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A study of the influence of room acoustics on piano performance

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Abstract : This study attempts to describe the behaviour of a pianist playing the same piece of music in different acoustics. An experiment was organized in march 1993 using carefully controlled experimental conditions. In the variable acoustics of the "Espace de Projection" at Ircam (Paris), seven professional pianists playing on a Disklavier MIDI grand piano were recorded with synchronous digital audio and midi systems. From these data a statistical analysis was performed in order to evaluate to what extent performance attributes are correlated to the perceptual dimensions of room acoustics. The strategy of experimentation, the acoustical realization, the measurements and the methodology of the statistical analysis are described.

1. INTRODUCTION

Several aspects of room acoustics perception, like the classification of perceptual factors, the adaptation of concert rooms to different types of music, or the coherence between visual environment and auditory perception have been addressed in a large number of studies. The principal aim of such studies is to establish relationships between objective, measurable criteria and the perceptual attributes linked to the room effect. But most of these studies are focused on the sensations experienced by the listeners and they may hence fail for the description of the sensations of the musicians on stage. An interesting additional problem in the case of a musician is the feedback phenomenon that exists between sound perception and sound control: this feedback will depend on the amount of information furnished by the hall (in comparison to the direct sound of the instrument) as well as the way different musicians will hear each other ("ease of ensemble").

The present study attempts to explain the influence of the phenomenon of auditory feedback on the interpretation parameters in the case of a pianist playing solo. It was started in 1991 with a preliminary study which gave significant results with limited equipment [1,2]. A more elaborate experiment under calibrated experimental conditions took place at Ircam (Paris). In the following we present each stage of the experiment, as well as first results.

2. THE STRATEGY OF EXPERIMENTATION

Seven professional soloists were asked to play nine times the same session composed of a few minutes of practising, some short imposed exercises and excerpts of pieces of their own choice. They were free to choose any style of piano music, provided it was entirely written and did not include improvisation. They were given no notice as to what was changing between sessions. At the end of each session they had to answer a questionnaire about their feelings on what they had just played and what they thought had changed or not. At the end of the nine sessions, they were asked for a general overview of the different interpretations as well as for their preference. Then we explained them the changes between the sessions, let them hear these changes while playing and answer a questionnaire about their perception of each acoustical condition. For each pianist the experiment was made in one long afternoon (approximately five hours).

The experiment was organised using the following strategy: we took care to change only the acoustical characteristics of the pianist's environment. That means that he or she played on the same grand piano, the same day and in the same visual environment, i.e. a dark room with light projected over the piano. Eight different settings of a modulable concert hall were chosen. In order to evaluate the reproducibility of the performances one of the settings was proposed twice during the full experiment. The acoustical criteria we decided to vary were the

reverberation time, the reverberation level, the energy ratio between the direct sound and the first reflections and the spectral characteristics of the reverberation.

3. THE ACOUSTICAL REALIZATION

The modulable concert hall used for this experiment was the "Espace de Projection" (ESPRO) at Ircam. The three portions of the ceiling can move independently, so that the room volume can be changed from 900 to 3 500 m^3. The walls and the ceiling are composed of elementary surface elements (0.80*2.50 m^2) that can be either high-frequency absorbent, low-frequency absorbent, reflective, or diffusive. The attainable reverberation times range from 0.8 to 4 seconds.

