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Effects of sound environment on perceived spaciousness

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ABSTRACT

People's perceptions of architectural environments are based on multiple senses, including vision and hearing. However, the importance of hearing has been commonly overlooked in architectural design. Architects usually focus on noise elimination in the environment and sound insulation between adjoining rooms instead of expecting sound to play an active role in architectural spaces. Therefore, a laboratory study was performed to explore the effects of the sound environment on perceived spaciousness in architecture. 30 subjects were exposed to 96 audio-visual stimuli and asked to evaluate their perceived spaciousness and preference for sound environment, using a 9-point verbal scale. The results showed that perceived spaciousness was significantly influenced by subjects' preference for sound environment, sound type and the reverberation time of the space, and the influence mechanism was not relevant to the spatial authenticity (visual scale cues). The more preference the sound environment was, the more spacious the space was perceived. Increasing reverberation time was also helpful to increase perceived spaciousness of a space, though this phenomenon was only apparent in medium-size spaces. These findings would possibly provide practical guidance to architectural designs.

1. INTRODUCTION

Spaciousness is one of the most basic factors in the design of architectural space. A great deal of research show that visual factors and spaciousness are inseparable. Horizontal area and height (the original volume of a space) are considered to be the most important factors affecting perceived spaciousness [1]. In addition, the shape of the room [2], window form [3], the visual permeability of the boundary [4], and the roughness of the room boundary [5] have also been proved to affect perceived spaciousness. In terms of architectural physics, researchers have found that the amount of light and the illumination uniformity [1,6] has significant effects on perceived spaciousness, but the indoor temperature has no effects on perceived spaciousness [7]. These studies provided valuable reference for architects.

However, compared with visual factors, the design of the sound environment in architectural space is always

ignored. The design of the sound environment in architecture was once limited to noise reduction [8]. In recent years, with the change from the basic three-dimensional space to a comprehensive perception in architecture, researchers start rethinking the sound environment of buildings. Canadian composer R. Murray Schafer proposed the concept of soundscape [9]. Schafer believed that only abating the noise was a negative design strategy, and in modern architectural design, designing against was considered to be a strategy rather than designing for. Hall and Zumthor also emphasized the role of sound in architectural design, he started to learn how sound environments play a role in architectural space and interact with other factors [10,11]. A number of studies have explored the perceptive factors of sound environments in various architectural functions and demonstrated the relationship between the sound environment and contextual experience [12-15]. These ideas and studies reflected the potential effect of the sound environment on perceived spaciousness. However, it is still difficult for architects to systematically think about the sound environment in architectural space design, even the current situation of sound environments in many existing architectural spaces run counter to the original design intention of architects [16].

Therefore, the purpose of the present study was to reveal the influence of sound environment on perceived spaciousness and provide the basic principles for architects to use sound environment in shaping the spaciousness. The following questions will be explored: (1) Whether the sound environment affects perceived spaciousness? (2) Whether the sound environment has the same influence on different original scales with different spatial authenticity (visual scale cues)? (3) How different types and physical parameters of sound influence the perceived spaciousness?

2. METHOD

To explore the effects of the sound environment on perceived spaciousness, a laboratory experiment with 30 participants was performed.

2.1 Experimental Stimuli

2.1.1 Visual Stimuli

In the experiment, three sizes of architectural space were selected. The large space was 21 x 14 x 8 meters and had a volume of 2352 m³. It represented the common large space in buildings such as halls, commercial space, and exhibition space. The medium space was 12 x 8 x 3.6 meters and had a volume of 345.6 m³. It represented the common medium-size space such as an office, conference room, and classroom. The small space was 5.4 x 3.6 x 2.8 meters and had a volume of 54.4 m³. It represented the common small space such as a living room, bedroom, and small office. In addition, most rooms contained objects used by people as the reference for determining its spaciousness. To explore whether the sound environment still has an effect when there is a clear visual cue in the room, real spaces and empty spaces with the same scale were set up in the experiment. According to the original scale set, the real space was set like a hall in a public building, an office, and a living room, respectively. To ensure the correctness of visual scale cues, all the main objects in the real space were constructed according to the standard human body scale. SketchUp and Vary were used to make panoramic pictures of the six kinds of spaces and the simulated viewpoints were fixed at 1.60 meters. All viewpoints were set in a corner of the room, so that the participants could observe the entire room more conveniently with VR. The six kinds of space and their VR images were shown in Figure 1.



Figure 1. Six spaces and their VR images

2.1.2 Auditory Stimuli

In terms of auditory stimuli, the present study focused on three factors: sound type, sound pressure level, and the reverberation time. For sound type, the selected sound should be common in architectural spaces and contain multiple sounds, with differences in preference. Therefore, soothing music, uplifting music, footsteps, and crowd noise were selected as the auditory stimuli of the experiment. For reverberation time, three kinds of space scale were modeled in Odeon 14. Then, by changing the sound absorption coefficients of the three spaces, the four kinds of sound stimuli were rendered as long reverberation time and short reverberation time, respectively. According to the common reverberation time under the three kinds of space volume and the limit of the change in reverberation time, the reverberation time was set as 1.6S/0.5S for large space, 1.3S/0.3S for medium-size space, and 1.0S/0.1S for

the small space. For the sound pressure level, based on an evaluation of the eight participants in the pilot study, 60 dB (relatively high but not noisy) and 40dB (relatively low but audible) were selected. In conclusion, four kinds of sounds were set as two sound pressure levels, and two reverberation times, which formed a total of 16 kinds of sounds. The 16 sounds, combined with the six kinds of space, formed 96 kinds of experimental audio-visual stimuli in total.

