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Musicians' Adjustment of Performance to Room Acoustics, Part III: Understanding the Variations in Musical Expressions

Kosuke Kato[a], Kanako Ueno[b] and Keiji Kawai[c]

[a]Center for Advanced Science and Innovation, Osaka University, Yamadaoka 2-1, Suita-shi, 565-0871 Osaka, Japan
[b]Institute of Industrial Science, University of Tokyo, Komaba 4-6-1, Meguro-ku, 153-8505 Tokyo, Japan
[c]Graduate School of Science and Technology, Kumamoto University, Kurokami 2-39-1, Kumamoto-shi, 860-8555 Kumamoto, Japan
kato@casi.osaka-u.ac.jp

This study attempts to investigate the acoustic variations in the musical sound signals produced by professional performers under different room acoustic conditions. The sound signals produced by four professional instrumentalists and an operatic baritone singer under simulated concert hall sound fields were recorded using a unidirectional microphone placed close to either the instruments or the mouth of the opera singer. In order to quantify the extent of the variations in the resulting sound signals due to the adjustment of the musical expressions, an acoustic analysis was conducted. The results indicated that the "note-on ratio," defined as the ratio of the tone duration and inter-onset interval, of several staccato tones decreased in reverberant halls. The higher harmonics of the tones of an oboist and a flutist were suppressed in reverberant sound fields, while the vibrato extent of a violinist varied considerably, as was reported in our previous study (Part II). On the basis of the interviews with the performers held during the recordings, it has been inferred that the variations in the musical sound signals had been produced by the performers to adjust to the room acoustic conditions.

1 Introduction

Many studies on concert hall acoustics assume that music sound source signals remain constant, regardless of the room acoustics. However, it is natural to suppose that the performed music varies depending on the room acoustics, because it is rather common that professional performing musicians consciously or unconsciously adjust their performing styles according to the room acoustics in order to convey their own music image to the listeners [1, 2]. If performing musicians create their musical performance on the stage by imaging the music listened in the audience area, it is worth to describe the subjective evaluation of the musical sound listened in the audience area in relation to the characteristics of music source signals varying depending on room acoustic conditions. Similar to our previous studies [3-4], before examining the musical sound listened in the audience area, this study also focuses on the investigation of the variations in musical sound source signal varying depending on room acoustic conditions.

In [3], musical sound signals were recorded for an acoustic analysis and to determine whether the performers consciously adjust their performing style under different room acoustic conditions. Interviews with the performers, who participated in the experiment, revealed that the performers adjust their performing style under different room acoustic conditions. An interview with professional musicians indicated that each musician who participated in the experiment adjusted his/her performing style according to some of the following attributes: music tempo, vibrato, harmonics, sonority of instrument sounds, articulation, agogics, and dynamics. A preliminary listening test for a violin tone recorded in the experiment indicated that the differences in music tempo, vibrato, articulation, and dynamics are commonly perceivable by third persons. Given the findings, [4] acoustically analyzed the recorded musical sound signals in order to examine the extent of the variations in music tempo, vibrato, and sound pressure level. The results revealed that three or more acoustical parameters of sound signals produced by each performer significantly vary depending on the room acoustic conditions. In particular, the results obtained for music tempo and frequency vibrato extent were in confirmation with the comments made by several professional performers.

Following these findings, this paper attempts to investigate further acoustic parameters of harmonics of tones and in the articulation of a staccato phrase, as these were elicited through the interview of the several performers [3].

Fig. 1 Musical scores used for the performing experiment.

2 Materials and Method

2.1 Musical sound signals for the acoustic analysis

In the performing experiment reported in Part I [3], five professional performers—1 violinist (VN1), 1 oboist (OB1), 2 flutists (FL1 and FL2), and 1 baritone singer (BR1) — played his/her instrument (or sang) under five different simulated room acoustic conditions: (1) an anechoic condition (AE) as an extremely dry condition, (2-4) three representative conditions for concert halls, ranging from a small to a large size (HS, HM, and HL), and (5) a condition in a church with excessive reverberation (CH). Reverberation time of each simulated room was AE: 0.0 s, HS: 1.4 s, HM: 1.4 s, HL: 2.4 s, and CH: 3.1 s. The volume of each simulated room was AE: 343 m^3, HS: 1,660 m^3, HM: 14,800 m^3, HL: 22,776 m^3, and CH: 13,333 m^3.

