Investigation on Influence of Additional Sound on Comfortableness of Living Environment

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Received January 23, 2015; final version accepted June 21, 2015

Adding a sound to a certain environment is likely to be effective for design of impression there in acoustical point of view. However, until now, little is known about the effectiveness of additional sound on the change in impression. In order to investigate the effect of additional sound, an experiment was conducted by using three kinds of audio-visual materials offering three environments and five kinds of additional sounds. The audio-visual materials were respectively recorded at “forest,” “park,” and “shopping street.” They represent “natural,” “artificial green,” and “urban” environments, respectively. Five kinds of sound stimuli were respectively chosen as: “bird singing,” “sound of stream,” “roaring of waves,” “traffic noise,” and “hum of voices.” The former three stimuli are regarded as sounds in nature, while the latter two are regarded as artificial ones. The experiment was based on the method of paired comparison, consisting of the unprocessed original audio-visual material and that with one of the additional sounds. The subjects evaluated relative comfortableness and naturalness of each pair. Sound pressure level of the additional sound was controlled in order to discuss the influence of the loudness of the additional sound to the evaluation. The experimental results showed that the comfortableness was improved when the additional sound was ‘bird singing’ or ‘sound of stream’ categorized in the nature sound and its sound pressure level was a little lower than that at the original environment. Moreover, it was found out that the naturalness is degraded gradually for almost of the additional sound stimuli, as their sound pressure level is increased.

KEYWORDS: design of environment, addition of sound to living environment, comfortableness, naturalness

1. Introduction

On daily basis, humans have acquired information of the surrounding environment using his/her five senses. Using various sensory information, we unconsciously recognize the surrounding environment constructed with a place, a time, a season, a weather and various factors. From acoustical point of view, there are a lot of sound sources in our living environment, and these sounds are different in various points. Some sound sources may be visually clear, and some may be not. It is not impossible to identify the sound source without visual information. However, it is clear that visual information greatly assists such identification. In other words, the recognition of sound environment is influenced by not only auditory information but also that perception through the other modalities. In this manner, the evaluation or impression of the sound environment is obtained as a result of integration of multimodal information.

Various kinds of sound in our living environment are divided into two types. One is the sound accompanying the objects, such as a murmur of brook, an idling of a car engine, and a singing of birds. Another is the sound intentionally given by human such as a sound radiated from loudspeaker (ex. background music or announcement). Such sound has its meaning as the sign. These sounds can be a factor to construct the sound environment.

Design of sound environment by intentionally adding some sounds was examined [1, 2], and the comfortableness of some environments was evaluated by using the audio-visual stimuli based on the soundscape [3, 4]. The former two studies [1, 2] were carried out with various impression categories including comfortableness, but the effect of the conditions on additional sound was not statistically clear. Moreover, the target environments were limited to public spaces. The latter two studies [3, 4] aimed at evaluating the comfortableness of the sound environment using audio-visual stimuli recorded there, but no sound was added. There is a possibility of rather spoiling the comfortableness when the sound stimulus is added to the environment without considering the kind of its stimulus or sound level. Therefore, it is necessary to clarify the parameter of the additional stimulus that influences the comfortableness of the environment. Shimai et al. reported on the relationship between the kind and level of the sound stimulus and its comfortableness [5]. They used a lot of sounds (from recorded sounds to artificial sounds) as experimental stimulus. As
a result, a pleasant sound stimulus tended to become more pleasant as its sound pressure level increases. However, as noted above, when the design of the sound "environment" is examined, it is necessary to consider not only auditory information but also the one from the other modalities.

In this paper, we conducted a psycho-acoustical experiment in order to understand the influence of the additional sound stimulus on the impression of the sound environment. In the case of noise reduction, the level of the sound source that emits the loudest unwanted sound is reduced. The basis on noise reduction is the subtraction techniques. In contrast, the control of the impression of sound environment by the addition of a sound is additive approach. There are studies based on this additive approach as mentioned above, but the effect of this approach was not clear in statistical and quantitative points of view. In this paper, the effect of additional sounds to the comfortableness of sound environments is discussed, focusing the relationship between the sound pressure levels (of the environmental and the additional sounds) and the subjects’ reported comfortableness or naturalness listened to them.

