EXPERIMENTAL STUDY ON THE EVALUATION OF STAGE ACOUSTICS BY MUSIC PLAYERS USING 6-CHANNEL SOUND SIMULATION SYSTEM

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Ueno Kanako; Tachibana Hideki
Institute of Industrial Science, University of Tokyo
Komaba 4-6-1, Meguro-ku, Tokyo
153-8505
Japan
Tel: +81-3-5452-6425
Fax: +81-3-5452-6426
E-mail: ueno@iis.u-tokyo.ac.jp

ABSTRACT

In order to investigate the effect of hall response on players, subjective tests on professional music players were performed in an electrically simulated sound field. As the experimental system, the 6-channel sound simulation technique was contrived in which the 6-channnel directional impulse responses measured in real halls are used to synthesize the test sound field. In the subjective experiment, the subjects (players) performed several types of notes and responded to the questionnaires. From the result of the experiment, relationship between subjective judgments and acoustical properties of the sound field was examined.

INTRODUCTION

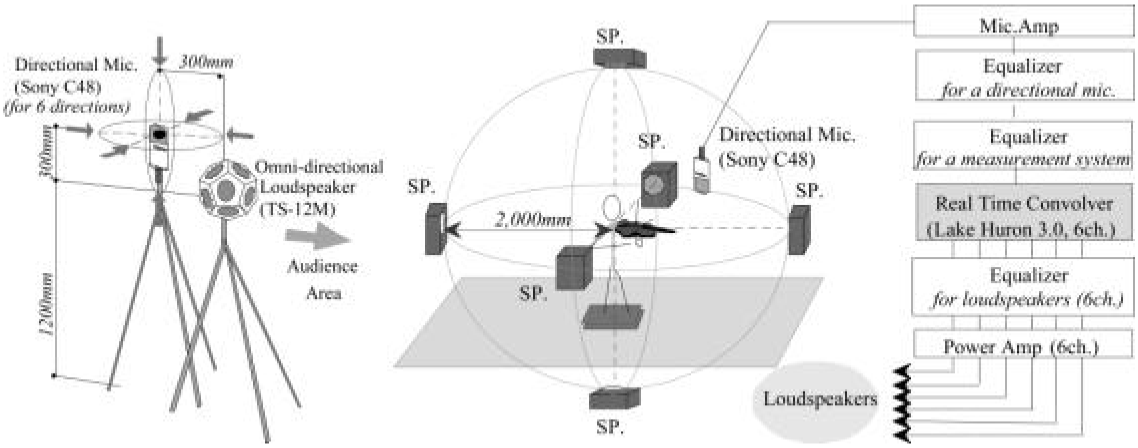
In concert hall acoustics, the acoustical requirements for music players should be considered as well as those for the audience. On this topic, subjective evaluation of stage acoustics, laboratory experiments in which the acoustic conditions can be changed freely and rapidly are quite effective and these experiments were conducted by several researchers [1-3]. In these experiments, however, sound field was simply modeled and therefore the sound quality and fidelity were limited.
In order to make the experiment on musicians with natural impression as actually being on a stage, a 6-channel sound field simulation system has been developed. In this paper, the simulation technique is introduced and a subjective experiment on professional music players performed by applying the system is presented.

EXPERIMENTAL SYSTEM

As a reproduction system of the actual sound fields with 3-dimentional information, authors have contrived a 6-channel sound field simulation system [4]. In the application of this technique to stage acoustics, the sound of a musical instrument being played are convolved with directional impulse responses in six orthogonal directions measured on the stage of real concert halls and are presented to the subject, player, in the simulated sound field.

<u>Basic System</u> Figure 1(a) shows the arrangement of the sound source and the microphone for the measurement of impulse responses at the player's position on a stage. This arrangement was determined by simplifying the geometrical relationship between a player and his/her

musical instrument. A dodecahedral loudspeaker system (TS-12M) with omni-directional characteristic up to 2k Hz is located at a representative position on the stage. An uni-directional microphone (Sony C48) is located at a point close to the sound source and directional impulse response is measured six times by rotating the microphone in 90-degree increments. To get the room acoustic indices, monaural impulse response is also measured at the receiving point using an omni-directional microphone. These measurements were executed by the "time stretched pulse" method.