Each musician was asked to play his/her instrument by imagining that he/she was performing on a real stage. Further, the musicians were instructed to play two phrases from *Ave Maria* (D839) composed by *Franz Schubert* and *Gavotte* by composed *François-Joseph Gossec* (Fig. 1). The phrases were repeated three times. The baritone singer performed *Gia il sole dal Gange* composed by *Scarlatti* instead of *Gavotte*.

The musical sound signals were recorded onto a DAT (Fs = 48 kHz), using a unidirectional microphone (Sony, C48) placed close to the instruments or the singer's mouth. These recorded sound signals were used for the acoustic analysis.

2.2 Acoustic analysis of tones and a staccato phrase

Five long tones from the recordings of *Ave Maria* were

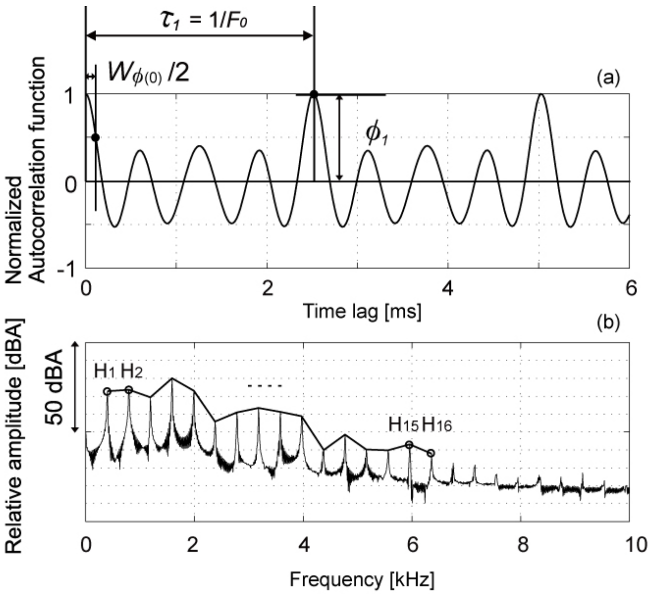

Fig. 2 Examples of the extraction of factors: $\tau_1(1/F_0)$, ϕ_1, and $W_{\phi(0)}$ from r-ACF and extraction of harmonics from corresponding r-PdS for oboe tone

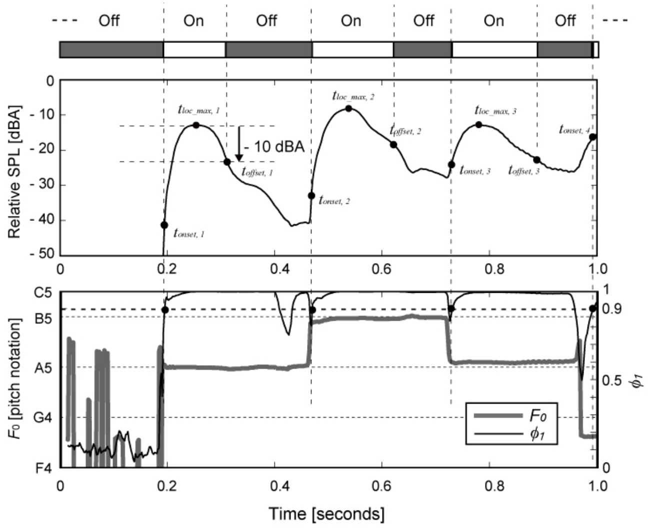

Fig. 3 Examples of the measured relative SPL (top figure), F_0, and ϕ_1 (bottom figure) for VN1 under a simulated room acoustic condition of HL.

used for evaluating the strength of the higher harmonics relative to the first harmonic. Fig. 2 shows examples of (a) the normalized running autocorrelation function (r-ACF; integration interval: 2T = 50 ms, step size: 25 ms, maximum time lag: 50 ms, time window: rectangular) of an oboe tone as a function of the time lag (τ), and (b) a power density spectrum (r-PdS) obtained by calculating the FFT of r-ACF (refer "FFT method C" described in Appendix A1 of ref. [5]). Here, the time lag of the first major peak of r-ACF (τ_1) corresponds to the inverse of the fundamental frequency (F_0), and the amplitude (ϕ_1) of this peak indicates the strength of the fundamental frequency.