The choice of acoustical configurations was governed by the concern to assure independent variations among a limited number of objective criteria that are known to be related to perceptual factors (for the case of listeners in the audience). Within the geometrical limitations of one single room, it is difficult to respect this condition of orthogonality even within a modulable concert hall, especially when looking for important variations of each criterion. Moreover, the number of settings has to be limited for reasons of time and fatigue of the pianists. So, whereas an independence of the criteria could be assured for a certain number of pairs, the criteria, especially the reverberation time and the reverberation level, are still correlated when considering the whole group of eight settings. The four acoustical criteria chosen were the following: the reverberation time "RT", the late reverberation level "Rev" (i.e. total energy after 80 ms after the arrival of the direct sound), the ratio between direct sound and first reflections "Dir/Ref" and the spectral characteristics of the reverberation "ΔRTBF" (ratio of reverberation level between bass and medium frequencies). The following table shows, for each criterion, their perceptual interpretation as discussed in [3], together with the range of variation attained for the experiment. Table 1 at the end of this paper gives a detailed characterization of the whole set of configurations.

criterion	perceptual interpretation	min	max
RT	reverberance	1,1 s	2,9 s
Rev	response of the room	- 17 dB	- 11 dB
Dir/Ref	transparency	10 dB	14 dB
ΔRTBF	boominess	- 2 dB	1 dB

The characterization of the acoustics of each configuration was made by impulse response measurements using the method of Maximum Length Sequences (M.L.S.) [4], with an omnidirectional microphone set close to a loudspeaker, in order to characterize the situation of a player listening to his own instrument. With the help of a predictive room acoustics software the measured values were corrected to compensate for the pronounced directional characteristics of the loudspeaker, when compared to the directivity of a piano.

As discussed above, the whole set of configurations does not provide independence among the chosen criteria. Hence, detailed analysis will have to consider only specific pairs of configurations in order to respect the condition of orthogonality of the objective criteria. Otherwise, a Principal Components Analysis (PCA) of the array of the objective criteria lets us visualise a space that can be considered as the least degenerate possible: its first two axes are, in order of importance, the "reverberance" axis, correlated to RT and Rev together, and the "transparency" axis, correlated to Dir/Ref. The importance of each axis is given by its percentage of explained variance, that are respectively, 65% and 28% which means that 93% of the variance of the criteria is explained in a 2D space. Then, a global analysis of the results may consist in projecting the interpretation parameters, or the perceptual judgements of the pianists, into this objective space.

4. INTERPRETATION AND PERCEPTUAL DATA

In order to study the behaviour of a pianist with respect to the way he perceives the sound of his own instrument, several data have been collected that may be seen as input and output signals: the acoustical pressure signal recorded by a microphone disposal as well as the answers of the pianist to the questionnaire about their perception of the acoustics, and the midi signal recording the motion of the keys and the pedals.

The audio signal was recorded with a microphone disposal set close to the pianist's head, and was digitalized on a MacIntosh computer with LabView (National Instrument) software. The gestures were coded with the midi signal given by the Yamaha Disklavier, that is the date (in ms) and the intensity (keystroke velocity coded from 0 to 127) of the "note on" (keystroke), the date of the "note off" and the movements of the pedals. The midi data were recorded using Max software (Ircam/Opcode). Possible classes of analysis parameters include the following: the intensity, the speed (or "tempo"), and the "overlap". Positive overlap (or "legato") and negative overlap ("staccato") can be measured for the keys as well as for the pedals and can be related to the variations of decay time. The musical parameters of speed are the average tempo and the general envelope of one excerpt. The musical parameters of intensity are the average value estimated over the whole excerpt ("global intensity"), the difference between two shades of one musical phrase (or "contrast"), the envelope of one phrase (or "phrasé") and the average peak value.

The questionnaire used to evaluate the subjective perception of the different acoustics is the one used by the room acoustics laboratory at Ircam for a measurement campaign in several European concert halls [5]. It lets the pianist evaluate subjective factors like reverberance, subjective dimension, dynamics, precision, strength, brilliance... The correlation between the different pianists' evaluations give information about differences in their subjective evaluation of the rooms. The correlations between the perceptual factors and the objective criteria let us gain insight on how the characteristics of the rooms will influence the perception of the sound produced by the pianist himself.