(a) Measurement on stages (b) Sound field simulation in an anechoic room

Fig. 1.- Outline of the 6-channel sound field simulation system

The simulated sound field is constructed in an anechoic room of 7 cubic meters in dimension (See Fig. 1(b)). The dry music signal from the subject's instrument is convolved with six-channel directional impulse response signals with duration of 2.7 s (from which the direct sound from the sound source and the reflection from the stage floor are excluded) using a 6-channel real-time digital convolution system (Lake, Huron 3.0). The dry music is detected using an uni-directional microphone (Sony, C48) set at a point close to the subject in the simulated field. The convolved signals are reproduced through six loudspeakers (TANNOY, T12) arranged on a spherical surface of 2 m radius in the anechoic room.
Regarding reproduction accuracy of the system, the experimental studies were performed by comparing the echo diagram and acoustic indices between the results measured in the original sound fields and those measured at the center position in the simulated field. As a result, considerably good agreement has been found in the physical characteristics between the real and the simulated sound fields [5].

<u>Modification of the System</u> In this study, it was aimed to examine the effect of early reflection, reverberation and late reflection, separately. For this aim, the 6 directional impulse responses measured in a concert hall (1,702 seats, volume:17,800 m^3, reverberation time in mid. frequency:2.3 s) with fairly smooth transient characteristic were adopted as the standard impulse response signals, and they were divided into these three parts. As shown in Fig.2, each part was changed artificially in steps to set the experimental conditions as mentioned below.

<u>Early Reflection</u> The time span of the early reflection was defined to be early 100 ms excluding the direct sound and the reflection from the floor. Since our previous research indicated that the effect of early reflection on players on the stage is very subtle [6, 7], the waveform of the early reflection which starts at 50 ms after the direct sounds was fixed and its energy level was changed in three steps in this study (see Table 1).

<u>Reverberation</u> For the reverberation process, the signals between 100 ms and 2,702 ms of the standard impulse response signals were used and they were modified by multiplying exponential functions to change the reverberation time in three steps (1.6 s, 1.9 s and 2.2 s, see Table 1).

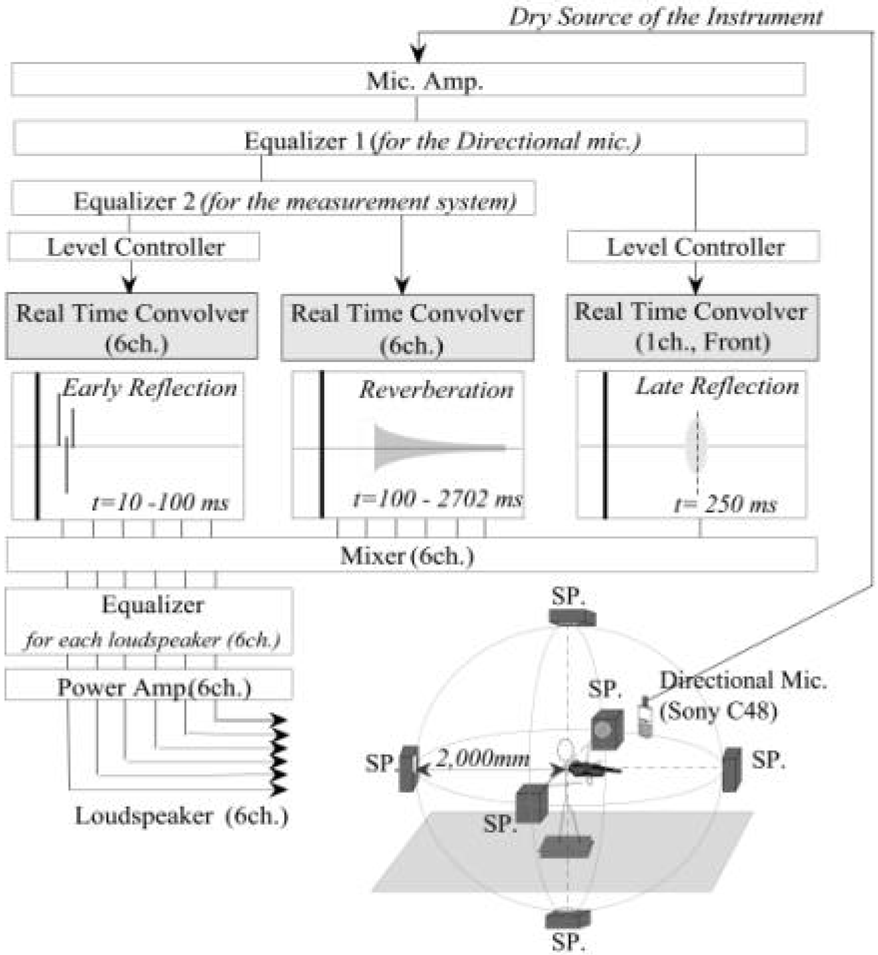
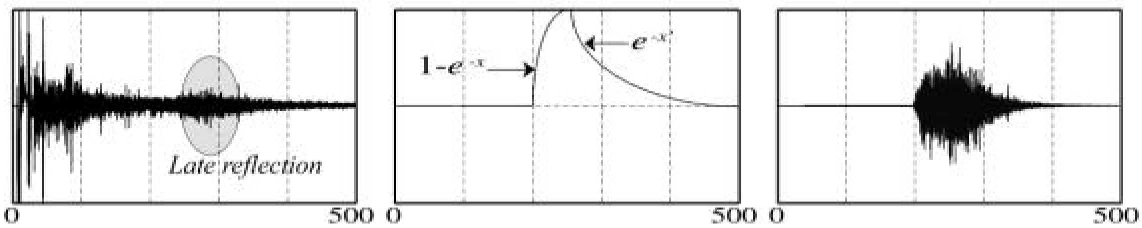