2.2 Participants

A total of 30 students from Tianjin University participated in the present study, including 17 males and 13 females. The average age of the participants was 24.3 years. All the participants had normal hearing.

2.3 Experimental Process

The experiment was conducted in a semi-anechoic room in School of Architecture, Tianjin University. The 96 kinds of audio-visual stimuli were randomly arranged for each participant. The spatial images were displayed using VR equipment (Pico a7210), and the binaural sound signals were played through headphones (AKG K702). During the experiment, each stimulus was played for 18 seconds. After each audio-visual stimulus was presented, the participants were asked to answer two questions: 1) How do you feel about the spaciousness? 2) Do you like this sound environment? A 9-point verbal scale was used in the questionnaire (Question 1: 1 = Extremely narrow; 9 = Extremely spacious; Question 2: 1 = Extremely dislike; 9 = Extremely like). The average duration of the experiment was about 90 minutes.

3. RESULTS

For all the spaces in the experiment, ANOVA analysis (Table 1) showed that sound environment preference was significantly influenced by sound type ($p < 0.01$) and SPL ($p < 0.01$), and perceived spaciousness was significantly influenced by sound type ($p < 0.01$) and spatial authenticity ($p < 0.01$). As shown in Figure 2, people's preference for sound environment was the highest when soothing music was broadcasted, followed by uplifting music, footsteps, and crowd noise. Figure 3 showed that people's preference for sound environment is higher when exposed to low SPL (40 dBA) than exposed to high SPL (60 dBA). For perceived spaciousness, as shown in Figure 4, when playing soothing music, perceived spaciousness was largest, and when playing crowd noise, perceived spaciousness was the narrowest. Effect of uplifting music

and footsteps were between soothing music and crowd noise, and perceived spaciousness was slightly larger when playing uplifting music than playing footsteps. Figure 5 showed that perceived spaciousness was more spacious when people experience an empty space rather than a real space.

Sound type	Sound environment preference		Spaciousness	
	F	p	F	p
	979.779	0.000**	19.925	0.000**
RT	2.701	0.100	0.900	0.343
SPL	114.235	0.000**	1.324	0.250
Spatial authenticity	0.380	0.538	12.623	0.000**
Sound type*SPL	20.459	0.000**	1.561	0.208

* and ** indicate significance at 0.05 and 0.01 levels.

Table 1. ANOVA of sound type, RT, SPL and spatial authenticity on people's preference for sound environment and perceived spaciousness.

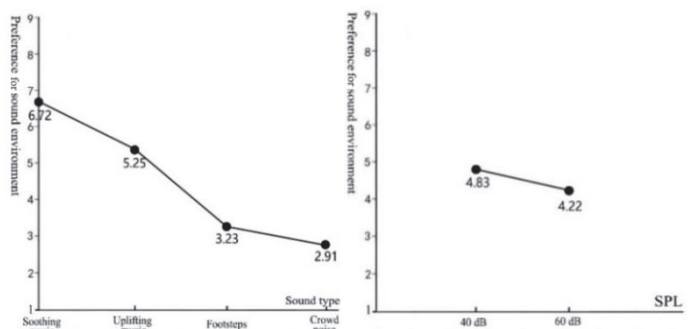


Figure 2. Effects of sound type on people's preference for sound environment.

Figure 3. Effects of SPL on people's preference for sound environment.

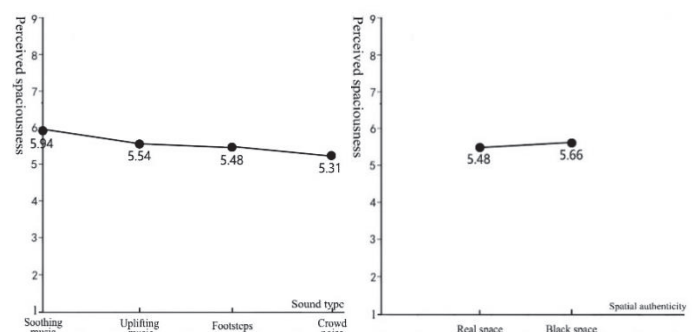


Figure 4. Effects of sound type on perceived spaciousness.

Figure 5. Effects of spatial authenticity on perceived spaciousness.

(In figures 2 to 5, the number under the dot represent mean values).

