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Evaluation of stage support for musicians' performance in a concert hall

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ABSTRACT

Stage support for both vocal and instrumental performers was evaluated for ensemble performance in concert halls. Halls with different seating capacities were selected for measurements of stage acoustics: ST_{Early} was measured at eight positions where musicians played for evaluation of ease in hearing oneself. In addition, mutual hearing on stage was evaluated by exchanging sources and receivers at the positions between soloist and orchestra. Stage acoustical parameters for stage support and mutual hearing are discussed with regard to the subjective tests results.

INTRODUCTION

The effect of stage acoustics on performer preference differs from the bulk of concert hall acoustics studies, which are mainly concerned with audience acoustical requirements. Hence, acoustical guidelines for performers have not been developed as much as those for audiences. Optimum conditions may be particular to individual performers, instrument types, or ensemble arrangements. Moreover, as the performer is both source and receiver, the derivation of a relevant stage parameter is difficult. A performer controls his own sound in response to the room's acoustics [1], as well as for ensemble with the other orchestra players.

Investigations to define stage parameters for evaluation of sound fields on an auditorium platform have been made since the late 1970s. The earliest acoustical experiments were made by Marshall *et al.* [2] and Barron [3]. In 1978, Marshall *et al.* [2] investigated acoustical conditions preferred for ensemble using synthesized reflections of sounds in an anechoic room, while Barron [3] carried out subjective tests with a small orchestra and objective measurements in an actual concert hall with variable stage settings. In 1989, stage support (ST1) as a stage parameter was proposed by Gade [4, 5] through both laboratory and field experiments. The definition of ST1 is clear (energy ratio between direct sound energy and reflection energy), and the measurement procedure is relatively simple (omni-directional source and microphone). Consequently, the revised ISO 3382-1 includes stage measures of ST_{Early} and ST_{Late} based on ST1 [6].

There are still some areas in which the interpretation of stage parameters might be improved. One is the consideration of the actual stage sound fields for deriving performer preference, and another is consideration of differing needs of various types of musicians. Stage acoustical conditions are very diverse even within a single hall. In one hall, Jeon and Barron reported that ST1 ranged from -18 to -8 dB [7]. Hence, subjective tests on the actual platform area could be the most effective way to evaluate the performer's stage impression.

In this study, the stage acoustics of a concert hall was evaluated objectively and subjectively for both vocal and instrumental performers. Objective evaluation included the measurement results of stage support and other room acoustical parameters. Subjective tests to evaluate performer's impressions were conducted in a real hall in relation to the objective evaluation results.

OBJECTIVE MEASUREMENT

Hall Description

Field measurements and auditory tests were carried out in a proscenium hall with orchestra shell. The hall has about a 3,000 seat capacity with a typical fan-shaped plan. The audience area includes 2nd and 3rd floor rear balconies. The stage floor area is about 270 m^2, stage width is ranged from 17.4 m to 28.4 m and stage height is ranged from 9.5 m to 12.5 m.

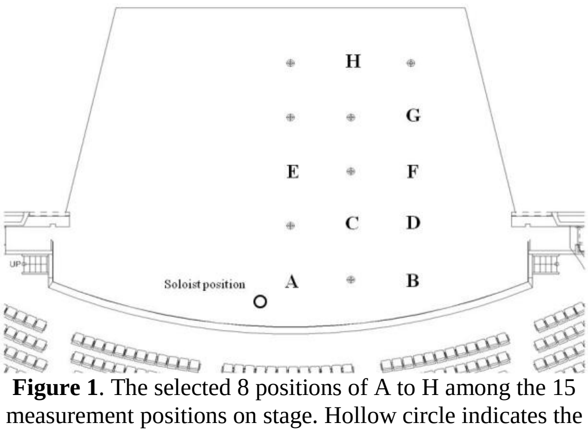


Figure 1. The selected 8 positions of A to H among the 15 measurement positions on stage. Hollow circle indicates the typical soloist position for room acoustical parameter measurement.

