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ROOM ACOUSTICS PREFERENCE OF SOLO SINGERS FOR MASTERING A PIECE—EXPERIMENTS USING "SOUND CASK": A 3D SOUND FIELD SIMULATION SYSTEM—

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ABSTRACT*

An appropriate acoustic environment is necessary in music practice rooms, and the preferred room acoustic conditions vary depending on various factors such as proficiency level, motivation, and contents to be practiced. In this study, we focused on practice elements that vary during the process of mastering a piece and investigated the preferred room acoustic conditions of solo singers for practice. To study the room acoustic condition "Sound Cask", a 3D sound field simulation system based on the boundary surface control principle, was used. First, an interview survey was conducted to understand the structure of the practice elements in the singers' process of mastering a piece. As a result, a three-step process was identified. The first is score reading, second is exploration of expression, and third is the ensemble and stage performance. Subsequently, a subjective experiment was conducted to evaluate three different room acoustic conditions (short, moderate, and long reverberation time) by asking the singer to play an assigned phrase of a piece considering the three-step process in each acoustic condition. Consequently, it was confirmed that the preferred acoustic conditions were changed during the process of mastering a piece.

Keywords: *Room acoustics, Music practice room, Musicians' preference, Sound field simulation*

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1. INTRODUCTION

An appropriate acoustic environment is necessary in musical performance and practice, and the preferred room acoustic conditions vary depending on various factors such as proficiency level, motivation, and contents to be practiced. A previous study on piano performance examined the correspondence between the changes in practice elements and the appropriate conditions for reverberation time in the process of mastering a piece [1-3].
In this study, we focused on practice elements that vary during the process of mastering a piece and investigated the room acoustic conditions preferred by solo singers for practice. Singers, whose own body is the instrument, are assumed to be considerably affected by reverberation in terms of physical load. We used "Sound Cask," a 3D sound field simulation system based on the boundary surface control principle, to present room acoustic conditions.

2. EXPERIMENTAL SYSTEMS

2.1 SOUND FIELD SIMULATOR

The BoSC system [4] was used to record and reproduce the room acoustic condition. The BoSC system comprises the BoSC microphone system (80-channel fullerene-shaped microphone array) and the reproduction room, namely, the "Sound Cask" (96 full-range loudspeakers (*FOSTEX FE103 En*) are installed on the walls and ceiling). In the BoSC system, the inverse filter (H_{ij}) was determined by an inverse system of a transfer function matrix measured for each loudspeaker and microphone pair.

In this study, we used the Sound Field Simulator to practice an ensemble of a solo musician and a piano accompanist. As data for the original sound field, the transfer function ($[w]_{A\text{-}A}$, Fig. 1) was measured from the position of the performer's instrument (source point A) to the position of his/her head (receiving point A). The transfer function ($[w]_{B\text{-}A}$, Fig. 1) was also measured from the position of the piano (source point B) to that of the performer's head (receiving point A). A dodecahedral omni-directional loudspeaker (*Brüel & Kjær Type 4292*) was used as the sound source, and a BoSC microphone was used for recording.