In order to quantify the overall strength of higher harmonics relative to the first harmonic, the following parameters were measured: (1) the peak width ($W_{\phi(0)}$) of the autocorrelation function, defined as double the time lag at which r-ACF becomes 0.5 at the beginning [6], and (2) the mean level of higher harmonics ($\overline{H}$), defined as the mean level relative to the first harmonic (H_1) of fifteen harmonics (H_2 – H_{16}), which appeared in the range of four octaves. Note that the larger the amplitude of higher harmonics, smaller is the value of $W_{\phi(0)}$ [7]. In order to evaluate the proportion (n-$W_{\phi(0)}$) of $W_{\phi(0)}$ for the fundamental period, the $W_{\phi(0)}$ value was normalized by τ_1. The total number of observation was 375 data (5 tones × 5 sound fields × 3 trials × 5 performers).

The initial nine tones from the recordings of *Gavotte* have been used for evaluating the articulation. Fig. 3 shows examples of the time-series data of (a) the relative A-weighted sound pressure level (relative SPL), (b) F_0, and (c) ϕ_1, each parameter was obtained by the analysis of r-ACF (integration interval: 2T = 25 ms, moving step: 2 ms, time window: rectangular). In this study, because it is recommended for tonal instruments to detect the tone onset in relation to the transient characteristics in frequency [8], each tone onset is determined from the points that satisfy both the conditions ϕ_1 = 0.9 and ϕ_1 > 0.9 at $t_{onset,n} \leq t \leq t_{loc\_max,n}$. Here, t_{loc_max} denotes the time for the maximum relative SPL of each tone. Each tone offset is determined from the points where the relative SPL decreases by 10 dBA of the maximum relative SPL.

In order to quantify the articulation, (1) the "note-on ratio" (*Note-on_ratio*), defined as the ratio of the note-on duration (*Note-on_dur*) and the inter-onset interval (*IOI*), and (2) the note-off duration (*Note-off_dur*), defined as the time interval from the tone offset to the next tone onset, were measured. Here, *Note-on_dur* denotes the time interval from the tone onset to the tone offset, and *IOI* is calculated as the time interval from a tone onset to the next tone onset. Note that the value of *Note-on_ratio* is 100 % for *legato*. The smaller *Note-on_ratio* is expected for a performance with sharper staccato and the longer *Note-off_dur* is expected for a performance with longer silence between the adjacent tones. The total number of observations was 480 data (8 tone intervals × 5 sound fields × 3 trials × 4 instrumentalists).

3 Results

3.1 Strength of higher harmonics of tones

On the basis of the interviews with the performers held during the recording experiment regarding tone quality, as listed in Table 1 [3], the values of n-$W_{\phi(0)}$ and $\overline{H}$ were assumed to have varied depending on the room acoustic conditions, due to their subjective adjustments in the harmonics of tones, in the sonority of instrument sound, and/or in the other timbre related attributes of performance.

Performer	AE	HS	HM	HL	CH
VN1	Creates sonority in violin		Performs without considering reverberation		Suppresses the sound of violin
OB1			Performs without any special care on reverberation		Play rather modestly Suppresses the harmonics
FL1		Clearer	Plays as one would with normal reverberation		Plays with a soft delicate nuance
FL2					
BR1					

Table 1 Adjustment of tone quality for different room acoustic conditions, which are assumed to affect harmonics of tones

