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Correlations between sound level and loudness, intimacy, reverberation, clarity, spaciousness in sequential spaces

Tingting YANG[1]; Jian KANG[2]

[1 2] Institute for Environmental Design and Engineering, The Bartlett, University College London,

London WC1H 0NN, United Kingdom

ABSTRACT

To explore the acoustic environment of sequential spaces, the paper discusses the correlations between sound level and five independent dimensions of acoustic environment including loudness, intimacy, reverberation, clarity and spaciousness. Two sequential spaces with similar spatial composition were selected for questionnaire survey and field measurement. The results showed that under the condition of no sound source, sound level only affected loudness. Under the condition of sound source, a higher sound level resulted in a higher loudness, reverberation and spaciousness. Sound level differences between the rooms did not necessarily correspond to assessment difference in these three indicators. Intimacy was negatively correlated to clarity, and there was a threshold of sound level difference related to assessment difference of these two indicators.

Keywords: Sequential Spaces, Sound Level, Subjective Evaluation

1. INTRODUCTION

Sequential spaces, defined as a series of spaces connected by openings, is a spatial form widely applied in designing non-acoustic spaces such as museums and commercials since 16th century and even earlier. Thus, acoustic perception of such spaces is important for indoor soundscape.

Listeners' responses have always been the focus of room acoustics. Researches on acoustic space are fruitful in this area. Previous studies proposed that there are at least five independent dimensions: clarity, reverberant response, impression of space, intimacy and loudness (1). Barron (2) mentioned that these five dimensions are not complete or definitive but they have provided a useful starting point for further discussion. Ando also showed that a concert hall has four subjective dimensions: loudness, reverberance, clarity and spaciousness (3).

Although loudness may not be the most appreciable indicator for designing a concert hall, the importance of acoustic perception is self-evident. The sense of loudness is predictably related to sound level and judgements overlap between intimacy and loudness (2). Hase et al. conducted an experiment on subjective reverberation in a concert hall with sound level of 70 and 80 dB, respectively, using both speech and music signals. The sense of reverberation of 80 dB was stronger than that of 70 dB when all other conditions were the same. Therefore, sound level is also considered to affect the reverberation (4). Furthermore, either a too high or low sound level will decrease clarity, which will also affect intelligibility. In the aspect of spaciousness, previous studies mentioned that when the mean forte sound level reaches 90 dB, there will be a satisfied sense of space (5).

Based on these studies, it can be concluded that sound level is an important objective parameter to evaluate the acoustic environment of a space, and there are close correlations between sound level and these five dimensions. However, these studies are developed on the researches of single space, which could be inadequate to analyse the sound field in non-acoustic sequential spaces (6, 7). Thus, the paper selected two sequential spaces, which are similar in spatial conditions, to explore the correlation between sound level and five independent dimensions of loudness, intimacy, reverberation, clarity, and spaciousness in sequential spaces.

[1] tingting.yang.18@ucl.ac.uk
[2] j.kang@ucl.ac.uk

2. METHODOLOGIES

2.1 Site Selection

The selection of site was primarily based on the consideration of spatial conditions to meet the requirements of subjective evaluation and objective measurement. The paper selected a gallery in London for investigation, in which most of exhibition spaces are sequential spaces of different scales exhibiting modern arts all the year round. This gallery is an enjoyable place for locals and tourists with comparatively high visiting amounts.

Two sequential spaces which are connected by the concourse on the right and left side were selected for the conditions of sound source. Figure 1 shows the floor plan of these two sequential spaces, concourse and the location of sound source. The sound source is a large sound installment formed as a cylindrical tower with hundreds of radios playing vocals, and music that are virtually unintelligible. Figure 2 shows a typical exhibition room. The basic conditions of spatial composition and coupling areas as well as design of the interior, exhibition environment, and peak hours of these two sequential spaces are essentially the same. Therefore, for the comparative study, the sequential spaces on the right side of the concourse in Figure 1 was defined as sound-source-group, and the sequential spaces on the left side of the concourse was defined as no-sound-source-group.

