The subjective effect of random-incidence scattering coefficients

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ABSTRACT

Diffusion has been regarded as one of the most important room acoustic components for the good acoustics of a room. Recently, ISO 17497-1 standard proposed the technique for measuring random-incidence scattering coefficients (RISC) in a reverberation room, which will provoke a broad application in the acoustic design process of a room. However, it has not been examined thoroughly how the change in RISC influences the room acoustic quality. The present work investigated the subjective effect of RISC on the audience using a scale model of a small performance hall. Simple periodic type diffusers were considered, since they were easy to define and comparable with many previous work. The effect of changes in RISC was measured and analysed based on listening experiments. Subjective attributes in question were reverberance, clarity, loudness, and spaciousness, since no subjective attribute has been fully describe the subjective impression of surface diffusions in a room.

1 INTRODUCTION

The importance of diffusion for the good acoustics of a music performance space has been emphasized since the development of QRD diffusers by Schroeder\textsuperscript{1,2}. Recently, ISO working group has standardized the measurement procedures for quantifying the amount of scattered sound from a surface in rooms\textsuperscript{3}. The scattering coefficient is a measure which describes the degree of scattered sounds from surfaces. However this method is only concerned with the amount of energy which is moved from the specular direction and not with the directivity of the scattered energy. Therefore, it is practical to be applied to room acoustic simulation models. More information on the measurement of scattering coefficients is well summarized in a reference\textsuperscript{4}. Apart from quantifying the scattered sounds from architectural diffusive surfaces in an enclosed space, the audibility of diffused reflections has been explored in a few previous studies\textsuperscript{5-9}. Cox et al.\textsuperscript{5} carried out subjective tests to investigate the perception of diffuse and specular reflections using an artificial system with respect to both tonal and spatial effects. They could not find any evidence that diffuse reflections play a significant role in determining preference in auditoria. Torres et al.\textsuperscript{6} investigated the audibility of diffusion using computer generated auralizations and reported audible differences due to changes of diffusion coefficients. Takahashi et al.\textsuperscript{7} investigated the subjective effects of tonal response caused by scattering from periodic-type diffusers using theoretical predictions and scale models. Three types of diffusers having different roughness size were used. The values of lowest frequency where the diffusers causes scattering were 227 Hz, 567 Hz and 1700 Hz for three types of diffusers, respectively.
The subjective experiments using both theoretical and scale models showed that the difference perception for tonal effects between specular and diffuse reflections due to periodic roughness increased with increasing surface roughness. The distance of difference limen for the receiver to detect a difference between specular and diffuse reflections at frequency bands above 567 Hz was found to be 4 m. The result suggested that a receiver located more than 4 m away from a diffusing surface is not likely to be influenced by the scattered sounds subjectively. Toyota et al. carried out a further study on the echo suppression effects and coloration of periodic-type diffusers using a subjective test. The result indicated that the coloration can be detected if the total length of the uneven part of the surface is longer than 8 m. Some studies were carried out to evaluate the effects of installing diffusers in a concert hall using a scale model. Suzumura et al. investigated the effects of installing arrays of columns around the stage and audience area based on the measured four acoustical parameters. The result showed that the diffusers installed on the stage improved the acoustical parameters, IACC and $\Delta t1$. Ryu et al. carried out a similar investigation to evaluate the scattered sound field in a concert hall, using hemisphere and polygon diffusers (RISC, 0.6 and 0.9 for hemisphere and polygon diffusers, respectively) in the 1-2 kHz octave bands. They concluded that the effects of scattered sounds on acoustical parameters highly depended on the receiver position and diffuser location. The results obtained from the subjective test indicated that the preference of scattered sound field correlated highly with loudness and reverberance.

As can be seen from the literature review of earlier studies, the effect of diffusers on the acoustics of a room has not been thoroughly explored in spite of its importance claimed in many literatures. Also, ISO’s RISC (random incidence scattering coefficients) is expected to be broadly used as an important input data for computer simulations in the acoustic design process of a room. However, the effect of changes in RISC on the both objective and subjective room acoustical parameters has not been clearly known. The present work intended to provide more information on how surface diffusion affects the acoustic quality of a room. A subjective test was carried out using a 1/10th scale model of a small performance hall with both varied RISC of side wall diffusers and the listening position in the room.