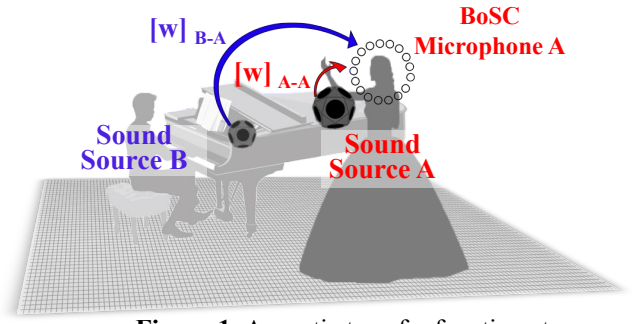

Figure 1. Acoustic transfer function at the sound field reproduction

2.2 EXPERIMENTAL SETUP

(1) Construction of experimental system

Figure 2 shows the experimental setup of the Sound Field Simulator. To simulate the room acoustic condition, we used a system mentioned in a previous study [5]. First, a directional microphone (*RODE, NTG-2*) was used to capture the performed sound inside the "Sound Cask" in the system. Then, a set of filters, which was processed by the inverse filter (H_{ij}) and the transfer function ($[w]_{A\text{-}Aj}$, except for the initial 14 ms), was convolved with the performance sound in real time. The sound was then played through a 96-channel loudspeaker array installed inside "Sound Cask." Using a part of the sound field reproduction and sharing system from a previous study [5], we constructed a system that can present piano accompaniment sounds to the performer (piano accompaniment ensembles) in the "Sound Cask." The electronic piano sound signal (*YAMAHA NP-11*) played by the accompanist passed through a filter processed by the inverse filter (H_{ij}) and transfer function ($[w]_{B\text{-}Aj}$). The sounds were then played through a 96-channel loudspeaker array, and the performer could listen to the piano sounds. The piano accompanist listened to the performer's sounds collected by a microphone installed in the "Sound Cask" and the piano sounds using a headphone (*SENNHEISER HDA300*).

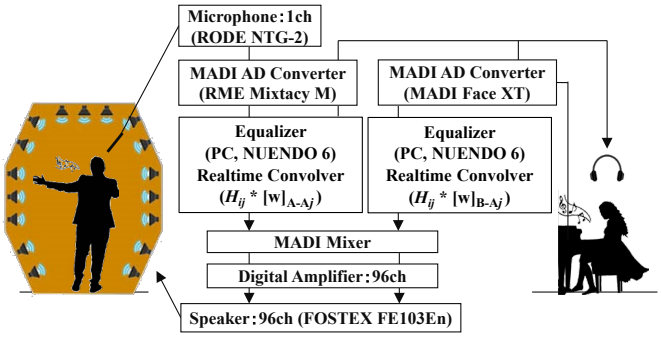

Figure 2. Systems for the Sound Field Simulator

Table 1. Acoustic conditions

Acoustic conditions	Sound Field	Capacity (Seat)	Volume [m^3]	Reverberation time [s]
condition 1	Music studio	–	43	0.4
condition 2	Small hall	492	5800	1.2
condition 3	Large hall	1114	12700	2.1

Condition 1: Music studio

Condition 2: Small hall

Condition 3: Large hall

Measuring scenery

Figure 3. Sound field and measuring scenery

(2) Experimental acoustic conditions

We measured the impulse response at the center of the reproduced sound field (H=1.5 m) to confirm the early reflection pattern (echo time pattern), reverberation time, and reverberation sound energy as an index to adjust the sound level. In order to reproduce typical room acoustic conditions for performance experiments,

we prepared three experimental conditions: music studio (Condition 1), small hall (Condition 2), and large hall (Condition 3). Table 1 shows the parameters of the original sound fields, and Fig. 3 shows a photograph of them.

3. EXAMINATION OF PROCESS OF MASTERING A PIECE OF SINGERS

3.1 METHODS

We conducted an interview survey to understand the structure of the practice method of singers in the process of mastering a piece. An interview survey was conducted with five singers (two professionals, two amateurs, and one vocal teacher) using the following procedure.

(1) Practice method in the process of mastering a piece: Focusing on the practice of the process by singers, each participant was asked to list "how to practice during their process from first sight of a piece (sight-reading) until just before the concert performance (just before concert)."

(2) Understanding the duration of each practice element: From the practice listed in (1), we aimed to understand the period and contents that singers are conscious of during the process from "sight-reading" to "just before concert." We asked participants when they practice each element in the process, setting the process as 1～10 (1: "sight-reading" and 10: "just before concert"). We asked them to fill in the range of the timing of doing or being conscious of each practice element.

3.2 RESULTS

In the practice obtained from all participants, 16 elements (excluding stretching, vocal exercise) related to the process of mastering a piece were analyzed as practice elements. In order to classify the duration of the practice elements, a cluster analysis (K-means method) with non-standardized Euclidean Square Distance was performed for the two variables of "Start" and "End." Then, we divided the data into three clusters.

Based on the above results, we defined Cluster 1 as "Step 1: Score reading," Cluster 2 as "Step 2: Exploration of expression," and Cluster 3 as "Step 3: Ensemble and concert performance" (Tab. 2 and Fig. 4). Then, practice elements that were expected to be affected by reverberation were extracted from each step. They were presented to the participants as typical practice elements in the performance experiment conducted in the next chapter.

