0.5	−0.5	−0.5	−1.1	−0.6
Unpleasant–cheerful	−1.0	−0.9	0.1	0.0	−0.3	−0.3	−1.2	−0.5	0.7	0.0	0.0	0.0
Warm–cool	0.1	0.2	0.1	0.5	0.4	−0.1	0.0	0.4	0.4	0.0	0.5	0.5
Inactive–active	0.7	−0.4	−1.1	−1.5	−1.1	0.4	0.5	−0.5	−1.0	−1.0	−1.6	−0.6
Inconsistent–unity	−0.6	−0.7	−1.1	−0.4	−0.6	−0.2	−0.7	−0.5	0.2	−0.1	0.1	0.2
Oppressive–open	−0.5	−0.1	−0.4	0.7	0.2	−0.5	−0.3	0.0	0.3	0.6	0.2	−0.4
Distinctive–indistinctive	0.3	0.7	0.4	0.8	0.6	−0.2	0.2	0.1	−0.1	0.4	0.6	0.2
Artificial–natural	−2.0	−1.8	0.2	−0.1	−0.6	−0.5	−1.0	−0.2	0.8	0.3	−0.3	−0.6
Dislike–like	−0.9	−1.0	−0.1	0.1	−0.2	−0.3	−1.0	−0.2	0.8	0.2	0.0	−0.2
Unharmonious–harmonious	—	0.0	—	—	0.0	—	—	−0.7	—	—	0.1	—
	5			6			7			8		
Noisy–quiet	−1.0	1.3	2.3	0.9	1.9	1.0	−1.0	−0.1	0.9	−1.4	−0.9	0.5
Gloomy–sunny	1.0	−1.2	−2.2	−1.0	−1.7	−0.7	0.2	−0.7	−0.9	0.2	−0.2	−0.4
Unpleasant–cheerful	0.5	−0.1	−0.6	0.0	0.0	0.0	−1.4	−0.9	0.5	−1.2	−0.9	0.3
Warm–cool	−0.5	0.9	1.4	0.5	0.8	0.3	0.1	0.3	0.2	0.0	0.0	0.0
Inactive–active	0.6	−2.0	−2.6	−1.4	−2.2	−0.8	0.5	−0.9	−1.4	0.3	−0.1	−0.4
Inconsistent–unity	0.5	−0.1	−0.6	0.1	0.5	0.4	−1.0	−0.9	0.1	−0.7	−0.3	0.4
Oppressive–open	0.6	0.4	−0.2	0.4	−0.5	−0.9	−0.9	−0.6	0.3	−0.7	−0.6	0.1
Distinctive–indistinctive	−0.7	−0.2	0.5	0.8	0.4	−0.4	−0.3	0.2	0.5	0.0	0.1	0.1
Artificial–natural	−1.2	−1.1	0.1	0.0	−0.4	−0.4	−1.7	−1.4	0.3	−1.5	−1.5	0.0
Dislike–like	0.5	−0.4	−0.9	0.1	0.0	−0.1	−1.3	−0.9	0.4	−1.0	−0.8	0.2
Unharmonious–harmonious	—	−0.5	—	—	0.1	—	—	−0.2	—	—	−0.2	—

①: evaluation scores on audio stimuli; ②: evaluation scores on audio + video stimuli; ②–①: difference between evaluations on audio stimuli and audio + video stimuli.

Two Step Cluster. We calculated the Euclidean Distance with the method of Average Linkage; and as a result three types of spatial formation were identified (as shown in Fig. 4). Fig. 5 is a photograph of the three types of street areas.

(1) The characteristics of the image on sound environment of each type

The characteristics of the image on sound environment of each type are shown in Table 5.

Type-1: This group includes three places (1) Main Street (I), (7) Aikei Road, and (8) Main Street (II). We can see from Table 5 that the sound environment of this group is characterized as unpleasant and artificial, and that the preference evaluation is the lowest among all the three types. When looking at the actual condition of these kinds of streets, it is noticeable that the number of vehicles passing is quite large, the number of people and activities are also considerable, and thus the image of artificialness is quite strong. Equally, the image of naturalness in this group is weakened or sheltered by the noisy sound of vehicles and people.

Type-2: This group includes (2) Saga Shrine Road (I), (4) Alley behind the Shrine; (5) Shirayama Arcade and (6) Alley behind the Arcade. The sound environment of this type is silent, gloomy and inactive. The overall evaluation on preference and congruence are higher than other types. As to the spatial property of this type, there are fewer buildings compared with other groups, and plenty of open spaces, so that the image of the sound environment is also congruent with the visual space formations. There are few transportation vehicles in these areas, and few human activities, and therefore the sense of silence is quite strong. In other words, there is also the image of loneliness. Furthermore, the natural and cultural elements are abundant compared with others, which enhances the sensation of silence, gloominess, and inactiveness to the sound environment.