Procedure

Stage acoustical parameters were measured based on ISO 3382-1 [6] at 15 positions in a rectangular grid at 3-m intervals, as shown in Figure 1. For the auditory tests, 8 positions were selected based on the measured ST_{Early} values. A dodecaheadral loudspeaker was employed as the omni-directional sound source. Stage support and other acoustical parameters such as RT, EDT and C80 were measured using an omni-directional microphone (AKG-414). In addition, a Head and Torso Simulator (HATS, B&K Type 4100) was used for measurement of IACC. Assuming that the orchestra members hear a soloist playing music for ensemble, another set of on-stage measurements were conducted. In this case, the same omni-directional source was located at the typical soloist position, and the HATS was facing the source, and located at the selected 8 positions as shown in Figure 1.

Evaluation parameters

The stage support parameters were calculated from impulse responses measured at the stage. The distance between the sound source and receiver was 1 m and the measurement height was also 1 m from the stage floor. ST_{Early} (ST1) is defined as a logarithmic ratio between direct sound energy (0 to 10 ms) and early reflection energy (20 to 100 ms). Stage support late (ST_{Late}), includes late reflections beyond 100 ms. Clarity at stage (CS) is defined in the same manner as C80. All stage parameters were averaged over the 250 Hz to 4 kHz octave bands. RT and Ts were averaged over the mid-frequency bands (500 Hz and 1 kHz). C80 and IACC were averaged from 500 to 2k Hz. Two time spans of early (within 80 ms, $IACC_{E3}$) and late (after 80 ms, $IACC_{L3}$) periods were considered for IACC calculation.

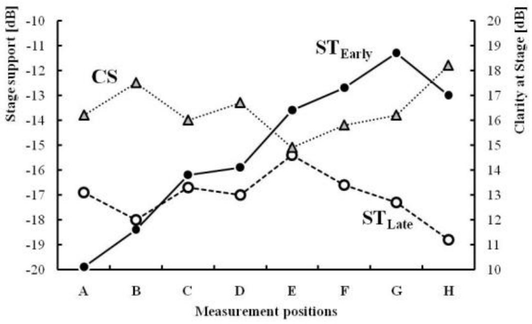


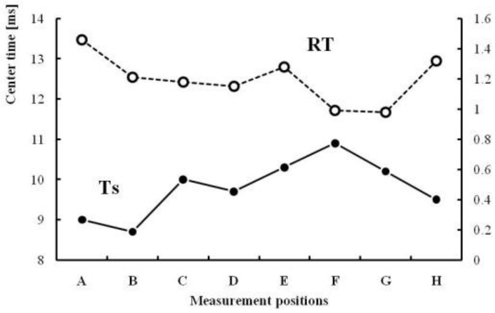
Figure 2. Measurement results of stage acoustics parameters when the source and receiver were located at the selected positions of A to H as shown in Figure 1 with the fixed source-to-receiver distance of 1 m

Results

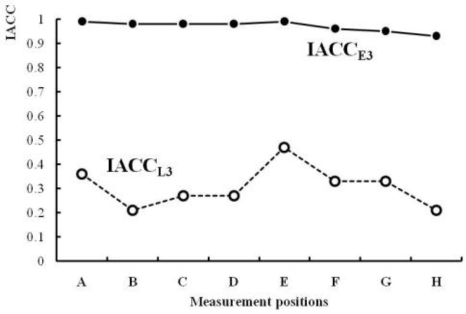
Figure 2 shows the measurement results of stage acoustical parameters. ST_{Early} ranged between -19.9 dB and -11.3 dB, and the mean ST_{Early} was -15.1 dB. ST_{Late} ranged between -18.8 dB and -15.4 dB, and CS ranged between 14.9 dB and 18.2 dB. ST_{Late} and CS were highly correlated (r = -0.97), but ST_{Early} and ST_{Late} showed no correlation (r = -0.01). ST_{Early} was dependent on the distance from the orchestra shell. The stage rear corner (Positions G and H) yielded the highest ST_{Early} values. The stage center position (Position E) yielded the highest ST_{Late} value and the lowest CS value.

The measurement results of room acoustical parameters with the 1-m separation between source and receiver are shown in Figure 3. RT ranged between 0.98 s and 1.46 s. Ts ranged between 8.7 and 10.9 ms. $IACC_{E3}$ ranged between 0.93 and 0.99. $IACC_{L3}$ ranged between 0.21 and 0.47. Ts showed significant correlation with ST_{Early} (r = 0.77), and $IACC_{L3}$ showed significant correlation with ST_{Late} (r = 0.87) and CS (r = -0.89).

