Preferred acoustical conditions for musicians on stage with orchestra shell in multi-purpose halls

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ABSTRACT

This study investigates the acoustical conditions in relation to stage support parameters for musicians’ performances in concert hall stages with a proscenium arch and an orchestra shell. Stage acoustical parameters, such as $ST_{\text{Early}}$ and $ST_{\text{Late}}$, were measured in order to characterize stage acoustics at various positions. In performance tests, solo and duet performances were investigated: subjective scores for hearing oneself (each other) and preference were gathered from musicians on stage. The results showed that the musicians highly preferred the central stage area, which had the highest $ST_{\text{Late}}$.

1 INTRODUCTION

Investigation of the effect of stage acoustics on performer preference differs from general concert hall acoustic studies, which are mainly concerned with acoustical requirements for the audience perspective. Hence, acoustical guidelines for the performers are comparatively underdeveloped. The optimum conditions may differ with individual performers, instrument types, or ensemble arrangements. Moreover, since the performer acts as both the sound source and the receiver, it is difficult to derive a single relevant parameter. To explain stage acoustics, a performer controls his or her own sound in response to the room’s acoustics as well as for the entire orchestra ensemble.

Since the late 1970s, acoustic experiments have been conducted to define the stage parameters required for evaluating sound fields on an auditorium platform. The definition of the stage parameter $ST_1$ is straightforward (i.e., the energy ratio between direct sound energy and reflection energy), and the measurement procedure is relatively simple. Chiang et al. conducted a series of objective and subjective experiments to improve stage acoustical parameters. Consequently, the revised ISO 3382-1 standard includes stage measurements of parameters $ST_{\text{Early}}$ and $ST_{\text{Late}}$.

In this study, the stage acoustics of a concert hall with a proscenium arch and an orchestra shell were evaluated both objectively and subjectively for instrumental solo performers. The stage support parameters were measured, and performer’s impressions were asked on stages, which were related to the objective evaluation results.
2 OBJECTIVE MEASUREMENTS THE STAGE PARAMETERS

2.1 Hall description

Sejong Great Theatre (SGT) has a proscenium with an orchestra shell. Its seating capacity is 3,022 with a typical fan-shaped plan. The audience area includes both the second and third floors with rear balconies. The hall’s configuration is as follows: the stage floor area is 333.2 m², the maximum and minimum lengths of the stage are 28.4 m and 17.4 m, respectively, and the maximum and minimum heights of the stage are 12.5 m and 9.5 m, respectively. The unoccupied reverberation time in the audience area with heavily upholstered chairs is 1.6 s in the mid-frequency bands.

Bongseo Hall (BSH) also has a proscenium with an orchestra shell. It has a seating capacity of 1,254 with a rectangular shaped plan. The audience area includes the second floor, with rear a balcony. The hall's configuration is as follows: the stage floor area is 221.5 m², the maximum and minimum lengths of the stage are 18.4 m and 11.4 m, respectively, and the maximum and minimum heights of the stage are 7 m and 9 m, respectively. The unoccupied reverberation time in the audience area is 1.1 s in the mid-frequency bands.

2.2 Measurement set-up

The stage acoustical parameters were measured based on the ISO 3382-1 standard. The measurement was conducted at 15 positions in a rectangular grid at 3-m intervals in SGT and 14 positions in a rectangular grid in BSH, as shown in Fig. 1. For the auditory tests, the number of each measurement position was selected based on the $ST_{Early}$ measurement conditions.

An omni-directional loudspeaker (Type Do 12, AVM) with omni-directional microphone (AKG-414, half-inch microphone) were employed. Stage support parameters were calculated with the impulse responses measured on the stage. The distance between the sound source and receiver was 1 m with a four cruciform direction, and the measurement height was 1.5 m from the stage floor. $ST_{Early}$ ($ST1$) was defined as the logarithmic ratio between the direct sound energy (0 to 10 ms) and early reflection energy (20 to 100 ms). Stage support late ($ST_{Late}$) included late reflections beyond 100 ms up to 1,000 ms. All the stage parameters were averaged over the 250 to 2,000 Hz octave bands.

![FIGURE 1: Positions for the auditory tests are denoted by characters. (Left: SGT/Right: BSH)]
2.3 Results

Figure 2 shows the measurement results of the stage acoustical parameters at the selected positions. $ST_{Early}$ ranged between -12.1 and -21 dB (SGT) and -9.6 and -16.3 dB (BSH), whereas $ST_{Late}$ ranged between -17.6 and -20.3 dB (SGT) and -14.4 and -18.1 dB (BSH). For both halls, the stage center position (denoted by E in Fig. 1) yielded the highest $ST_{Late}$ value.