Table 2. Practice elements of the process of mastering a piece

Cluster	Type of practice	Start	End	Distance
1	Seeing and playing piano accompaniment a music piece	1.0	1.0	3.14
	Listening to music (model performance)	1.0	3.0	0.33
	Reading score and taking note	1.0	2.4	0.69
	Understanding and confirming lyrics	1.0	3.5	0.35
	Understanding the composer's background	3.7	4.7	4.13
	Singing (a cappella)	2.3	4.7	1.54
2	Practicing language and pronunciation	1.5	6.5	1.52
	Considering the structure of a piece	4.0	6.3	3.59
	Understanding a music	1.0	10.0	3.62
	Putting lyrics to sound	1.0	7.0	1.55
	Practicing performance technique	3.0	9.0	1.09
	Adding expression to performance	3.0	8.6	0.67
3	Memorizing music and lyrics	5.0	6.7	4.85
	Making ensemble with an accompanist	5.8	9.4	0.99
	Having consciousness of a concert hall	8.0	9.0	0.95
	Rehearsal	8.6	10.0	2.99

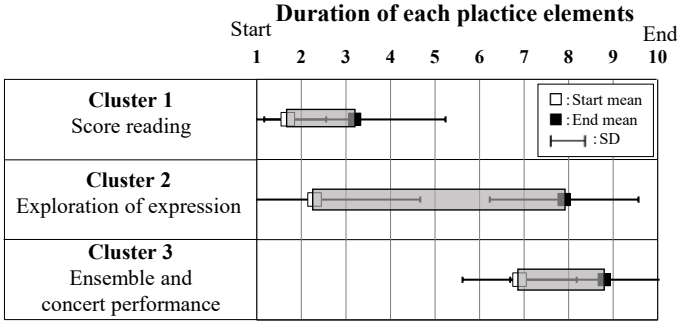

Figure 4. Duration of each practice elements

4. PERFORMANCE EXPERIMENT

4.1 METHODS

In order to clarify the appropriate room acoustic conditions for the singers' practice elements, performance experiments were conducted in the reproduced sound fields (condition 1-3) shown in section 2. Under each condition, the participants practiced based on the practice elements in the process of mastering a

Figure 5. Experimental and interview

Table 3. Music pieces used in the experiment

Pieces	Title of pieces	measure
A	Piacer d'amor	4～12
B	Lascia ch'io piaanga	13～34
C	Caro mio ben	5～13

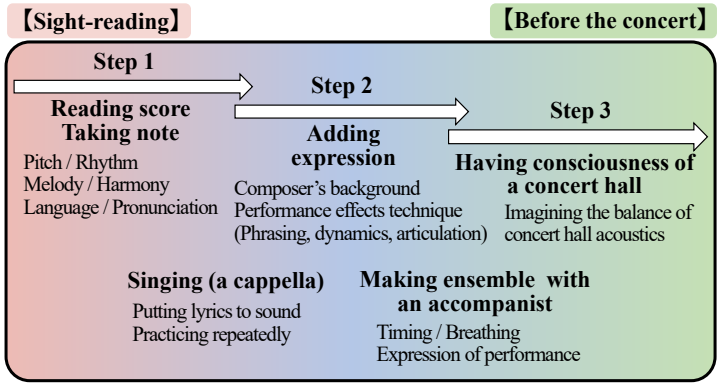

Figure 6. Process of mastering a piece

piece shown in Section 3. The experimental scene is shown in Fig. 5. Three singers (two professionals and one amateur; 6~36 years of experience) and four choralists (students who belong to a choral circle; 6~9 years of experience) participated in this experiment. In the next section, the former will be denoted as "singers" and the latter as "choralists."

The participants practiced one of the three typical phrases from the "*ARIE ANTICHE ITALIANE 1*" shown in Tab. 3, from "sight-reading" until "just before concert" in each acoustic condition. Music pieces were selected based on the following points: "easy to have the flow of the music, slowly tune, and a phrase of about 30 seconds." The order of acoustic conditions and pieces to practice were randomly assigned to the participants.

We presented "process of mastering a piece" (Fig. 6) and checked for any differences in recognition, followed by the visual image of room acoustic conditions to the participants before beginning the experiment. The participants performed a complete set of practice in accordance with the "process of mastering a piece" in each acoustic condition, and were asked to evaluate each condition. We set a practice time of 15-20 minutes in each experimental condition. After the practice under each experimental condition, the participant was asked to rate evaluation items shown in Tab. 4 on a 7-point scales. The above procedure was repeated in the three conditions.

During the experiment, the participant and piano accompanist (an experimental assistant) communicated with each other. In addition, after the experiments, the participant was asked "which condition was the best to perform practice of each step" and "How they would like to utilize "Sound Cask" for their practice."