2. Outline of the experiment

2.1 Recording and processing of audio-visual stimuli

The sounds and the moving pictures recorded in three places were prepared as the audio-visual materials. Three places were “forest,” “park,” and “shopping street,” respectively. These places were selected as the “natural,” “artificial green,” and “urban” environments, respectively. The sound stimuli were recorded by a digital data recorder (RION DA-20) through a dummy head microphone (NEUMANN KU-100) for achievement of high fidelity. The visual stimuli were recorded along with the sound using a HDV camera (SONY HDR-FX1). Duration of the recording for each audio-visual data was about 30 minutes. A ten-second-long segment of each recorded audio-visual data that consisting of the typical characteristics of the recording place was selected and cut out as a stimulus for experiment. The selected audio stimulus was binaurally presented to the subjects via headphones (STAX SR-202). The transfer functions of the headphones to the outer ears of the dummy head were compensated such that the correct sound pressures were reproduced at the eardrums of subjects [6]. The equivalent sound level of the sound stimulus after the processing mentioned above is as follows: The equivalent sound level ($L_{eq}$) of “forest” is 43.0 dB, that of “park” is 55.3 dB, and that of “shopping street” is 64.0 dB. These levels are calculated from the averaged power of sound at both ears. Figure 1 shows the sample pictures captured from the moving pictures recorded at three places.

2.2 Additional sound stimuli

In this experiment, “bird singing,” “sound of stream,” “roaring of waves,” “traffic noise,” and “hum of voices” were picked up as the additional sound stimuli. They were selected so as to contain the sound that seems to be comfortable or uncomfortable when hearing each of them alone. These sounds are heard in our daily life. The additional sound can be obtained via recording somewhere as the audio-visual stimuli. However, the generality problem arises when both sounds are from our recorded materials. Therefore, the sounds from a commercial CD stored various sounds [7] were selected as the additional sounds. In order to possibly simulate each additional sound is localized in front of the subject, the acoustic transfer functions from 1.5 m front to both ears of the dummy head were convolved with it. The presentation level of the additional sound stimulus was controlled based on the equivalent sound level of each sound environment. Table 1 shows the condition of the presentation level. Based on the preliminary test, the conditions in which the additional sound is perceived too loud were omitted. Since the environment sound completely masks the additional sound when the level of the additional sound is low, the corresponding level conditions were also excluded. However, at least one condition was included, in which the level of the additional sound is higher or lower than that of original environment sound. The symbol “○” means a combination of sound environmental and additional sound used in the experiment. On the other hand, the symbol “—” means a combination not used for the experiment.

2.3 Experimental procedure

The experiment was used by Scheffe’s method of paired comparison modified by Ura [8]. Under the combination of each sound environment and each additional sound stimulus (3 × 5 conditions), the pair of the audio-visual stimulus added the additional sound stimulus with a different sound pressure level in sound environmental data was presented to the subjects. The subjects were asked to evaluate which was more comfortable/natural. However, two types of evaluation were not performed at the same time. A five-category bipolar scale was used for the evaluation of each pair. The stimuli without additional sound stimulus were also included as the control condition.

Figure 2 shows the experimental system. The experiment was carried out in a soundproof room that turned off the lights. A moving picture of sound environmental data was presented to the subjects via a 50” plasma display (PIioneer PDP-503CMX). Subjects were ten male undergraduate students, with normal hearing and sight acuities.

3. Result

The results using data of all subjects are shown in Figure 3. Figure 3(a-1)–(a-5) is the results of the experiment using
Fig. 1. Pictures of recorded environments.

Table 1. Conditions of the relative level of additional sound stimulus with reference to the equivalent sound level of each recording sound environment.

