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Acoustic evaluation of orchestra occupancies in concert halls: Effect of sound absorption by orchestra members on audience acoustics

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ABSTRACT

This study investigated changes in the reverberation time at concert hall seats due to the sound absorption of orchestra musicians. Different percentages of musician-occupied areas and densities of the musicians were analyzed on the stages of two 1:10 scale concert hall models. Increasing numbers of musicians was associated with a significant increase in the early-to-late sound index and a significant decrease in the reverberation time at the seats. The effects of volume and absorption coefficients associated with the presence of musicians were investigated in simple computer simulations of shoebox and fan-shaped halls. The results revealed that changes in the orchestra absorption ratio had a greater effect on the reverberation time at the seats than that of the total sound absorption. Therefore, for any given number of musicians in the scale model, the reverberation time at the seats decreased as the percentage of the stage area occupied by the orchestra increased. The reverberation time decreased by more than 0.5 s when the occupied area reached 90%. Furthermore, computer simulations of 12 concert halls showed that the reverberation time at the seats varied in relation to the orchestra absorption ratio.

1. Introduction

Concert hall acoustics would be ideally evaluated with musicians and audience members occupying the space in the same manner as during an actual performance. However, ISO 3382-1 requires that the seat occupancy status and measurement conditions be described in the test report because acoustic measurements are generally performed in an empty hall [1]. In fact, scale models are often used to investigate the sound absorption status around the sound source. In one such scale model experiment, Barron and Lee [2] found that the sound pressure at the seats was 1.3 dB less when the hall was empty than when it was fully seated. Furthermore, when Jeon and Barron [3] placed orchestra musicians on the stage in a scale model experiment, they found that the sound reflection from the rear wall of the stage was reduced by the musicians, but that the reduction was offset by the sound reflection from the bodies of the musicians. Dammerud and Barron investigated the sound propagation in an orchestra [4] and discovered that wider spacings between musicians increased the attenuation of high-frequency sounds. Beranek and Hidaka [5] calculated the total sound absorption (S_T) in a concert hall with musicians onstage; however, they neglected to address the effect of the sound absorption by musicians on the sound field of the concert hall. Studies on concert hall acoustics that consider the presence of musicians have been conducted using actual concert halls and scale models [6,7], as well as computer simulations [8,9].

The audience's perception of orchestral performances has also been researched. Galiana et al. [10] examined the differences in acoustic perceptions of experts and nonexperts in an actual concert hall, and Gimenez et al. [11] investigated the correlations between room acoustic indicators and the perceptions of audience members in the seats, again in an actual concert hall. Jeon et al. [12] studied the preferences of orchestral musicians depending on their placement on the stage; however, this study did not address the sound absorption effects on audience acoustics according to the musicians' stage occupancy.

The seats, audience, and musicians all commonly have high sound absorption factors, and the number of audience members in the seats has the largest effect on reducing reverberation in a concert hall. Initial studies on the sound absorption by audience members in concert halls were conducted by Beranek et al. who studied the effects of fully occupied seats [5,13,14]. To predict the reverberation time (RT) in the design of a concert hall, Beranek and Hidaka [5] classified upholstered chairs as having light, medium, or heavy upholstery, and regarded the audience as one block because of the uniform spacing and high density of individual members. Other studies [15–17] also investigated the correlations between laboratory measurements and predicted values. To quantify the sound absorption of seats and audiences, ISO 354 [18]

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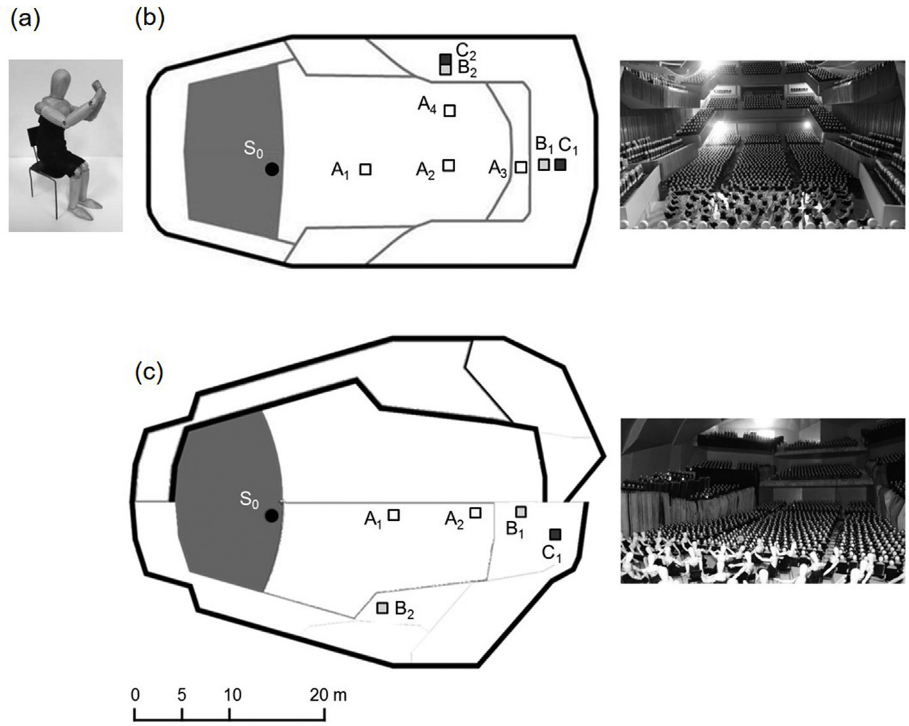