In the ANOVA analysis, the interaction was only found existed between sound type and sound pressure level on people's preference for sound environment ($F = 20.459$, $p < 0.01$). When playing soothing music and uplifting music, people's preference for sound environment increased with the increase in SPL. When playing footsteps and crowd noise, people's preference for sound environment decreased with the increase in SPL. It is worth mentioning that spatial authenticity had no interaction with other factors. It showed that there was no difference in sound environment's influence on people's preference for sound environment and perceived spaciousness in the empty or real space.

Table 2,3 and 4 showed the effects of sound type, RT, SPL and spatial authenticity on people's preference for sound environment and perceived spaciousness in small space, medium-size space and large space, respectively. In large space and small space, the influence mechanism was consistent with the overall space (Table 1). However, the difference was observed in medium-size space. In medium-size space, perceived spaciousness was not only influenced by sound type and spatial authenticity, but also influenced by the reverberation time ($p < 0.05$). As shown in Figure 6, perceived spaciousness increased with the increase in the reverberation time of the space. In general, for all three kinds of space, reverberation time had a limited effect on perceived spaciousness. Additionally, same with the analysis of overall spaces, the interaction was only found between sound type and sound pressure level on people's preference for sound environment.

	Sound environment preference		Spaciousness	
	F	p	F	p
Sound type	325.895	0.000**	3.561	0.014*
RT	2.440	0.119	0.131	0.717
SPL	38.530	0.000**	2.606	0.107
Spatial authenticity	1.580	0.209	18.889	0.000**
Sound type*SPL	7.506	0.000**	0.906	0.438

* and ** indicate significance at 0.05 and 0.01 levels.

Table 2. ANOVA of sound type, RT, SPL and spatial authenticity on people's preference for sound environment and perceived spaciousness in small space.

	Sound environment preference		Spaciousness	
	F	p	F	p
Sound type	277.587	0.000**	11.714	0.000**
RT	0.134	0.715	5.668	0.017*
SPL	35.475	0.000**	0.348	0.556
Spatial authenticity	2.741	0.098	9.218	0.002**
Sound type*SPL	8.231	0.000**	1.245	0.292

* and ** indicate significance at 0.05 and 0.01 levels.

Table 3. ANOVA of sound type, RT, SPL and spatial authenticity on people's preference for sound environment and perceived spaciousness in medium-size space.

	Sound environment preference		Spaciousness	
	F	p	F	p
Sound type	375.959	0.000**	8.117	0.000**
RT	2.253	0.134	0.115	0.734
SPL	24.061	0.000**	0.072	0.788
Spatial authenticity	3.183	0.075	11.921	0.001**
Sound type*SPL	11.558	0.000**	0.797	0.496

* and ** indicate significance at 0.05 and 0.01 levels.

Table 4. ANOVA of sound type, RT, SPL and spatial authenticity on people's preference for sound environment and perceived spaciousness in large space.

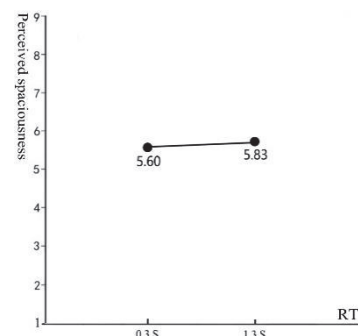


Figure 6. Effects of RT on perceived spaciousness in medium-size space, the number under the dot represent mean values.

As shown in Table 5, for all three kinds of space, the result of the regression analysis showed that perceived spaciousness was significantly influenced by people's preference for sound environment and sound type. This indicated that people's preference for sound environment is an important factor to influence on perceived spaciousness. When people experienced a space with higher preference for sound environment, the perceived spaciousness would be more spacious.

Model	R	R ²	Adjusted R ²	SC	Sig.
SEP				0.316	0.000**
RT	0.255	0.065	0.064	0.020	0.276
SPL				0.022	0.237
Sound type				0.103	0.000**

SEP = sound environment preference; SC= Standardized Coefficients

Table 5. regression analysis of sound environment factors to perceived spaciousness.

4. CONCLUSIONS

From the overall results, perceived spaciousness is significantly influenced by people's preference for sound environment, sound type and the reverberation time of the space. People's preference for the sound environment and the sound type had a greater impact on perceived spaciousness than reverberation time. The sound environment preference represented the subjective factors of the architectural environment and the sound type represented the content of the sound environment, while the reverberation time and sound pressure level were physical indices. In other words, the resonance between the sound environment and architectural space context was more important than the physical acoustic indices, which proved the importance of content and subjective perception of sound environment, namely the soundscape.

In summary, the present study explored the effects of sound environment on perceived spaciousness, and the following conclusions were obtained from the experiments.

1) Sound environment had significant effects on perceived spaciousness.

2) Perceived spaciousness was significantly influenced by people's sound environment preference, sound type and the reverberation time of the space. Sound environment preference and sound type were influential at all three spatial scales; however, the reverberation time of the space only had significant effects in medium-size spaces. The influence of sound environment on perceived spaciousness was not relevant to the spatial authenticity (visual scale cues).

3) Perceived spaciousness increased with the increasing in people's preference for the sound environment. In a medium-size space, it also increased with the increasing in the reverberation time of the space.

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