| additional sound       | target sound environment | relative level [dB] |  |  |  |  |  |
|------------------------|--------------------------|---------------------|---|---|---|---|---|
|                        |                          | −21     | −14 | −7 | 0  | 7  | 14 |
| bird singing           | forest                   | ○       | ○   | ○  | ○  | ○  | ○  |
|                       | park                     | ○       | ○   | ○  | ○  | ○  | ○  |
|                       | shopping street          | ○       | ○   | ○  | ○  | ○  | ○  |
| sound of stream       | forest                   | —       | —   | ○  | ○  | ○  | ○  |
|                       | park                     | ○       | ○   | ○  | ○  | ○  | ○  |
|                       | shopping street          | ○       | ○   | ○  | ○  | ○  | ○  |
| roaring of waves       | forest                   | ○       | ○   | ○  | ○  | ○  | ○  |
|                       | park                     | ○       | ○   | ○  | ○  | ○  | ○  |
|                       | shopping street          | ○       | ○   | ○  | ○  | ○  | ○  |
| traffic noise          | forest                   | —       | —   | ○  | ○  | ○  | —  |
|                       | park                     | —       | —   | ○  | ○  | ○  | —  |
|                       | shopping street          | —       | —   | ○  | ○  | ○  | —  |
| hum of voices          | forest                   | —       | —   | ○  | ○  | ○  | —  |
|                       | park                     | —       | —   | ○  | ○  | ○  | —  |
|                       | shopping street          | —       | —   | ○  | ○  | ○  | —  |
the sound environment of “forest,” (b-1)–(b-5) is the ones for the sound environment of “park,” and (c-1)–(c-5) is the ones for the sound environment of “shopping street”. The index numbers (*-1)–(*-5) respectively indicate the kind of additional sound stimulus (1: bird singing, 2: sound of stream, 3: roaring of waves, 4: hum of voices, and 5: traffic noise). The abscissa axis in each panel is the equivalent sound level of additional sound stimulus. The vertical axis of each panel is the preference point. The results of evaluation concerning comfortableness are plotted using the solid line, and the ones of evaluation concerning naturalness are plotted using the broken line. When the level of additional sound stimulus is $-\infty$ dB, the original sound environment to which no additional sound stimulus is added is presented to the subject. Each arrow near the results of original sound environment is yardstick for 5% significant level. The condition significantly different from the result of original sound environment in each panel is shown in Table 2. In addition, vertical dash-dotted line represents the level of original sound environment, and vertical dashed line is the level of additional sound that the additional sound is masked with sound environment.

Firstly, the results concerning the comfortableness is examined. As shown in Fig. 3(*-1) and (*-2) where “bird singing” or “sound of stream” or “roaring of waves” was added, the improvement of the comfortableness is found as the level of additional sound increases from the lowest level to the middle level. In addition, the comfortableness in some conditions are beyond that of the original sound environment. However, the improvement saturated at a certain level. The comfortableness of sound environment is deteriorated as the level of additional sound exceeds the peak level. On the other hand, in Fig. 3(*-4), (*-5) where “hum of voices” or “traffic noise” was added, the comfortableness at all level of additional sound is more unpleasant than that of the original sound environment. Furthermore, the deterioration is growing as the level of the additional sound increases. This improvement and deterioration were more than the yardstick, meaning that they are significant.

Secondly, naturalness of sound environment is examined. The improvement of naturalness was observed only on the condition of adding “bird singing” (see Fig. 3(a-1)). This tendency is different to the result concerning the comfortableness. In the other conditions, the naturalness of sound environment has decreased gradually as the level of additional sound.

4. Discussion

As for the relationship between the type of additional sound and the comfortableness of sound environment to which its sound was added, there is the improvement of comfortableness when the “bird singing” and “sound of stream” were added to each sound environment, except a condition that “sound of stream” was added to “shopping street” (refer to Table 2). These additional sounds have a pleasant impression as sound alone. However, in urban environment, the sound of stream may be associated with the street gutter. On the other hand, in natural environment, the sound of stream evoked the flow of natural water. Generally, the sound from street gutters has a bad impression as compared with the natural sound of water such as river. These facts are probably reasons for little improvement in comfortableness when the sound of stream is added to the shopping street. Furthermore, these facts also suggest that the change in the comfortableness of sound environment by the additional sound is varied depending on the environment. For the other additional sounds, the improvement of comfortableness was not obtained. Therefore, only the sounds that seem to be
Fig. 3. Relationship between the level of additional sound and its evaluation concerning comfortableness/naturalness. In each panel, the vertical dash-dotted line represents the level of original sound environment, and vertical dashed line is the level of additional sound that the additional sound is masked with sound environment.
comfortable may contribute to the improvement of the sound environment. However, even if the sounds that seem to be comfortable is added, the comfortableness of sound environment does not necessarily improve.