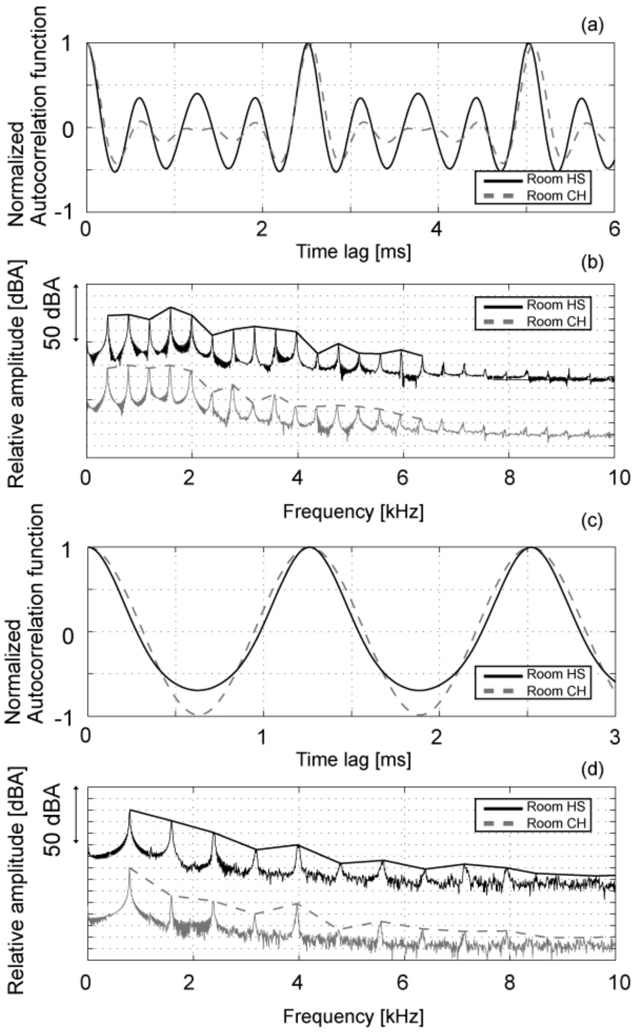

Fig. 4 Examples of measured r-ACF and r-PdS of tones under two different simulated room acoustic conditions of HS and CH: (a) r-ACF and (b) r-PdS for OB1, and (c) r-ACF and (d) r-PdS for FL1.

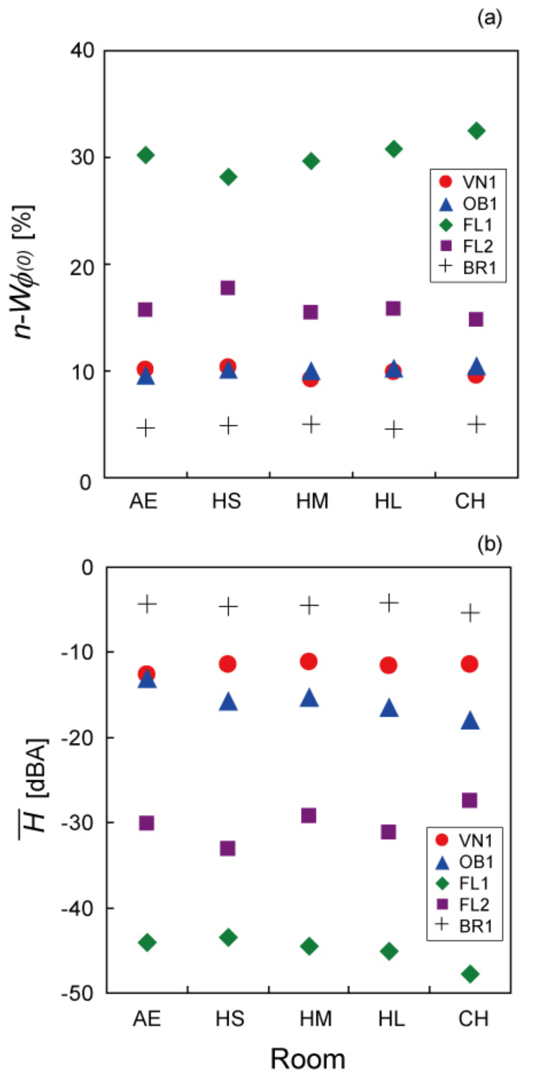

Fig. 5 Measured (a) n-$W_{\phi(0)}$ and (b) $\overline{H}$ for five room acoustic conditions.

Figs 4a–d show examples of the measured r-ACF and r-PdS of tones played under two different simulated room acoustic conditions. For both OB1 and FL1, the width of the peaks of r-ACF of the tone played under the simulated condition CH were observed to be wider than those played under the simulated condition HS. For both OB1 and FL1, the amplitude of higher harmonics relative to the first harmonic of the tone played under the simulated condition CH were observed to be weaker than those played under the simulated condition HS.