![Figure 2: Contour of $ST_{Early}$ (Left: SGT/Right: BSH)](image)

FIGURE 3: Contour of $ST_{Early}$ (Left: SGT/Right: BSH)

3 SUBJECTIVE EVALUATIONS FOR MUSICIAN PERFORMANCES

3.1 Test procedure

The field auditory tests, conducted by musicians, were carried out on the hall stages. The musicians evaluated the stage sound fields at selected positions in each hall. On the SGT stage, three violinists, an oboist, a flutist, and a trombone player participated in the test and only played solo. On the BSH stage, four violinists, two cellists, and two violists played solo for the test, and twelve flutists played a duet for the test.

The stage sound fields were evaluated by a five-point rating method. The musicians also rated on four subjective impressions, shown in Table 1, on a discrete scale. For Support, Timbre and Ensemble, a rating of ‘the worst’ represents the lowest score and a rating of ‘the best’ represents the highest score.’ For Reverberance, ‘the least’ represents the lowest score and ‘the most’ represents the highest score. The overall quality of position was evaluated on a five-point rating scale.
### TABLE 1: Description of subjective impressions used for the five-point rating test

<table>
<thead>
<tr>
<th>Subjective Impression</th>
<th>Descriptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Support</td>
<td>The degree to which the stage environment supports hearing oneself</td>
</tr>
<tr>
<td>Timbre</td>
<td>The influence of the room on the tone color of the instrument</td>
</tr>
<tr>
<td>Reverberance</td>
<td>Amount of reverberation when a note or tone stops</td>
</tr>
<tr>
<td>Ensemble (Only for duet)</td>
<td>Ease of playing together</td>
</tr>
</tbody>
</table>

### 3.2 Results

The results of the five-point rating test in which musicians evaluated the stage sound fields in terms of Support, Timbre, Reverberence, Ensemble (only for duet), and Preference. Results show that at both halls, position E was the highest rated among all five subjective impressions for solo playing. For a duet performance, position E was again the highest rated with regard to Timbre, Reverberence, Ensemble and Preference.

Table 2 shows the correlation coefficients for the results of the objective measurement and the five-point rating scale. $ST_{Late}$ had the highest correlation with the subjective impressions. In particular, Preference is highly correlated with $ST_{Late}$ in all the three cases.

### TABLE 2: Correlation coefficients between the results of the objective measurement and the five-point rating test (* $p<0.05$ and ** $p<0.01$).

<table>
<thead>
<tr>
<th>Subjective Impressions (five-point rating test)</th>
<th>Solo (SGT)</th>
<th>Solo (BSH)</th>
<th>Duet (BSH)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$ST_{Early}$</td>
<td>$ST_{Late}$</td>
<td>$ST_{Early}$</td>
</tr>
<tr>
<td>Support</td>
<td>0.38**</td>
<td>0.38**</td>
<td>0.13</td>
</tr>
<tr>
<td>Timbre</td>
<td>0.12</td>
<td>0.37**</td>
<td>0.54**</td>
</tr>
<tr>
<td>Reverberance</td>
<td>0.40**</td>
<td>0.30*</td>
<td>0.47**</td>
</tr>
<tr>
<td>Preference</td>
<td>0.14</td>
<td>0.52**</td>
<td>0.47**</td>
</tr>
<tr>
<td>Ensemble (only duet)</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Multiple regression analysis was used to derive prediction models of preference in terms of objective parameters. When considering $ST_{Early}$ and $ST_{Late}$ as independent values, only $ST_{Late}$ is significant in all cases.
Case 1: Solo at SGT

Preference = 0.87 (ST_{Late}) + C \quad (R=0.52, R^2=0.27) \quad (1)

Case 2: Solo at BSH

Preference = 0.50 (ST_{Late}) + C \quad (R=0.56, R^2=0.318) \quad (2)

Case 3: Duet at BSH

Preference = 0.41 (ST_{Late}) + C \quad (R=0.47, R^2=0.217) \quad (3)

In the prediction model, unstandardized coefficients are used to define a slope and a constant coefficient. The multiple correlation coefficient R and the coefficient of determination (R^2) represent the variance explanation power regarding the relation between a dependent value and an independent value.

4 CONCLUSIONS

This study investigated the subjective and objective characteristics of performer preference through field measurement and auditory tests in two proscenium-style concert halls having 3,000 seats and 1,250 seats. The early stage support parameter, ST_{Early}, ranges over 6 dB on a single stage, and the stage acoustical parameters were found to be diversely distributed according to the measurement location. The auditory test results indicate that the stage center is the most favorable position for musicians. ST_{Late} was found to be a dominant factor in the preference models. Although this study only considered proscenium concert halls with an orchestra shell, in principle, the existing stage enclosure dimensions may be extended to other concert halls for improving ST_{Early} and ST_{Late}.

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REFERENCES