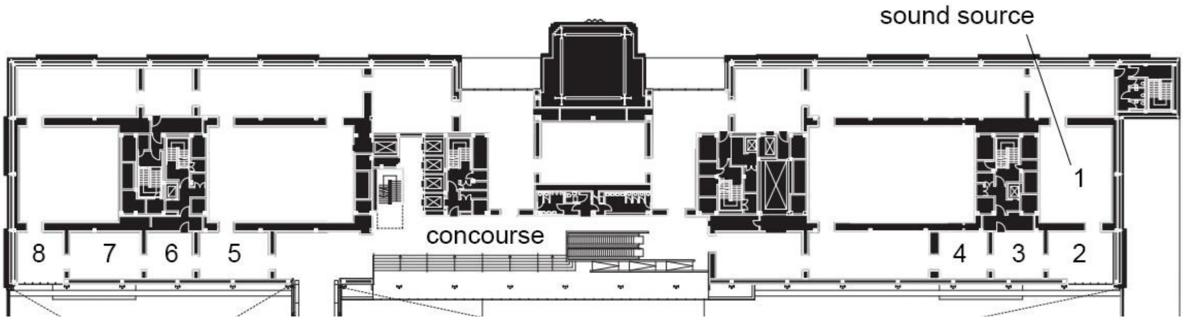

Figure 1 – Floor plan of two sequential spaces, concourse and the location of sound source

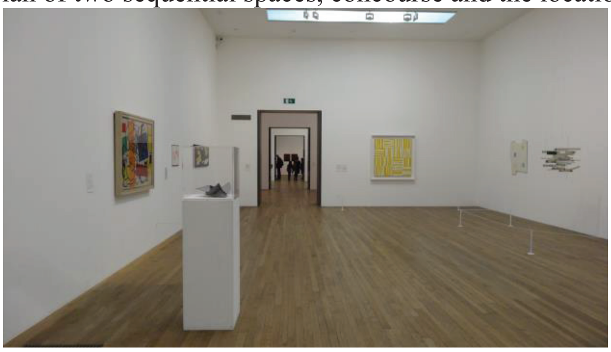

Figure 2 – Site photo: a typical exhibition room

2.2 Questionnaire Survey and Field Measurement

To explore the correlation between sound level and five dimensions, a questionnaire survey on subjective evaluation was carried out. The questionnaire consisted of questions on person factors (age and sex) and assessments of loudness, intimacy, reverberation, clarity, and spaciousness. The respondents were instructed to answer on a five-point unipolar category scale using the following response alternatives: (1) “not at all”, (2) “slightly”, (3) “moderately”, (4) “very”, and (5) “extremely”.

The subjects were randomly recruited among the visitors in the concourse who completed their visit to the exhibition space on Level 4. The experiment employed soundwalking and the subjects walked individually through the prescribed route and rated the subjective evaluation of each marked room while standing in the center of each space. All subjects in the no-sound-source-group took the direction from rooms 5 to 8, while the subjects in the sound-source-group were further subdivided into two smaller groups. The subjects who took the direction from rooms 4 to 1 were defined as towards-sound-source-group, and the subjects who took the direction from rooms 1 to 4 were defined as away-sound-source-group. A total of 36 subjects in each group were surveyed based on the criterion of normal distribution number that the sample size should be larger than 30. Each 108 subjects completed the questionnaire for four rooms, which amounted to 432 valid questionnaires.

To measure the mean value of sound level of each room, HEAD Acoustic SQobold was used to capture a one minute long recording of the environment close to the place where the subjects filled in the questionnaire representing the physical characteristics of the occupied condition. The measurements of sound level were averaged as the results.

3. RESULTS

3.1 Measured Sound Level

Table 1 shows mean values and variances of sound level in each room of no-sound-source-group and sound-source-group through the measurements during the data collection. For the no-sound-source-group, the highest mean value was 59.1 dBA in room 5, while that in rooms 6, 7 and 8 were basically equivalent. Statistical significance between rooms 5 and 6 was great (mean value difference = 2.2 dBA, $p < 0.01$). For the sound-source-group, the highest mean value was 68.3 dBA in room 1, while that in rooms 1 to 4 showed a descending tendency. There was statistical significance between rooms 1 and 2 (mean value difference = 5.7 dBA, $p < 0.01$) as well as between rooms 2 and 3 (mean value difference = 3.8 dBA, $p < 0.01$).

Table 1 – Mean values and variances of sound level of sound-source-group and no-sound-source-group

	Sound-source-group				No-sound-source-group			
	Room 1	Room 2	Room 3	Room 4	Room 5	Room 6	Room 7	Room 8
L_{Aeq}	68.3±2.41	62.6±2.80	58.8±2.95	59.7±3.37	59.1±4.66	56.9±4.81	55.3±5.49	53.8±5.71

3.2 Correlation between Sound Level and Five Dimensions

Based on the results of sound level in section 3.1, the correlations between sound level and five dimensions were analysed with no-sound-source-group and towards-sound-source-group depending on the mean values and their difference among the rooms.