Fig. 1. (a) Configuration of the 1:10 scale model musician. (b) and (c) Floor plans of the 1:10-scale model halls with source (S_0) and receiver positions in (b) Hall A and (c) Hall B. A_n, B_n, and C_n indicate the receiver positions on the main floor, the first balcony, and the second balcony, respectively.

assigns an equivalent sound absorption area of the seats based on the number of seats. However, to calculate a room's acoustic parameters by computer simulation, the sound absorption area of audience seats must be converted to an absorption coefficient for the area of the floor that is occupied by chairs. These absorption coefficients, which are measured with various chair arrangements in the reverberation chamber and used to calculate the absorption coefficients of audience seats, have shown a linear relationship with the actual perimeter/area (P/A) [19]. In addition, the actual measured RT value has been found to match well with the absorption coefficient in a concert hall because the RT value reflects the difference in the total volume of the concert hall due to the sound absorption of the seats, which is predicted by considering the audience as a single seating block [20,21]. However, the P/A method requires repeated measurements to predict the various sound absorption amounts associated with the distinct P/A ratios of different samples. Therefore, to determine the absorption coefficient of an orchestra, the absorption coefficients of seats in a reverberation chamber must be measured for different arrangements, because although the absorption coefficient per seat is constant, the absorption coefficient is also affected by the spacing between seats [16,22,23].

However, musicians and audience members present different sound absorption characteristics, such as seating arrangement, number of exposed edges, and distance from the sound source. Just as the sound absorption of the seats occupied by the audience is influenced by the absorption coefficient of the chairs, the effect on sound absorption of the onstage musicians varies in relation to the size of the empty stage, which constitutes a reflective floor. According to Barron [24], an orchestra of 100 musicians, including percussion instruments, occupies an area of approximately 150 m^2. Therefore, an almost 200-m^2 stage is required to accommodate solo musicians and percussion instruments, as well as a 1-m-wide empty space in front of the stage and additional spaces for the stage riser and access ways. Therefore, to investigate the effects of musicians on concert hall acoustics, the absorption coefficient of the musicians who occupy most of the stage area must be included in the calculations.

In this study, to evaluate the acoustics of a concert hall that is fully occupied by both musicians and audience members, the absorption coefficients associated with the musicians were measured with various musician arrangements in a reverberation chamber, using two 1:10 scale concert hall models [25,26] and 10 computer simulations of actual concert halls. The effects of the sound absorption of musicians on acoustic parameters in the audience were investigated according to various sound absorption characteristics, space volumes, and numbers of musicians, and the measurement data from the two experimental models were also applied in additional computer simulations.

2. Scale model

In architectural acoustic design, 1:25 or higher scale models have been used to evaluate the acoustic effects of complex shape factors such as organs or diffusers in concert halls [27,28]. In this study, the absorption coefficient of musicians fabricated as 1:10 scale models were first measured in a reverberation chamber, and then the sound absorption effects of the presence or absence of musicians on the acoustic indicators at the concert hall seats were investigated using a 1:10 scale model of a concert hall.

2.1. Model musician and hall

The absorption coefficient of orchestra musicians was measured in accordance with ISO 354 [18]. First, to consider the number of orchestra musicians and the types of instruments on the concert hall stage, the average stage area per musician was set at 1.9 m^2 based on Beranek [29], and for the sound absorption surface area per cello musician, the equivalent sound absorption area was set at 2.3 m^2/person based on Harwood and Burd [30]. The musician model was constructed based on these values as shown in Fig. 1(a); extrapolated to life size, this model would have a waist measurement of 0.35 m, a shoulder measurement of 0.55 m, and height of 1.35 m when seated. The bodies of the 1:10 scale musicians were fabricated of wood, and their chests and upper legs were wrapped with 1-mm-thick fabric. The chairs of the musicians were made of polyurethane plastic sheets and iron wires. The