Figure 4 shows the results of acoustical parameters at the stage in case of the soloist source. (Subscript "S" was added for this measurement case) RT_S ranged between 1.41 s and 1.59 s. EDT_S ranged between 0.80 s and 1.50 s. As the receiver approaches the orchestra shell, RT_S increased and EDT_S decreased. $C80_{3B,S}$ ranged between 3 dB and 8.6 dB. $LF_{E4,S}$ ranged between 0.04 and 0.33. EDT_S (r = -0.91), RT_S (r = 0.86) and $LF_{E4,S}$ (r = 0.75) showed significant correlations with ST_{Early}.

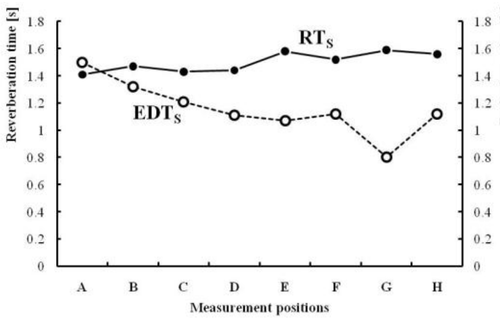


(a) RT and Ts

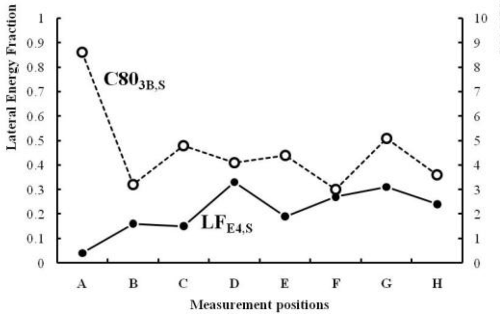


(b) $IACC_{E3}$ and $IACC_{L3}$

Figure 3. Measurement results of room acoustical parameters when the source and receiver were located at the selected positions A to H as shown in Figure 1 with the fixed source-to-receiver distance of 1 m



(a) RT and EDT



(b) C80 and LF_{E4}

Figure 4. Measurement results of room acoustical parameters when the source was located at the soloist position and the receivers were located at A to H as shown in Figure 1

SUBJECTIVE EVALUATIONS

Procedure

The field auditory tests by musicians were carried out on the hall stage guided by the experimenter. Subjects evaluated the stage sound fields at the selected 8 positions as shown in Figure 1 by playing music. Twelve experienced musicians participated in the auditory test. They included 6 instrumentalists (3 violinists, 1 trombonist, 1 flautist and 1 oboist) and 6 singers (4 sopranos, 1 tenor and 1 baritone).

The stage sound fields were evaluated by paired comparison and 5-pt rating methods. The paired comparisons test was used to investigate preference for stage sound field. A randomized order of 28 pairs was prepared. Each subject performed sufficiently at the selected 8 position. Then, they were asked to select the prefered sound field with short test performance from the two positions in each pair. Scale values of preference were calculated from the subject's response using Thurstone's Law IV [8]. Significance of individual response was validated by a consistency test procedure, and significance of overall scale value was validated by an agreement test procedure [9]. As for the 5-pt rating test, subjects rated the five subjective impressions shown in Table 1 on a discrete scale. For *Support* and *Blending*, 1 represents 'worst' and 5 represents 'best'. For *Size*, *Directivity* and *Reverberance*, 1 represents 'least' and 5 represents 'most'.

Table 1. Description of subjective impressions used for the 5-pt rating test

Subjective impression	Descriptions
Support	The degree to which the stage environment supports hearing oneself
Blending	The degree to which one's performed music notes are well blended by diffusivity of stage enclosure
Size	Acoustically perceived hall size
Directivity	Degree of spreading when one makes a sound
Reverberance	Perceived reverberation when one note or tone stops