Fig. 2.- Block diagram of the simulation system for subjective experiment

Late Reflection In concert halls, it is often observed that noticeable late reflections with considerably long delay time are included in the reverberation process. On this point, the authors have examined the effect of this kind of reflection on players by sound field simulation technique [8, 9]. As a result, it was found that this kind of late reflection is not necessarily disturbing but it can be beneficial for the players if its magnitude and delay time are proper. According to this finding, the effect of the late reflection was again examined by changing its level in three steps in this study. That is, the late reflection signal was synthesized by modulating a late reflection measured in another concert hall (1,527 seats, volume: 14,800 m^3, reverberation time: 1.4 s) shown in Fig.3(a) by an envelope signal shown in Fig.3(b) and its delay time was fixed at 250 ms as is often observed in large concert halls. The late reflection was radiated from the loudspeaker simulating the sound from the rear part of the audience area.



(a) Original impulse response (b) Envelope function (c) Filter coefficient

Fig. 3.- Processing the filter coefficient of late reflection

SUBJECTIVE EXPERIMENT

In advance of this study, a preliminary experiment was performed to examine the subjective reality and naturalness of the simulated sound field used in this study. As a result, it was confirmed that the subjects (music players) can get realistic sensation in playing as in real halls. A few players, however, pointed unnaturalness in tonal quality.

Conditions To examine the effect of the elements of impulse response mentioned above, three parameters, that is, level of the early reflection, reverberation time, and level of the late reflection were changed in three steps, respectively (See Table 1). The experimental conditions were determined by considering the measurement results of 10 acoustical conditions at center points on the stage in 7 large concert halls in Japan (*1) in Table 1).
To examine the acoustical conditions in the simulated sound field, the impulse response at a center point of the simulated field was measured by the same set-up of equipments shown in Fig.1 except that an omni-directional microphone was used here. The values in Table 1 are the results in the middle frequency range of 2 octave band covering 500 and 1k Hz oct. bands.
Reverberation times were obtained by the integrated impulse response method. Concerning the level of reproducing sound, two kinds of ST values (ST_1 and ST_{late}) proposed by Gade [10] were obtained under the condition of source-receiver distance mentioned above. The results of ST_1 for the energy level of early reflection are shown in Table 1. ST_{late} for the energy level of reverberation was set to be almost consistent value of –20 dB for all conditions by considering the fact that the average value of ST_{late} in the real halls was –20.4 dB. Regarding the late reflection, no reflection was set as a standard condition L1 (None). Then, another two conditions were set as follows; L2 (-6 dB) in which the reflection was softly audible, and L3 (0 dB) in which it was clearly audible when an impulsive sound was generated. The levels of the late reflection were adjusted relatively for the input signal shown in Table 1.