Type-3: (3) Saga Shrine Road (II) is included in this type. The evaluations on almost all categories were found to be between those of Type-1 and Type-2, so it can be concluded that it is the middle type. But the evaluation on congruence is the lowest. Its spatial condition is also characterized as in-between big noisy streets and small silent alleys. Although there is a profusion of natural elements in this type, there are also plenty of vehicles and human activities, which lead to the less than ideal evaluation on congruence.

(2) Influence of visual elements on the image of soundscape of each type

The cluster analysis grouped the study points into three types. The description of the three types of streets, are further strengthened and analysed using the evaluation of the preference between audio only and audio with video survey. Table 6 showed the average difference between the image evaluation scores of audio only and audio with video, from which we can observe that the comprehensive evaluation of "preference (dislike–like)" of sound environment is not influenced a lot by the addition of visual factors in general, but the perceived image in detailed semantic differential terms change according to different types of urban street soundscape.

Type-1: Area (1) Main Street (I)

Type-2: Area (2) Saga Shrine Road (I)

Type-3: Area (3) Saga Shrine Road (II)

Fig. 5. Photograph of the three types of street. (a) Type-1: Area (1) Main Street (I), (b) Type-2: Area (2) Saga Shrine Road (I) and (c) Type-3: Area (3) Saga Shrine Road (II).

Table 5
Average scores of image profiles of each type

Evaluation items	Type-1	Type-2	Type-3
Noisy–quiet	−0.66	1.13	−0.05
Gloomy–sunny	−0.45	−1.22	−0.45
Unpleasant–cheerful	−0.91	−0.10	−0.48
Warm–cool	0.17	0.65	0.36
Inactive–active	−0.46	−1.71	−0.50
Inconsistent–unity	−0.66	−0.01	−0.48
Oppressive–open	−0.46	0.11	0.02
Distinctive–indistinctive	0.31	0.32	0.06
Artificial–natural	−1.59	−0.58	−0.21
Dislike–like	−0.89	−0.15	−0.21
Unharmonious–harmonious	−0.14	−0.07	−0.67

Table 6
Average differences between the image evaluations of video only and video with audio

Evaluation items	Type-1	Type-2	Type-3
Noisy–quiet	0.63	0.80	1.10
Gloomy–sunny	−0.36	−0.93	−0.50
Unpleasant–cheerful	0.30	−0.22	0.70
Warm–cool	0.10	0.52	0.40
Inactive–active	−0.97	−0.90	−0.10
Inconsistent–unity	−0.20	−0.05	0.20
Oppressive–open	0.00	0.50	0.30
Distinctive–indistinctive	0.33	−0.03	−0.10
Artificial–natural	0.17	−0.35	0.80
Dislike–like	0.17	−0.37	0.80

Type-1: The image of soundscape of this type has the characteristics of being unpleasant and artificial, and the preference evaluation is the lowest. The visual and spatial condition of this type is well developed urban street areas with large quantity of transportation and human activities. With the highest $L_{A,eq}$ (62.78 dB(A)) among three types, it is evident that the sound of transportation dominates the whole sound environment. In these kinds of situations, the influence of the visual elements on the sound environment image in terms of "noise–quiet" is the smallest (0.63) among three types, and the influence in almost all the other image categories are not apparent compared with the other two types. The reason might be that the high sound pressure level is so overwhelming in an auditory sense that the influence of visual elements is weakened. Therefore, it could be said that the development of sound environment of this type should focus on the control and elimination of the transportation and other noise that seems to be the basic, strong factor in the image of the soundscape.

Type-2: The image of soundscape of this type is silent, gloomy and inactive; and the spatial condition consists of small alleys where natural factors (such as trees, creeks and animals) and cultural factors (such as temples) are abundant, and people's activities and vehicles are few. The visual factors furthermore increase the image of "quiet" to some extent (0.80), and thus make the feeling of gloominess and inactiveness stronger. It could be said that in these kinds of street areas, the enhancement of natural sound components are quite effective in obtaining a comfortable and attractive soundscape. For example people can enjoy such natural sounds as bird and insect chirping, wind blowing, tree rustling and so on together with visual landscape. As we found in the interview of sound preference, most of the people interviewed have not heard or paid attention to the natural sound in urban street areas. As a matter of fact, Type-2 has the high latent possibility to create an attractive soundscape with its abundant components.

Type-3: The image of soundscape of this type is characterized with incongruence, as the spatial property is abundant with natural factors such as trees, creeks and animals, cultural factors such as temples as well as human activities and vehicles. We can see that the changes of the image evaluation scores, with and without video are more apparent than other two types. The "quiet" image increased a lot with the addition of the visual component (1.10), and the image of cheerfulness and naturalness increased to some extent (0.70, 0.80). The image of dislike also increased (0.80), as the image gap between the visual and auditory sense of this type was more noticeable. Therefore the influence of the visual element on auditory sense appears to be considerable. In short, the balance or the congruence between visual landscape and soundscape should be improved in the development of this kind of street areas.