As for the relationship between the level of additional sound and the comfortableness of sound environment, the equivalent sound level of additional sound at which the improvement becomes the maximum was the same to that of sound environment or lower than it, when the comfortableness improved. The reason why the comfortableness decreases rapidly when the equivalent sound level of the additional sound is higher than that of the sound environment is that the naturalness of sound environment is degraded because only the level of the additional sound is remarkably high. This suggests that the level of additional sound to obtain the maximum improvement concerning the comfortableness is decided relative to that of sound in the environment. Shimai et al. showed that a pleasant sound stimulus tended to become more pleasant as its sound pressure level increases when the sound is presented alone [5]. The comfortableness did not increase as the level of the additional sound, meaning that the result of our experiment was different from them. This difference may be brought by the difference in the listening condition, i.e., a certain sound was heard alone in the experiment by Shimai et al. [5], while the additional sound was heard together with the environment sound in our experiment. Moreover, the result suggests that the sound pressure level of the additional sound should be appropriately determined in order to have the highest score of comfortableness.

Naturalness is significantly improved only when the “bird singing” was added to “forest”. The reason for this result is that the possibility that this combination exists in the real world is higher than the other combinations. In many combinations, naturalness was significantly degraded. However, the naturalness was not significantly degraded in a few combinations (ex. “park” + “bird singing”, “shopping street” + “hum of noise” or “traffic noise”) when the level of additional sound is lower than that of sound environment, though the improvement was neither observed. These combinations have the high possibility that exists in the real world like the combination of “bird singing” and “forest”. Therefore, it seems that degradation was not observed. Although the combination of “forest” and “sound of stream” has also actuality, the improvement is not obtained. However, the vision of stream is not included in the moving picture of “forest”. This is the cause of the difference. In other words, hearing the sound of stream or roaring of waves at the place without the river and the sea may be unnatural.

As described above, the comfortableness was improved by comfortable additional sounds like “bird singing” and “sound of stream” even if its naturalness was decreased. However, our result shows that it is necessary to set an appropriate level to achieve a desirable effect. From these results, it can be said that the impression control concerning comfortableness of the sound environment by the additional sound is feasible. However, our experimental results show that the effect is achieved under the limited situation. It is necessary to clarify the factor that influences the comfortableness to make the environmental design by additional sound more practicable.

### Table 2. Results of significance tests for impression concerning comfortableness and naturalness of sound environment.

| sound environment | additional sound | comfortableness | naturalness |
|-------------------|------------------|-----------------|-------------|
|                   |                  | relative level of additional sound [dB] | relative level of additional sound [dB] |
|                   |                  | -21 -14 -7 0 +7 +14 | -21 -14 -7 0 +7 +14 |
| forest (L\text{eq}: 43.0 dB) | bird singing | ○ ○ ○ ○ | ○ ○ ○ |
|                   | sound of stream | ○ ○ ○ x | x x x |
|                   | roaring of waves | x x x x | x x x |
|                   | hum of voices | x x x x | x x x |
|                   | traffic noise | x x x | x x x |
| park (L\text{eq}: 55.3 dB) | bird singing | ○ ○ ○ ○ x | ○ ○ ○ |
|                   | sound of stream | ○ ○ ○ x x | x x x |
|                   | roaring of waves | x x x x | x x x |
|                   | hum of voices | x x x x | x x x |
|                   | traffic noise | x x x | x x x |
| shopping street (L\text{eq}: 64.0 dB) | bird singing | ○ ○ ○ ○ | ○ ○ ○ |
|                   | sound of stream | x x x | x x x |
|                   | roaring of waves | x x x | x x x |
|                   | hum of voices | x x x | x x x |
|                   | traffic noise | x x x | x x x |
5. Conclusion

In the paper, an experiment was conducted by using our recorded audio-visual materials and the additional sounds extracted from database CD in order to investigate the influence of addition of sound stimulus on the comfortableness and naturalness of sound environment. The experimental results showed that the comfortableness was improved depending on the environment when the additional sound was considered as the sound that have good impression and its sound pressure level was a little lower than that at the original environment. The naturalness decreased gradually for almost of the additional sound stimuli, as the sound pressure level of additional stimulus increased. These results suggest that the comfortableness of the sound environment may be changed by the additional sound.

On the contrary, it is well known and natural that the subtraction of unwanted sounds is also effective in the design of the sound environments [9]. In order to design any given sound environments, there may exist these two techniques and their combination. More researches are required to completely clarify the usage of these techniques. This is one of the future works.

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