Table 1 Experimental conditions

Group	step	Measured conditions: Rev. Time [s]	ST_1 [dB]	Late reflection	Presented order
Reverberation	R1	1.6	-20.9	None	1
	R2	1.9			2
	R3	2.2			3
Early reflection	E1	1.9	-18.1	None	4
	E2		-20.9		5
	E3		-23.7		6
Late reflecion	L1	1.9	-20.9	None	7
	L2			-6 dB	8
	L3			0 dB	9
Average *1)		2.1	-21.3	-	-
S.D. *1)		0.3	2.2	-	-

Methods The subjective tests were performed on 13 professional music players; 3 flutes, 1 clarinet, 2 oboes, 4 violins, and 3 violas.
Under each condition (9 in total) as indicated in Table 1, the subject positioned at the center point of the field was asked to perform imagining that he/she was on the stage of a real concert hall and to answer his/her impression of each experimental condition. In the experiment, the subject was allowed to play freely, that is, each subject selected proper piece or technique to find the characteristics of each condition in detail. After playing, he/she judged the condition by 5 step categories, where the items were determined for each subject by interview survey conducted in advance. Besides, the subject was asked to describe the condition to the experimenter on such point as reverberation, spatial size, response, and so on.
The subject was asked to not only evaluate each condition but also compare the differences among the three conditions in each group (early reflection, reverberation, and late reflection). The experimenter was also in the anechoic room and asked the subject's response directly.

Results As a result, the judgments by the subjects participated in this experiment diverged as was expected and the categorical judgments were neither decisive nor stable. Therefore, the response of each subject was examined individually and the free comments were mainly taken into consideration. As an example, the results of the six wind instrument players are arranged in Table 2.

Table 2 Results of the experiment

Player	Group of the conditions		
	Reverberation	Early reflection	Late reflection
Fl.-a	R1: (4) R2: (5) the best R3: (5) R1: Reverberation is thin. R2: Easy to play as it is similar to my accustomed hall. R3: Good for solo but difficult for orchestra.	E1: (2) E2: (5) second E3: (5) the best E1: Like in a bit small hall. E2: Ordinary, large hall. E3: Very comfortable for ears and like in the S-hall (center stage type).	L1: (5) L2: (5) the best L3: (3) L1: Not so bad but sound does not go forward. L2: Comfortable to ears. Easy to estimate the sound in the audience area. Easy to make reverberation of music. L3: Reverberation is too much.
Fl.-b	R1: (2) second R2: (2) most favorable R3: (2) Reverberation changed, but the difference was small. All conditions were not so good. R1: Tone is not comfortable R2: Technique cannot be effective. R3: Reverberation became longer.	E1: (5) the most pleasant E2: (4) E3: (4) good Hall became larger. E1: Pleasant for solo. Small hall. E2: A little bit too reverberant. E3: Comfortable as in a large concert hall.	L1: (3) L2: (5) the best L3: (4) L1: Featureless. L2: Very comfortable and easy to play though the hall is big. Detailed expression seems to be conveyed to the audience. L3: Sound is felt stiff and thin
Fl.-c	R1: (2) R2: (4) the best R3: (2) not good R1: Reverberation is not enough. R2: Proper reverberation, helping me to play in relief. R3: Very reverberant.	E1: (1.5) E2: (3.5) E3: (3) relatively favorable E1: Artificial because reverberation is close though the hall is felt large. E3: Large hall and response of the hall is dull.	L1: (3.5) L2: (4.5) good L3: (4.3) the best L1: Response is too fast and it is difficult to control. B,L3: Sound became thick and uneasiness felt in large hall is reduced.
Cl.-a	R1: (3) R2: (4) good for with piano R3: (3) pleasant for solo Size of the hall was getting larger. R1: Small hall. R2: More reverberant and more preferable. R3: Like in very large hall. It might be too reverberant for hearing each other.	E1: (3) not preferable E2: (3) not preferable E3: (3) preferable Spatial impression was quite different among the three. E1: Hall is in small or medium size. Sound is artificial and not comfortable. E3: Large hall, and the sound is natural. Good for solo. Also matches with orchestra.	L1: (4) L2: (3) the best L3: (2.5) L1: Plain featureless box. L2: Extremely preferable as well acoustical designed hall for classic music. L3: Too large space with much reverberation.
Ob.-a	R1: (5) R2: (5) most favorable R3: (4) too reverberant Reverberation is getting more and longer. All conditions are acceptable because playing technique can be changed to the condition.	E1: (3) not so good E2: (4) E3: (3) relatively favorable Difference is very subtle among three conditions. E1: Space is felt small. E2: Sound does not go forward. E3: Seems difficult to control.	L1: (3) L2: (5) the best L3: (4) L1: Very reverberant. L2: Dynamics is wide and it is natural. L3: Sound is not enough to make forte.
Ob.-b	R1: (3) R2: (4) preferable R3: (4) preferable R1: Very plain. R2: Easy to play by support of hall. Warm sound. R3: Felt a little cold.	E1: (4) good E2: (2) not good E3: (4) most preferable E1: Small hall. E2: Sound does not go to the audience. E3: Feel easy by support of hall.	L1: (4) preferable L2: (3) L3: (4) preferable L1: Reverberation helps play. L2: Getting nervous because fine expressions seem to be conveyed too precisely. L3: Not necessary to be nervous. Feel at ease.