Table 4. Items used to evaluate each condition

No.	Evaluation item
Q1. Ease of practice in each acoustic condition (7-point scale, 1: "Disagree" - 7: "Agree")	
1	**Taking note**: Easy to take note of a piece
2	**Pitch**: Easy to check for correct pitch
3	**Rhythm**: Easy to check for correct rhythm
4	**Pronunciation**: Easy to pronounce of words
5	**Singing** (a cappella): Easy to practice run-through
6	**Expression** (Phrasing / Dynamics / Articulation
7	**Making ensemble with an accompanist** (Timing / Breathing / Expression of performance)
8	**Consciousness of a hall**: Easy to imagine the performance in a concert hall
Q2. Impression of the sound field when you performed (7-point scale, 1: "Not at all" - 7: "Very much")	
9	**Reverberation**: Degree of reverberation
10	**Enjoyment**: Enjoying performance in the sound field
11	**Comfort**: Feeling good reverberation for performance
12	**Fatigue**: Getting tired to practice with the condition

4.2 RESULT AND DISCUSSION

Ease of practice elements and impression of acoustic fields: Figures 7 and 8 show the results of evaluation of "Ease of practice" and "Sound field of impression." In Fig. 7, result shows "singers" and "choralists" have characteristics in their evaluation of the ease of practice in each acoustic condition. Through overall tendency, the basic practice elements such as "Taking note," "Pitch," "Rhythm," and "Making ensemble with an accompanist" evaluated high in condition 1, while "Run-through a piece," "Expression," and "Having

consciousness of a concert performance" were evaluated high in conditions 2 and 3. Previous study indicated that singers rely on both external auditory feedback and proprioceptive feedback associated with internal voice sensitivities [6] and pitch inaccuracy in singers is affected by the level of the external auditory feedback and the level of training [7]. The result that Condition 1, with less reverberation, was preferred during the basic practice phase may be related to the fact that reverberation is an external auditory feedback that affects the accuracy of the performance. As the sound field reverberation becomes longer (from condition 1 to 3), the evaluation for basic practice elements and making ensemble with the accompanist goes down in choralists, which is different from singers. This can be related to the fact that choralists are more susceptible to external auditory feedback than singers, which has been confirmed in the previous study [8].

Figure 8 shows that there was a similar tendency between singers and choralists in the evaluation item of "Reverberation", "Enjoyment", and "Comfort", while the results differed in terms of "Fatigue". It was supposed to be caused by the fact that choralists have fewer opportunities to perform

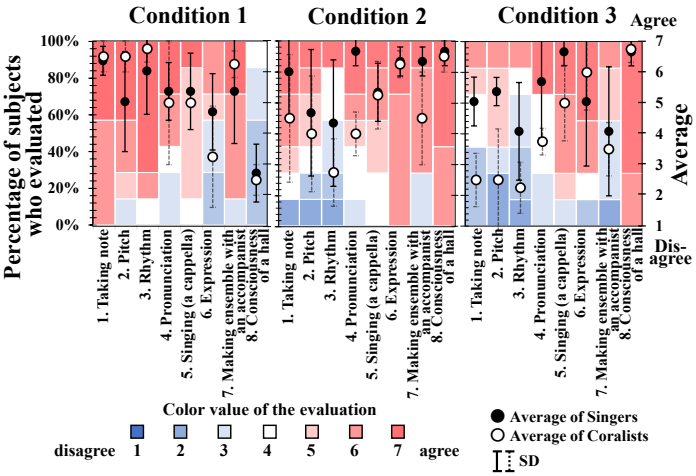

Figure 7. Ease of practice in each acoustic condition

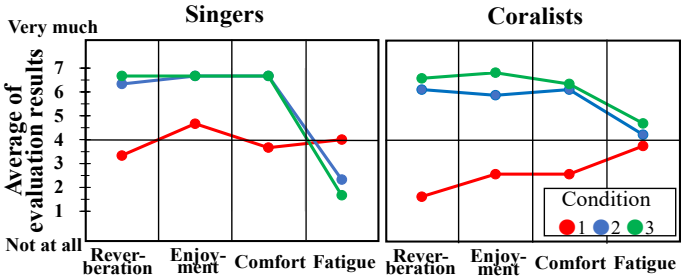

Figure 8. Impression of the sound field

Table 5. Comprehensive evaluation and comments (Singers: A, B, C Choralists: a, b, c, d)