Fig. 5 presents the distribution of (a) n-$W_{\phi(0)}$ and (b) $\overline{H}$ of five tones of the music *Ave Maria* played under the five different room acoustic conditions. A negative correlation ($r = -0.90$ to -0.74) were observed between the parameters n-$W_{\phi(0)}$ and $\overline{H}$ for the four instrumentalists. The result of the two-way analysis of variance (ANOVA) revealed that n-$W_{\phi(0)}$ for the two flutists (FL1 and FL2) varied significantly depending on the room acoustic conditions ($p<0.05$), and that $\overline{H}$ for the three instrumentalists (OB1, FL1, and FL2) varied significantly depending on the room

Performer	AE	HS	HM	HL	CH
VN1				Shorten tones	Shorten tones for short notes
OB1	Make intervals between adjacent tones shorter			Shorten tones	
FL1	Longer staccato	Cut the tones clearly		Shorten tones	Shorten tones slightly
FL2					Make intervals between tones longer

Table 2 Adjustment of articulation for different room acoustic conditions

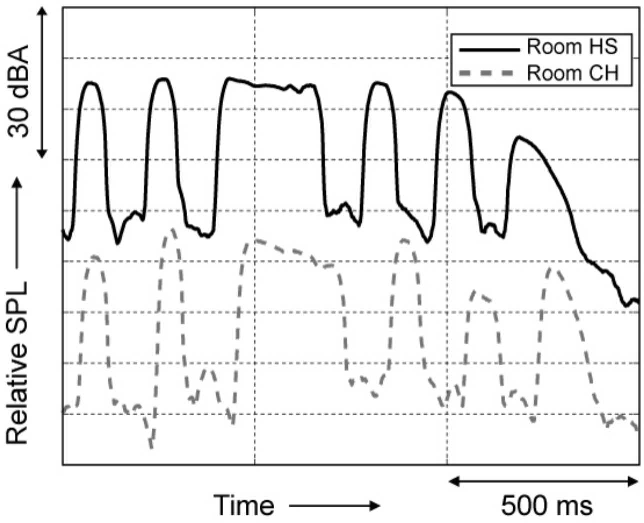

Fig. 6 Examples of measured relative A-weighted sound pressure level of staccato phrase played under two different room acoustic conditions (top: HS and bottom: CH) by OB1

acoustic conditions (p<0.01). Moreover, the result of the two-way ANOVA also showed that each of the variation in the mean n-$W_{\phi(0)}$ and mean $\overline{H}$ depending on the room acoustic condition was larger than that depending on the repeat of performance under each room acoustic condition. The maximum interindividual variations in the mean n-$W_{\phi(0)}$ and mean $\overline{H}$ depending on different room acoustic conditions were found to be 3.1% and 5.7 dBA, respectively (for FL2 under the room acoustic conditions HS and CH).

3.2 Articulation of a staccato phrase

On the basis of the interviews with the performers held during the recordings regarding articulation, as listed in Table 2 [3], the values of *Note-on_ratio* and *Note-off_dur* were assumed to have varied depending on room acoustic conditions, due to their subjective adjustments of the length of tones and the length of the silence between the adjacent tones.

Fig. 6 shows an example of the measured relative sound pressure level contour of a staccato phrase in *Gavotte* played under two different simulated room acoustic conditions. The length of each tone for the simulated room condition CH was observed to be shorter and the length of each silence between the adjacent tones for the simulated room condition CH was observed to be longer than those for the simulated room condition HS.