( ): categorical judgement for the ease of solo playing, 1:very difficult to 5:very easy

In the results, the following general tendency was observed.

- The subject preferred the reverberation condition R2 (1.9 s). When it was shorter, the reverberation could be judged not satisfactory enough to feel the support of the hall.

Meanwhile, it might be disturbing especially for hearing each other in ensemble if it was felt too long or too much reverberant.

- When changing the level of the early reflection, the subjective impression of on the spatial size was changed. In the condition with strong early reflection, the space was felt small. On the contrary, when the early reflection was relatively weak, it was felt large. Generally, the condition of the weakest early reflection was preferred.
- Concerning the late reflection, the subjects liked the condition in which the late reflection was audible rather than the condition of not audible. Under such condition with audible late reflection, they could feel at ease and/or they could convey the detailed expression to the audience.

In the results of the experiment on string instrument players, the tendency mentioned above was not clearly found. The variance of their judgments might be caused by the individual difference of performing activity, playing style, role in creating music (soloist, “top”, or “tutti”), etc.

Discussions In the conventional method of the psychological study, the statistical examination to extract psychological quantity from the subjects is usually adopted. In these methods, researchers decide the items of psychological scales preliminary, impose them on the subjects, and analyze the outputs as the psychological phenomena, which is in the one-sided relationship. However, the psychological structure of musicians should not be so simple as to be understood by using such conventional method. In this study, music player’s subconscious to the sound field was extracted through cooperative conversation. In this kind of psychological study, such interactive relationship between the subjects (musicians) and the researcher is very important.

CONCLUSIONS

In this study, the newly developed simulation technique to reproduce realistic sound fields was adopted to subjective experiment on stage acoustics. Using the system, the relationship between physical conditions and subjective impression was examined. As a result, it has been found these factors as reverberation time, energy of early reflection, and audibility of late reflection can change the players’ impression. From the comments of the subjects, it has been suggested that the players can feel the support of the hall by late reflection rather than by early reflection. To realize the conditions desirable for music players, structure of reflections not only in early time but also in late time domain should be carefully considered in the acoustical design of concert hall.

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BIBLIOGRAPHICAL REFERENCES

[1] A. C. Gade, “Investigations of musicians’ room acoustics conditions in concert halls, Part 1: Methods and laboratory experiments”, Acustica, 69, 193 (1989).
[2] A. H. Marshall and J. Meyer, “The directivity and auditory impressions of singers”, Acustica 58, 130 (1985).
[3] I. Nakayama, “Preferred delay conditions of early reflections for performers”, Proc. 12th ICA, (1986).
[4] S. Yokoyama, K. Ueno, S. Sakamoto and H. Tachibana, “6-channel recording/reproduction system for 3-dimensional auralization of sound fields,” Acoust. Sci. & Tech. 23, 2, 97 (2002).
[5] K. Ueno, K. Yasuda, H. Tachibana and T. Ono, “Sound field simulation for stage acoustics using 6-channel system”, Acoust. Sci. & Tech. 22, 4, 307 (2001).
[6] K. Ueno, F. Satoh, H. Tachibana, T. Ono and M. Senju, “The effect of early reflection on players in concert hall”, Proc. 16th ICA, 673 (1998).
[7] K. Ueno, F. Satoh, H. Tachibana, T. Ono and M. Senju, “Experimental study of the effect of early reflections on players by binaural simulation technique”, J. Acoust. Soc. Jpn. (E) 21, 3, 167 (2000).
[8] K. Ueno, F. Satoh, H. Tachibana, T. Ono and M. Senju, “Subjective experiment on the effect of hall response on a violin player in a simulated sound field”, Proc. 3rd ASA/ASJ Meet., 103 (1996).
[9] K. Ueno, F. Satoh, H. Tachibana and T. Ono, “Subjective experiment on the effect of long-path reflection on players in a simulated sound field”, Proc. of WESTPRAC., 973 (2000).
[10] A. C. Gade, “Investigations of musicians’ room acoustics conditions in concert halls, Part 2: Field experiments and synthesis of results”, Acustica, 69, 249 (1989).