2 EXPERIMENTAL ARRANGEMENTS

2.1 Physical scale model

A 1:10 scale model was constructed by simplifying an existing small hall. The hall was a small shoebox type performance hall. The hall has a volume of 1213.9 m$^3$ and accommodates 190 seats (Table 1). Room surfaces except ceiling area were finished acoustically reflective by applying a varnished medium density fiber board (MDF). Except the sidewall area where diffusers were installed, the rest of room surfaces were treated as flat as possible. The average occupied T30 of the hall measured without sidewall diffusers was 1.64 s averaged over mid frequencies (500 and 1,000 Hz).

<table>
<thead>
<tr>
<th>Table 1: Architectural details of the hall</th>
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<tbody>
<tr>
<td>Stage height (m)</td>
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<tr>
<td>1</td>
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Figure 1: Occupied T30 of the hall for the 1/1 octave band center frequency (room average ± standard deviation). T30 was measured at nine positions without installing side-wall diffusers.

2.2 Diffusers

Periodic type diffusers were considered in the present work. Continuous arrays of perfect square columns with an equal distance between columns were used for diffusers in this work. Figure 2 shows the cross-section of the diffuser used in the present study, where the distance between each square was kept equal to the side length of a perfect square. The diffuser was installed to fully cover both side walls on the area of 83.82 m². The scattering coefficient of each diffuser was measured in a scale model reverberation chamber based on ISO 17497-1. A rigid edge strip with a thickness of 3mm was applied along the perimeter of a test specimen in order to avoid overestimation due to the edge effect.

Figure 2: A cross-section of periodic type diffusers used in the present work (‘a’ equals to 5cm, 10cm and 22cm in a full scale for type 1, type 2 and type 3, respectively).

Figure 3: The interior view of the hall with diffusers installed on the side wall.
Figure 4: Random incidence scattering coefficients (left) and absorption coefficients (right) of each diffuser, measured in a 1/10 scale model reverberation chamber, was illustrated at the centre frequency of the one third octave band. N.D. denotes a flat varnished MDF.

2.3 Listening experiment

Two listening positions, C2, and C3 were selected well within the distance of difference limen in order to investigate the effect of installing diffusers on the side walls of the hall (Figure 5). Both positions were located 1.5m from the sidewall diffuser. Position C2 is placed at the centre of the diffuser while position C3 was located at the edge of the sidewall diffuser, where the diffusive sidewall and reflective rear wall cross. Position C2 was expected to receive relatively higher density of early diffuse reflections. The anechoic music source (a music motif (Lascia Chi’O Pianga) from George Friderick Handel’s opera, Rinaldo) was convolved with impulse responses obtained at each position using a 1/10 scale model of a dummy head (ACO Pacific, MK-224). The convolved music sources were stored on a computer hard-disk and then played back to a listener through a headphone (Sehnheiser, HD600). The playback of stimuli and collection of a listener’s responses were performed using a music experiment software, MEDS12. The listening experiment was carried out using a 2AFC (alternative forced choice) paradigm based on Thurston’s comparative judgment13. Listeners were asked to choose the one which provokes larger sensation with respect to the subjective attribute in question. The subjective attributes in question were reverberance, clarity, loudness and spaciousness. 18 students from the department of music in Chonbuk National University voluntarily participated in the listening experiment. All listeners had at least ten years of musical training and they were aged between 22 and 28. Each listener was found to have a normal hearing by audiometric tests14. The experiment took about twenty minutes for each listener to finish at each position.

Figure 5: Selected source and receiver positions for the measurement in the model hall.
3 RESULTS AND DISCUSSION

The perceived acoustics of listeners with respect to changes in the RISC of sidewall diffusers were measured and analysed. The psychological scale values of reverberance, clarity, loudness and spaciousness were calculated based on Thurston’s Case V of his law of comparative judgements. In spite of its usefulness in this kind of psychophysical experiments, the lack of ability to compute confidence interval in the formulation has been known to limit the implementation of Thurston’s law. There, the empirical formula, proposed by Montag\textsuperscript{15-16}, was used for creating error bars (95% confidence intervals) in the present work. The room acoustic parameters, known to be correlated with the subjective attributes considered in the present work, were measured at both positions. Table 2 presents the measured room acoustical parameters averaged over mid-frequencies at two different listening positions. The presence of diffusers made a clear difference for the $T_{30}$, $C_{80}$ and $G_{80}$ at both positions, which exceeds jnds for these parameters (1 JND for $T_{30}$ is 0.05 s, and for $C_{80}$ and $G_{80}$ is 1 dB\textsuperscript{5}). Changes in RISC within the ranges of this work did not significantly influence the acoustical parameters except for $C_{80}$.

