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Preferred positions for solo, duet, and quartet performers on stage in concert halls: *In situ* experiment with acoustic measurements

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A B S T R A C T

The relationship between the objective characteristics of the stage performance environment and the subjective impressions of musicians was investigated in two chamber halls with different architectural characteristics. In order to characterize the stage, acoustical and visual parameters were measured and representative parameters were derived using principle components analysis. Stage support (ST) parameters, such as ST_{Early} and $ST_{Late,}$ were selected as main factors and measured at various measurement positions on the stage according to ISO 3382-1. Subjective evaluations were also conducted to find the musicians' subjective impressions of acoustic conditions, including overall quality in solo, duet, and quartet performances during in-situ performances at six positions on the stage. Subjective evaluations indicate that the stage front is the most preferred position for musicians and the differences in response to the positions were less significant for a solo performance compared to those for duet and quartet performances. The relationship between ST parameters and subjective impressions was investigated using correlation and multiple regression analyses. From the results, it was found that the soloists' preferences increased but the quartet performers' preferences decreased under conditions with stronger early and late reflections.

1. Introduction

The investigation of stage acoustics for performer preference differs from the bulk of studies on auditorium acoustics, which are mainly concerned with the acoustical requirements of the audience [1,2]. Hence, the number of acoustical design guidelines for the stage area is quite low compared to the number of acoustical design guidelines for the audience area [3]. The optimum conditions may be unique for individual performers, instrument types, or ensemble arrangements [4–10]. Moreover, as the performer is both the source and receiver, the derivation of a single relevant parameter is difficult [11–13].

Investigations for defining the parameters for the evaluation of sound fields on a platform have been conducted with acoustical experiments since the late 1970s [14,15]. The preferred acoustical conditions for an ensemble were investigated using synthesized reflections of sounds in an anechoic room [14], while subjective tests with a small orchestra and objective measurements were carried out in an actual concert hall with variable stage settings [15]. Stage support (ST) was proposed as a parameter by Gade [16,17] based on both laboratory and field experiments. The definition of ST is straightforward (i.e., the energy ratio reflected energy to the direct sound energy, expressed in decibels), and the measurement procedure is relatively simple (i.e., an omnidirectional source and microphone). With a series of objective and subjective experiments, the stage acoustical parameters were improved to better relate acoustical design to perception for musicians [18–21]. Consequently, the revised ISO 3382-1 includes stage measurements of ST_{Early} and ST_{Late}, which are based on ST [22].

There are still some areas in which the interpretation of ST parameters can be improved. One is the consideration of the actual stage sound fields in deriving performer preference, and another is the consideration of the different needs of various types of musicians. Beranek suggested the preferred range of ST_{Early} based on field measurements and conductors' survey results [23,24]. However, stage acoustical conditions are very diverse, even within a single hall. The range of ST_{Early} that was measured using computer

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simulation and scale model was from −18 to −8 dB, for various hall conditions [25]. Therefore, it was proposed to create an open database of various subjective and objective data from actual halls, to encompass a number of degrees of freedom in hall design [26]. In order to improve the interpretation of ST parameters in musicians' preference, most previous studies used orchestral interviews and/or questionnaires as a subjective rating method to compare acoustical differences between the stages of concert halls [27–29]. However, owing to the difficulty of a subjective evaluation in such studies tends to be based on the musicians' remembered experience in the hall. Furthermore, the music played by the orchestra in a hall may be diverse and complex, involving sound produced by many musicians together – so the specific phenomena influencing responses may be hard to glean. By contrast, some researchers have used laboratory experiments involving simulation systems to control acoustical conditions to investigate the influence of ST parameters on musicians' perception [4–6,30]. However, these systems may still lack of realism due to considerable difficulties in simulating real time sound fields where the performer is both the source and receiver, and also laboratory test rooms (usually anechoic rooms) are visually very different to auditoria and this could bias results. There are also considerable logistical problems in conducting controlled laboratory studies involving more than one or two musicians. A hybrid approach, drawing on laboratory methods, but conducted in real auditoria, can ensure realism while providing more specific information than the more usual questionnaires and interviews, similar to previous studies on audience areas [31,32], would be the most effective way to evaluate the performer's stage impressions. While none of these methods provides a complete solution, understanding of the effects of stage acoustics can be advanced by research following these methods, interpreted by considering the advantages and limitations of each.