4. Conclusions

4.1. Findings of the research

In this research, we studied the sound environment of urban street areas from the viewpoints of image evaluation and spatial analysis of sound environment types. By doing this case study of the urban streets in Saga City, the following results have been obtained:

(1) Sound components of urban street areas: Through on-site investigations by investigators, the sound components and the structure of urban street areas have been made clear, involving artificial sounds (such as sound of transportation, sound of pedestrian light, guidance of buses, background music from shops); activity sounds (such as speaking voices, walking sound, bicycle sound); and natural sounds (such as insect chirps, sound of animals, murmur of wind in the trees, sound of the wind and so forth).

(2) Preference of various sound components under various street conditions: From the interview to people on the streets, we obtained the preference and congruence evaluation on sound components, and found that different places could give people different feelings to the same sound with the same physical properties. It

should also be noticed that the natural sound components are deficient or not paid attention to in almost all types of street areas, including the areas with abundant natural elements.

(3) Semantic differential image of soundscape: The semantic differential profiles of soundscape are useful in helping us to understand the perceptual nature of the sound environment of urban street areas, and to create deeper context of soundscape.

(4) Pattern of urban street soundscape: We studied the soundscape of urban street areas using the meso-level approach by clustering the soundscape of urban street areas into several types, and then clarifying the characteristics of each type. Three types have been defined to fit well with the functions and visual properties of the streets. Type-1 serves as the center of the transportation and activities of the urban street network, with an auditory image of being unpleasant and artificial; and the preference of it as evaluated by people is very low. Type-2 includes the streets with plenty of natural and cultural elements with little or no transportation and human activity. These are usually located in the back streets. The auditory feelings of this type are silent, gloomy and inactive; and the evaluation on preference and congruency is very high. Type-3 is characterized as being between the above two types; however the congruence of the soundscape with landscape is evaluated lowest.

(5) Interaction between auditory and visual element: Through the experiments by student subjects, we analysed the influence of visual elements on the auditory sense using the meso-level approach. We found that the evaluation on "preference" (dislike–like) of sound environment did not vary a lot by the addition of visual elements, but the image in detailed terms shown in Fig. 2 changed with differentiated types of urban street soundscape. In Type-1 streets, the influences of visual factors on sound environment are not so apparent, for the image of noise is very strong. Therefore the main point of the improvement of the soundscape of this type is to reduce noise. On the other hand, the sound senses in streets were influenced considerably by landscape in the natural and silent places like Type-2, especially in terms of gloomy–sunny, noisy–silent, and inactive–active characteristics. The method of enhancing and inducing abundant natural or cultural sound components to create a comfortable and attractive soundscape in this type could be effective. In the areas with natural and silent visual image but noisy transportation and human activities like Type-3, it was seen that visual information can change the image of soundscape a lot, for example, it can increase preference, and the image of being quiet, cheerful, and natural, because of the gap of the visual and auditory stimuli.

We believe that it is important to understand the sound environment of urban street area in a comprehensive and active approach in order to create a more abundant and attractive sound environment. According to the above findings, the following points have been made clear in this research. (1) The methods of studying urban sound environment not only by physical method, but also through image evaluation, as well as the consideration of spatial structure of soundscape are effective. (2) Specifically, the semantic differential profiles in addition to the "preference (dislike–like)" can make us understand the perceptual nature of soundscape more deeply and comprehensively. (3) Furthermore, the meso-level approach of grouping similar areas into patterns and understanding the characteristics of each pattern can help us to understand the diversity of soundscapes, and give advice to the improvement of each pattern effectively and efficiently. (4) The analysis of the influence of visual factors on auditory ones is also performed with different patterns. This method could be effective in understanding the variety of soundscape patterns and the similarity within the pattern.

4.2. Future research for application

The results of this research hope to present references and a unique direction to the research in urban sound environment and the planning practice of street areas at various levels, such as in urban master plan, land use plan, street plan, architecture design of roadside buildings, construction of open spaces, and so forth. For this purpose, we think that the following points should be emphasized in future research to make the findings more applicable:

(1) As to the methodology, the increasing and more systematic selection of study areas, as well as experimental subjects are necessary, in order to make the findings more generalized. For example, much wider scope of experimental subjects with varied attributes such as age, gender, occupation, background and so on should be applied. It also cannot be denied that the selection of the eight locations in this research is based on our pre-perceived ideas. In the next step, we should select the sample locations systematically, for example as suggested, on the grid or at random locations, in order to obtain the general cluster results of spatial condition of street sound environment with more universality.

(2) In the spatial analysis of sound environment, the quantitative analysis between the objective spatial attributes (width of the street, area of green space, height of surrounding buildings, area of open spaces, transportation quantity, etc.) and the subjective images should be performed, the results of which could be applied directly and effectively to the planning of soundscape of urban street areas.

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