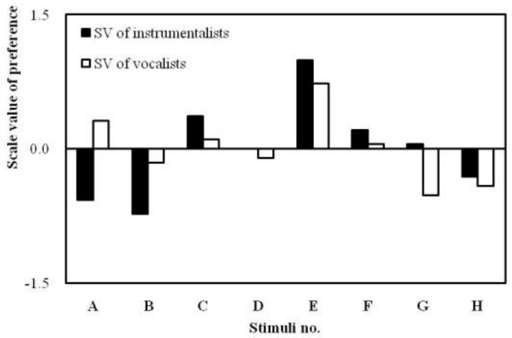
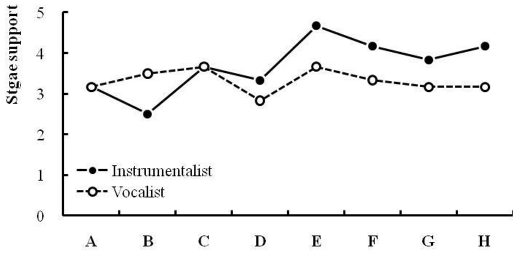


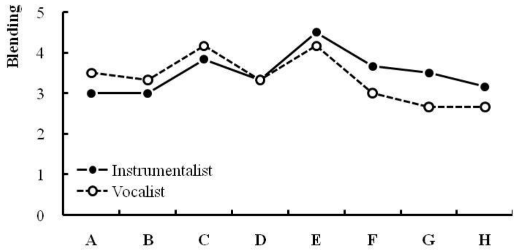
Figure 5. Scale value of performer's preference from the paired comparison test. (Solid box: the results of instrumentalists; Hollow box: the results of vocalists)

Results I: The paired comparison test

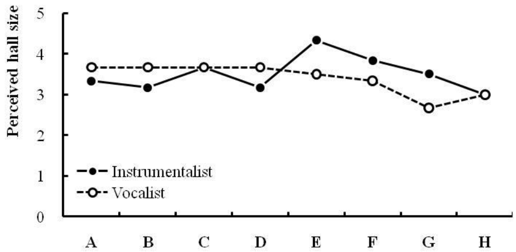
Individual responses of all subjects passed the consistency test, and the averaged values, separated by the performer type (instrumentalist and vocalist), passed the agreement tests. Figure 5 showes the results for scale value of preference from the paired comparison test. Position E (stage center) was most preferred for both instrumentalists and vocalists. Most subjects explained that the stage center gave the most balanced stage support with appropriate reverberance. However, it was found that the least preferred positions differ for instrumentalists and vocalists. Instrumentalists showed the lowest scale values of preference at the positions A and B (stage front), whereas vocalists showed the lowest scale values of preference at the positions G and H (stage rear).



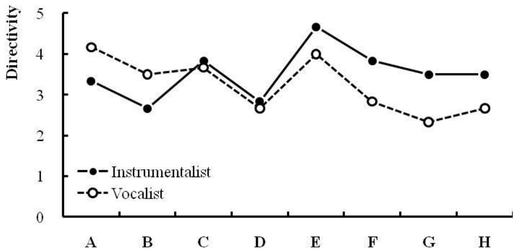
(a) Support



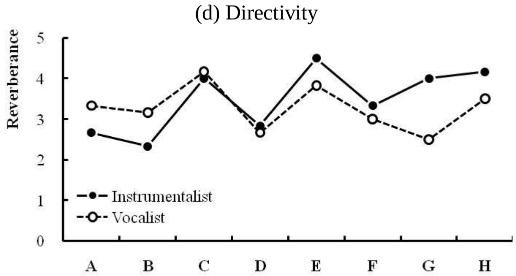
(b) Blending



(c) Size



(d) Directivity



(e) Reverberance

Figure 6. The results of subjective impressions from the 5-pt rating test. The solid circle indicates the results of instrumentalists, and the hollow circle indicates the results of vocalists

Table 2. Results of correlation coefficients between the results of the paired comparison test and the 5-pt rating test

Subjective impressions (5-pt rating test)	Scale value of preference	
	Instrumentalists	Vocalists
Support	0.79*	
Blending	0.98**	0.82*
Size	0.87**	
Directivity	0.85**	0.82*
Reverberance	0.73*	

(* p<0.05, ** p<0.01)

Table 3. Results of correlation coefficients between objective parameters and scale value of preference

Objective parameters	Scale value of preference	
	Instrumentalists	Vocalists
ST_{Late}	0.77*	0.82*
CS	-0.76*	-0.72*
$IACC_{E3}$		0.77*