Step Evaluation	Practice	Condition 1	Condition 2	Condition 3
1 7	Taking note Pitch Rhythm Pronunciation	Easy to check for correct pitch (A, a) I'm not disturbed by reverberation (a,b) The contours of my voice and rhythms are clear (a, d) Easy to check for correct note-lengths (B, d) Easy to plan a schedule for practice (C)	Difficult to concentrate (B, a) I can listen to my voice too good by reverberation (c) I can hear my own voice, also sing easily (A) Easy to sing and pronounce with reverberation (A)	Difficult to concentrate and to correctly practice (B, a, b) Difficult to take with rhythm (d) Difficult to listen to consonants because of reverberation (A, B) Easy to listen to the vowels because of reverberation (d)
	Singing (a cappella)	Feels like bored practice (c)	Easy to catch the flow of music with reverberation (A)	Easy to catch the flow of music with reverberation (A)
2 1 6	Expression	Easy to be conscious of accuracy, but difficult to explore the expressions (b, c) Hard to practice without reverberation (b) It is difficult to imagine the reverberation (a)	The reverberation supports the singing (b) The reverberation is not too much, so it is effective to practice (A, C, d) Easy to phrase a piece and add dynamics with reverberation (c, d)	A little difficult to make expression because of too much reverberation (C, a, d) I can listen to my voice very well because of reverberation (c) I feel like just playing (B) Easy to sing emotionally and add expression for performance effects (A)
3 1 6	Making ensemble with an accompanist	Easy to be conscious of consonants and match them with vowels (B) Easy to match the timing and Breathing with piano accompanist (B,c) I can check accuracy (c)	Easy to match timing, breathing, and expression with the accompanist (b) Easy to practice the ensemble in the middle reverberation place (A, d)	Difficult to match timing with the accompanist because of too much reverberation (A,B,C,b) Easy to imagine expressions with the accompanist like in concert hall performances (A)
	Having consciousness of a concert hall	Difficult to imagine the concert hall performance (b) Difficult to be conscious of expression with performance effects (b. c)	Easy to be conscious of the concert hall performance (A, b) Condition 2 doesn't have enough reverberation (B)	Easy to imagine the balance of concert hall acoustics (A, C, a) Easy to imagine my own expression sounds in the concert hall (B, C, a, b)

※■Condition 1, ■Condition 2, ■Condition 3, / ( ): Subjects No. / Red: Positive comments, Blue: Negative comments

in solo in concert halls, compared to singers.
Table 5 shows that comprehensive evaluation and comments about "which condition was the best to perform practice of each step" by each participant. These comments showed good agreement with "ease of practice" (Fig. 7). In Step 1, condition 1 was preferred, and we have obtained comments about accuracy such as "It's easy to practice correctly not being affected by reverberation." On the other hand, condition 2 and 3 were not preferred. For these conditions, we have obtained comments such as "I can't concentrate" and "I can listen to my voice too good because of reverberation." In Step 2, condition 2 was preferred and we have obtained comments such as "It's easy to make expression (phrasing, dynamics, articulation etc.)" On the other hand, comments such as "I can't be conscious of the exploration of expression" were obtained in condition 1, and "It's too much reverberation" and "I feel like just playing" were obtained in condition 3. In step 3, condition 3 was preferred and we obtained comments such as "I can imagine how to make my voice sound in a concert hall." On the other hand, we also received comments that "conditions 1 and 2 would also be necessary when we make adjustment of timing and expression with the accompanist." These comments were obtained from both singers and choralists.

Utilizing "Sound Cask" for practice: Regarding the possibility of utilizing "Sound Cask" in daily practice for the process, the participants' comments indicate that "Sound Cask" would be useful in steps 2 and 3, but would not be necessary in step 1. This is because participants do not require any particular reverberation in step 1, and their familiar practice space is appropriate. On the other hand, in step 2 and 3, the participants could make use of "Sound Cask" to "confirm expression with reverberation" and "have consciousness of performing in concert hall."

5. CONCLUSION

In this study, a performance experiment was conducted to clarify the relationship between practice elements and room acoustic conditions in the process of singers mastering a piece. As a result, the acoustic conditions preferred for each practice step were indicated. It was also shown that the utilization of "Sound Cask" for the latter process of mastering a piece (after step 2 "exploration of expression") was effective. As a future work, we would like to propose the 3D sound field simulation system that can present the preferred acoustic environment for practice of various performers.

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