Table 2: Measured room acoustic parameters averaged over mid-frequencies at two positions.

<table>
<thead>
<tr>
<th>Diffuser types</th>
<th>C2</th>
<th>C3</th>
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<tbody>
<tr>
<td></td>
<td>$T_{30}$</td>
<td>$C_{80}$</td>
</tr>
<tr>
<td>N.D.</td>
<td>1.72</td>
<td>0.6</td>
</tr>
<tr>
<td>Type 1</td>
<td>1.34</td>
<td>1.6</td>
</tr>
<tr>
<td>Type 2</td>
<td>1.41</td>
<td>1.2</td>
</tr>
<tr>
<td>Type 3</td>
<td>1.41</td>
<td>0.4</td>
</tr>
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Figure 6: Psychological scale value of the reverberance as a function of RISC of side wall diffusers (error bars present ± standard deviations). N.D. denotes the room condition without sidewall diffusers.
Figure 6 shows the measured reverberance as a function of RISC of sidewall diffusers at two different listening positions. Listeners perceived the sound heard from the hall without treating sidewall diffusers more reverberant than those for treating sidewall diffusers. This result was expected because the diffusers considered in the present work were relatively more absorptive than the flat wall without diffusers and the measured $T_{30}$ without diffusers were longer than those for the room with diffusers. The difference of perceived reverberance with or without sidewall diffusers was more than 1 JND ($JND=0.05s$). The effect of sidewall diffuser on listeners’ perceived reverberance was highly dependent on the listening position. At the position C3, located at the edge of the sidewall diffuser, the sounds heard less reverberant as the RISC increased, while the increased RISC provoked larger reverberance at the center position of the diffuser.

![Psychological scale value of clarity](image1)

Figure 7: Psychological scale value of the clarity as a function of RISC of side wall diffusers (error bars present ± standard deviations).

Figure 7 shows the perceived clarity as a function of RISC of sidewall diffusers at both positions. It was found that the perceived clarity of sounds was not significantly influenced by the RISC change at the center position of the diffuser. However, the perceived clarity was observed to be gradually improved with increasing RISC at the edge position of the diffuser. It was also found that the difference of the perceived clarity between type 3 and other types of diffusers was statistically significant.

Figure 8 shows the perceived loudness as a function of sidewall diffusers at both positions C2 and C3. It was found that the perceived loudness was increased without installing sidewall diffusers made sounds less loud at both positions, except for the room treated with type 2 diffusers at position C2. A correlation analysis showed that the difference in the early energy strength significantly influenced ($r^2=0.90$, $p<0.05$) the perceived loudness of listeners.

Figure 9 shows the perceived spaciousness as a function of RISC of side wall diffusers at both positions C2 and C3. The perceived spaciousness was increased in the room without treating diffusers than those for with treating diffusers at both positions. The increase in RISC tended to negatively influence the perceived spaciousness at position C2. The effects of RISC on the perceived spaciousness of listeners were statistically significant at position C2, but not for those found at position C3.
Figure 8: Psychological scale value of the loudness as a function of RISC of side wall diffusers (error bars present ± standard deviations).

Figure 9: Psychological scale value of the spaciousness as a function of RISC of side wall diffusers (error bars present ± standard deviations).

4 CONCLUSIONS

The effects of changes in the RISC of sidewall diffusers on listener’s perceived acoustics were measured and analysed based on the subjective test. It was found that the presence of sidewall diffusers in the room significantly influenced the perceived reverberance, loudness and spaciousness. It was also found that the effect of RISC was highly dependent on the listening position in the room. No significant effect of increasing RISC on the perceived reverberance and clarity was found at the middle position of the sidewall diffuser, while the perceived clarity was significantly increased at the edge position of the sidewall diffuser. Also, the perceived spaciousness was found to be deteriorated by the increase of RISC. The perceived spaciousness was not significantly changed at the edge position of the sidewall diffuser. It is more likely that the density of early diffuse reflections resulted in the difference at two listening positions.
ACKNOWLEDGMENTS

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REFERENCES