For the no-sound-source-group, loudness and spaciousness were different between each room ($p < 0.05$). Table 2 reveals mean value and variance of loudness and spaciousness in each room. In terms of loudness, the highest mean value was rated at 2.5 in room 5, and that in rooms 6, 7 and 8 were basically equivalent. There was statistical significance between rooms 5 and 6 (mean value difference = 0.5, $p < 0.01$). In terms of spaciousness, the lowest mean value was rated at 2.6 in room 6, and that in rooms 5, 7 and 8 were basically equivalent. Statistical differences between rooms 5 and 6 (mean value difference = 0.6, $p < 0.01$) and rooms 6 and 7 were great (mean value difference = 0.6, $p < 0.01$).

Table 2 – Mean values and variances of loudness and spaciousness of no-sound-source-group

	Room 5	Room 6	Room 7	Room 8
Loudness	2.5±0.81	2.0±0.77	2.0±1.07	2.0±0.83
Spaciousness	3.2±0.95	2.6±0.96	3.2±0.93	3.1±0.95

Loudness was closely related to sound level, and 2.2 dBA difference resulted in different perceived loudness in sequential spaces. On the other hand, spaciousness showed a wide disparity with sound level. Thus, under the condition of no sound source, spaciousness is not directly related to sound level in sequential spaces.

For the towards-sound-source-group, all five indicators showed statistical significance ($p < 0.05$). Table 3 gives mean values and variances of all five indicators in each room. In terms of loudness, the highest mean value was rated at 3.9 and it showed an ascending tendency from rooms 4 to 1. The difference between rooms 1 and 2 (mean value difference = 0.9, $p < 0.01$) as well as rooms 2 and 3 was very statistically significant (mean value difference = 0.6, $p < 0.01$). In terms of intimacy, the highest mean value was rated at 3.0 in room 1. Statistical significance was shown in rooms 2 and 1 (mean value difference = 0.5, $p < 0.05$). In terms of reverberation, the highest mean value was rated at 3.2 and the difference between rooms 2 and 3 was great (mean value difference = 0.5, $p < 0.01$). In terms of clarity, the highest mean value was rated at 3.2 and there was statistical significance between rooms 2 and 1 (mean value difference = 0.7, $p < 0.01$). In terms of spaciousness, the highest mean value was rated at 3.4 and the difference between rooms 2 and 3 was great (mean value difference = 0.6, $p < 0.01$).

Table 3 – Mean values and variances of loudness, intimacy, reverberation, clarity and spaciousness of

towards-sound-source-group				
	Room 1	Room 2	Room 3	Room 4
Loudness	3.9±0.57	3.3±0.59	2.4±0.73	2.2±0.64
Intimacy	3.0±1.23	2.5±0.88	2.5±1.08	2.1±1.08
Reverberation	3.2±1.18	3.0±0.84	2.5±0.91	2.6±0.77
Clarity	2.5±1.06	3.2±0.85	3.2±0.96	3.0±1.11
Spaciousness	3.4±1.25	3.1±0.82	2.7±0.68	2.9±0.95

Note that assessment difference in loudness between rooms 2 and 3, which was paired with sound level difference 3.8 dBA, was larger than that of rooms 1 and 2, which were paired with sound level difference 5.7 dBA. This indicates that sound level difference does not necessarily correspond to assessment difference in loudness. A positive correlation between sound level and loudness was observed, which shows consistency to the results of single space. Intimacy increased with sound level as loudness in the room containing the sound source. However, this was not necessarily the case in the room with no sound source. Similarly, the result of 0.7 assessment difference in clarity paired with 5.7 dBA but no difference under 3.8 dBA indicates that 4 dBA sound level difference may not result in different perceived clarity, while 6 dBA difference would do. Room with a higher sound level in sequential space had a higher reverberation. However, similar to loudness, sound level difference did not necessarily correspond to assessment difference on reverberation. It could be also concluded that spaciousness is affected by the sound level as well under the condition of sound source and a higher sound level resulted in a higher spaciousness in sequential spaces.