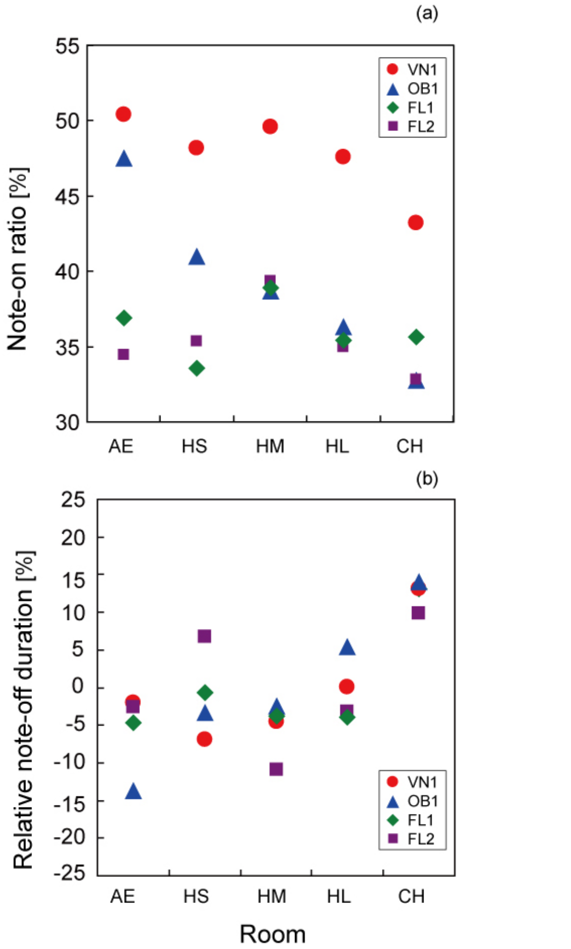

Fig. 7 Measured (a) note-on ratio and (b) note-off duration relative to each performer mean for five room acoustic conditions.

Fig. 7 presents the distribution of (a) *Note-on_ratio* and (b) *Note-off_dur* for the initial staccato phrase in *Gavotte* played under the five different room acoustic conditions. A negative correlation ($r = -0.79$ to -0.57) was observed between the values of *Note-on_ratio* and *Note-off_dur* for each performer. The result of the two-way ANOVA revealed that both *Note-on_ratio* and *Note-off_dur* for the three instrumentalists (VN1, OB1, and FL1) varied significantly depending on the room acoustic conditions (p

< 0.05). The result of the two-way ANOVA also showed that each of the variation in the mean *Note-on_ratio* and mean *Note-off_dur* depending on the room acoustic condition was larger than that depending on the repeat of performance under each room acoustic condition. Among the five performers, OB1 showed the largest interindividual variations both in *Note-on_ratio* and *Note-off_dur* depending on the room acoustic conditions: the mean *Note-on_ratio* for the simulated room condition CH was 15 % smaller and the *Note-off_dur* for the simulated room condition CH was 28 % longer than those for the simulated room condition AE, respectively.

4 Discussion

Depending on room acoustic conditions, either n-$W_{\phi(0)}$ or $\overline{H}$ of the tones played by the three instrumentalists (OB1, FL1, and FL2) varied. In particular, the higher harmonics of the tones of OB1 and FL1 were suppressed under a reverberant simulated room condition CH. The results obtained for OB1 were in confirmation with his statement that he had suppressed the overtones under the simulated room condition CH. Considering that the level of harmonics of flute tones generally decreases with decreasing the velocity of air flow inside the instrument, the present results obtained for FL1 were also in confirmation with her statement that she had played with a soft delicate nuance under the simulated room condition CH.

Both of *Note-on_ratio* and *Note-off_dur* for the staccato phrase played by the three instrumentalists (VN1, OB1, and FL1), who subjectively adjusted their performance according to reverberation in room, significantly varied depending on the room acoustic conditions. In particular, VN1 and OB1 considerably reduced *Note-on_ratio* and increased *Note-off_dur* under the reverberant conditions. Considering the fact that reverberation shortens the length of the silence between the adjacent tones for the music signals detected in the audience area, it is inferred that VN1 and OB1 might have tried to maintain the silence between the adjacent tones constant irrespective of room acoustic conditions.

5 Conclusions

As an investigation of the musicians' adjustment of their performing style according to the room acoustic conditions, following the previous study [4] in that the music tempo, the vibrato, and the sound pressure level were examined, this study investigated acoustic parameters of harmonics of tones and in the articulation of a staccato phrase.

The analysis showed that the overall strength of the higher harmonics of tones and the articulation of a staccato phrase has been changed by several instrumentalists depending on room acoustic conditions.

In the case where the adjustments in the articulation were made consciously, the result for the "note-on ratio" and the result for the note-off duration were in confirmation with the subjective reports on the adjustment of the length of tones and of the length of the silence between the adjacent tones, respectively.

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