In this study, the stage acoustics of two chamber halls were evaluated objectively and subjectively for solo, duet, and quartet performers. Objective measurements included the stage support and other room acoustic parameters. Subjective tests to evaluate musicians' impressions were conducted in the actual hall and were related to the objective measurement results. Based on an analysis of the results, relationships between the objective parameters and subjective preferences were investigated.

2. Method

2.1. Objective measurements

2.1.1. Hall descriptions

The halls investigated in this study were Sejong chamber hall (Hall A) and Baeknam hall (Hall B) for recitals in Seoul, with about 500 seats. The architectural data for the two halls are shown in Table 1, below. The definitions of the geometrical parameters are provided by Beranek [23] and Gade [26].

Hall A has a seating capacity of 443 includes a gallery, has a volume of 2700 m^3 and a reverse fan shaped plan, as shown in Fig. 1a. The configuration of auditorium is as follows: the average length is 18.8 m, the width is 13.1 m, and the minimum and maximum heights are 7.0 m and 10.0 m, respectively, due to the open ceiling which was renovated to provide more volume for the auditorium. The values of L/W and H/W are 1.4 and 0.5, respectively. The configuration of stage is as follows: the stage floor area is 74 m^2; the average depth is 6.6 m; the average height is 6.0 m, which is similar to the level of the open ceiling of the auditorium; and the range of widths is from 9.6 m to 13.5 m. The average height and depth are almost same. The angle between the side walls on stage is 36°. The stage enclosure has saw-tooth shaped diffusers as shown in Fig. 2a. The unoccupied reverberation time in the audience area is 1.0 s in the mid-frequency bands.

Hall B has a seating capacity of 585 with an audience area that includes a second floor with rear balconies, as shown in Fig. 1b. It has a volume of 3600 m^3. The configuration of auditorium is as follows: the average length is 14.2 m, minimum and maximum widths are 10.9 m and 26.8 m, and the heights are 7.3 m and 8.4 m. The value of L/W is 0.8 and the shape of Hall B is a reverse fan type, similar to a lozenge, which produces the small H/W of 0.4. The stage of Hall B has ceiling reflectors and the configuration of the stage is as follows: the stage floor area is 134 m^2; the average depth is 9.7 m; and the average height is 6.1 m, which is similar to the stage height of Hall A; and the range of widths is from 5.5 m to 17 m. The angle between the side walls on stage is 90° due to the plan shape of the hall. The stage enclosure has acoustic shell type panels as shown in Fig. 2b. The unoccupied reverberation time in the audience area is 1.2 s in the mid-frequency bands.

2.1.2. Room acoustic conditions

The stage acoustical parameters for the two halls were measured according to the ISO 3382-1 [22] standard on an empty stage. The measurements were conducted with an omnidirectional loudspeaker (B&K type 4296) and omnidirectional microphones (B&K type 4189). As shown in Fig. 3, measurement positions were selected such that they could cover the whole stage area on one side of the mid-line (9 and 12 positions) in a rectangular grid with intervals of 2 m horizontally and 1.5 m and 2 m longitudinally in Hall A and Hall B, respectively. All measurement positions were at a distance of more than 2 m from the walls and objects. In case some positions along the line that were 2 m far from the wall, the receivers considered them not to be arranged within a 2 m distance from the walls.

Stage support parameters (ST parameters) were derived from the impulse responses measured on the stage. The distance between the sound source and receiver was 1 m, with a four point cruciform orientation, and the measurement height was 1.5 m from the stage floor. Acoustical parameters were calculated from the measured impulse responses: ST_{Early}, ST_{Late}, T20, EDT, and BR. ST_{Early} was defined as the logarithmic ratio between the early reflection energy (20–100 ms) and the direct sound energy (0–10 ms). The

Table 1
Geometrical parameters of hall A and hall B.

Hall	Auditorium dimensions					
	Length (m)	Width (m)	Height (m)	L/W	H/W	Volume (m^3)
A	18.8	13.1	7.0	1.4	0.5	2700
B	14.2	18.4	7.8	0.8	0.4	3600
Hall	Stage dimensions Depth (m)	Width (m)	Height (m)	Stage volume (m^3)	Area (m^2)	Pwall angle (°)
A	6.6	11.6	6.0	447	74	36
B	9.7	11.2	6.1	663	134	90