4. DISCUSSIONS

4.1 Categories of Correlation

As discussed in section 3.2, correlations of sound level and five dimensions could be divided into two categories under the condition of sound source: first is loudness, reverberation and spaciousness. Figure 3 shows the tendency from rooms 1 to 4. They are directly affected by sound level. Second is intimacy and clarity. Figure 4 shows the tendency from rooms 1 to 4. Both of them show a peak in sound source room and a plateau in the other rooms, which indicates a threshold of sound level and acoustic perception difference.

These results also indicate the correlation within the five dimensions in sequential spaces. Note that spaciousness is not related to sound level under the condition of no sound source. Thus, it is suggested that since designing a sound source in sequential spaces would be very likely to result in a sequenced sound level throughout the rooms, a sequenced perception of spaciousness would be created as well.

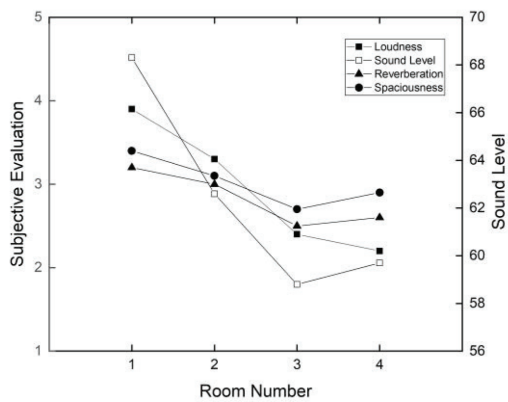

Figure 3 –Mean value tendency from rooms 1 to 4 (sound level, loudness, reverberation and spaciousness)

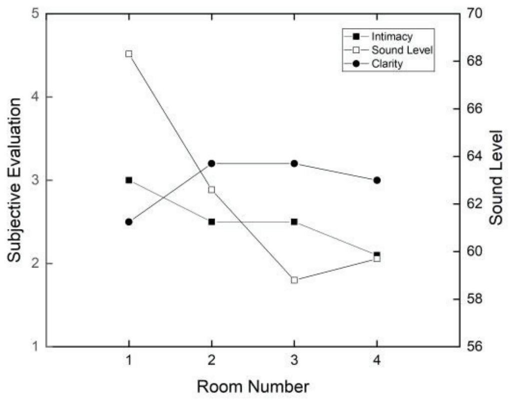

Figure 4 – Mean value tendency from rooms 1 to 4 (sound level, intimacy, clarity)

4.2 Difference of directions

To identify the effect of direction in subjective evaluation, a T-test comparison was further conducted in the away-sound-source-group. There was statistical significance between loudness and clarity ($p < 0.05$). Table 4 gives mean values and variances of these two indicators. In terms of loudness, the highest mean value was rated at 3.1 in room 1 and the difference between rooms 1 and 2 (mean value difference = 1.2, $p < 0.01$) as well as rooms 2 and 3 (mean value difference = 0.3, $p < 0.05$) was statistically significant. In terms of clarity, the lowest mean value was rated at 2.4 in room 1. The statistical significance between rooms 1 and 2 (mean value difference = -0.7, $p < 0.01$) was high.

Compared to the results of loudness and clarity in the towards-sound-source-group, it is observed that sound level difference was corresponding to assessment difference in loudness in the away-sound-source-group, while in the towards-sound-source-group, a larger sound level difference resulted in a smaller difference in perceived loudness. The expectation of loudness in two directions was more likely to be different. On the other hand, the difference in clarity in rooms 1 and 2 were basically equivalent of these two groups and showed the same tendency throughout the rooms.

Table 4 – Mean values and variances of loudness and clarity of away-sound-source-group

	Room 1	Room 2	Room 3	Room 4
Loudness	3.1±0.55	1.9±0.75	1.6±0.56	1.7±0.72
Clarity	2.4±0.94	3.1±1.09	3.4±1.16	3.2±1.17

5. CONCLUSIONS

The paper took subjective evaluation and objective parameter as the research object exploring the correlations between sound level and five independent dimensions of acoustic environment in sequential spaces. Under the condition of no sound source, sound level only affected loudness. Under the condition of sound source, the result showed that a higher sound level resulted in a higher loudness, reverberation and spaciousness. Sound level difference did not necessarily correspond to assessment difference of these three indicators. Intimacy was negatively correlated to clarity, and there is a threshold of sound level difference related to acoustic perception of these two indicators.

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