(* p<0.05, ** p<0.01)

Results II: The 5-pt rating test

Figure 6 shows the results of the 5-pt rating test in which subjects evaluated the stage sound fields in terms of *Support*, *Blending*, *Size*, *Directivity* and *Reverberance*. As shown in Figure 6 (a), position E had the highest-rated perceived stage support, which is dissimilar to ST_{Early} values. The distribution range of *Support* was 0.8 for vocalists (2.8 to 3.7) and 2.2 for instrumentalists (2.5 to 4.7). This indicates that the instrumentalists are more sensitive to perceived stage support than vocalists. As shown in Figure 6 (b), (d) and (e), the positions E and C had the highest *Blending*, *Directivity* and *Reverberance* for both instrumentalists and vocalists. Instrumentalists reported relatively high *Blending*, *Directivity* and *Reverberance* at the rear stage (F, G and H), whereas vocalists reported high values at front stage (A, B and D) except for positions E and C. Perceived *Size* was similar to the perceived *Support* as shown in Figure 6 (c).

Results of correlation and regression analysis

Table 2 shows the correlation coefficients between the results of the paired comparison test and the 5-pt rating test. For instrumentalists, all 5 subjective impressions from the 5-pt rating test yielded significant correlations with the scale value of preference from the paired comparison test. Among them, it was found that *Blending* had the highest correlation (r = 0.98). However, in case of vocalists, only *Blending* and *Directivity* showed the significant correlations to the scale value of preference.

Through the multiple regression analysis, the prediction models of preference in terms of subjective impressions were derived according to the performer type as shown in Equations (1) and (2). As a result, it was found that *Blending* was the dominant factor to predict preference of stage sound fields for both instrumentalists and vocalists. However, it seems that some unrevealed factors such as visual impressions remained for vocalists' preference due to relatively low R-squared value of 0.67.

$$S.V._{Instrumentalists} \backsim 0.98\,(Blending) + C\ (R^2 = 0.95) \qquad (1)$$

$$S.V._{Vocalists} \backsim 0.82\,(Blending) + C\ (R^2 = 0.67) \qquad (2)$$

Correlation analysis was carried out to determine the connection between subjective preference and objective parameters. Table 3 shows the correlation coefficients between the measured acoustical parameters and the scale value of preference. ST_{Late} and CS were significantly correlated with the scale value of preference for both instrumentalists and vocalists. In case of vocalists, $IACC_{E3}$ was correlated to the scale value of preference additionally.

As results of the multiple regression analysis, prediction models of preference in terms of objective parameters were derived according to the performer type as shown in Equations (3) and (4). For instrumentalists, ST_{Late} was the dominant factor for preference judgment with R-squared value of 0.59. However, for vocalists, ST_{Late} and RT were found as the model factors with R-squared value of 0.93. ST_{Late} was common to both prediction models. This indicates that late reflections beyond 100 ms are essential to determine performer's preference on stage acoustics.

$$S.V._{Instrumentalists} \backsim 0.77\,(ST_{Late}) + C\ (R^2 = 0.59) \qquad (3)$$

$$S.V._{Vocalists} \backsim 0.87\,(ST_{Late}) + 0.50\,(RT) + C\ (R^2 = 0.93) \qquad (4)$$

CONCLUSION

In this study, the subjective and objective models of performer preference were investigated through field measurement and auditory tests. The existing stage parameter, ST_{Early}, ranged over 10 dB on a single stage. Stage acoustical parameters are diversely distibuted according to the measurement location. This study extended range of the measurable stage parameters to the room acoustical parameters such as RT, EDT, Ts and IACC. ST_{Early} was connected to Ts with the fixed source-to-receiver distance of 1 m, and RT, EDT and LF in case of the source on the soloist position.

The auditory test results emphasized that stage center is the most favourable for both instrumentalist and vocalist. However, the instrumentalists do not prefer the stage front area, whereas the vocalists do not prefer the stage rear area. This indicates the different perception model between instrumentalist and vocalist. Blending of played music and ST_{Late} were found as dominant factors in preference models. In this study, the subjective aspect of performer's preference was limited to evaluate the acoustic quality in hearing oneself. In further studies, mutual hearing will be examined, along with other types of concert halls, to develop the stage acoustical parameters

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