5. METHODOLOGY OF ANALYSIS

Two types of analyses are possible: first, individual pairs of configurations, where only one objective criterion was varied, can be studied to see whether significant variations in the performance parameters exist. Otherwise a global analysis is possible via the projection of the interpretation parameters into the non-degenerate objective space obtained via PCA. The pianists data for these analyses can be either from a single excerpt, the total data of one pianist or the mean performance of all pianists.

Before analysing the variations of a parameter, we first evaluate the significance of its variation: to be really significant, a parameter should present a good standard deviation across sessions, and a small variability between the two recordings in the same acoustics. We then evaluate the intercorrelation between all measures of one parameter, so that we make the difference between an influence that appears on every pianist, on one single pianist, or on one single recording. In order to relate the performance variations to acoustical conditions, correlations may be computed between interpretation parameters and the objective criteria.

6. THE FIRST RESULTS

At the moment of writing we only have results on perceptual factors, and on the average intensity, the contrast and the tempo made on large midi recordings.

The analysis of the questionnaires shows a maximum of variance for the following questions: reverberance, precision and strength, respectively strongly correlated to RT, -RT and Rev. The sensation of reverberance expressed by the pianists is better correlated with the RT measured in medium and high frequencies rather than in bass frequencies, confirming the results established with audience listeners. The intercorrelations between the answers of the pianists are higher than what was encountered for listeners during the measurement campaign of concert halls, which lets us think that they mutually agree on a "pianist's point of view" on room acoustics perception. Furthermore, they almost unanimously prefer one room, indicating the possibility of an "optimum setting" within the proposed configurations, for all of the pianists, despite the variety of the musical excerpts they had chosen (from Mozart to Berio). This once again can be contrasted to the case of listeners in concert halls where the subjects can often be separated into two classes that agree on perceptual description, but do exhibit distinctly separate preferences [6,7].

The average contrast and average tempo, estimated over complete excerpts, give bad results on their standard deviation and variability. That means that these interpretation parameters do not seem to be really influenced in a global way by acoustical changes. However, the fact that the standard deviation is bigger when the excerpt is shorter let us think that measures on single phrases could precise these results. Nevertheless, the fact that the global tempo seems not to be influenced by such parameters as the RT is rather surprising, especially when considering the range of this criterion (1 to 3 s) which covers the extreme values encountered in concert halls or auditoria. It could be interesting to investigate this question with other instrument families for it is known that for orchestras the tempo is affected by this acoustical parameter. Three variables might account for this difference of behaviour: the quality of transients as well as the decay characteristics of the different instruments, the size of the ensemble (from duets to a large orchestra including choirs) and the intermediate role of the conductor in the feedback phenomenon.

In the case of the average intensity, the standard deviation across tests is better, and the variability of the double measure is smaller, so that we can consider the observations to be consistent. The interpretation is based on the analysis of the correlations between the intensity and the set of objective criteria. Figure 1 shows the projection of the correlation vectors onto the first two axes given by a principal components analysis of the objective variables. One can see a significant negative correlation between global intensity and the couple formed by the Rev and RT criteria. This first result confirms the preliminary study of April 1991. However, the separate influences of reverberation time and intensity are still not distinguishable. As mentioned above, this precision will have to refer to specific couples of configurations where these criteria show independent variations.

7. CONCLUSION

A series of tests was performed under controlled laboratory conditions in order to evaluate the influence of acoustical variations on the interpretation parameters of solo pianists. Both performance information and perceptual judgements were recorded during the experiment. Global results show good correlations between the perceptual judgements of the pianists when they are asked to describe their impressions on the different acoustical conditions. It could be verified that the reverberance of a concert room is influencing the intensity of playing of a pianist, in the sense that he tries to compensate for the importance of the room effect. On the contrary the global tempo and the contrast did not show significant variations. These observations were made on a portion of the data: further studies, dealing with specific couples of acoustical conditions as well as shorter excerpts, are necessary in order to investigate the separate influences of the different acoustical criteria .

8. AKNOWLEDGEMENTS

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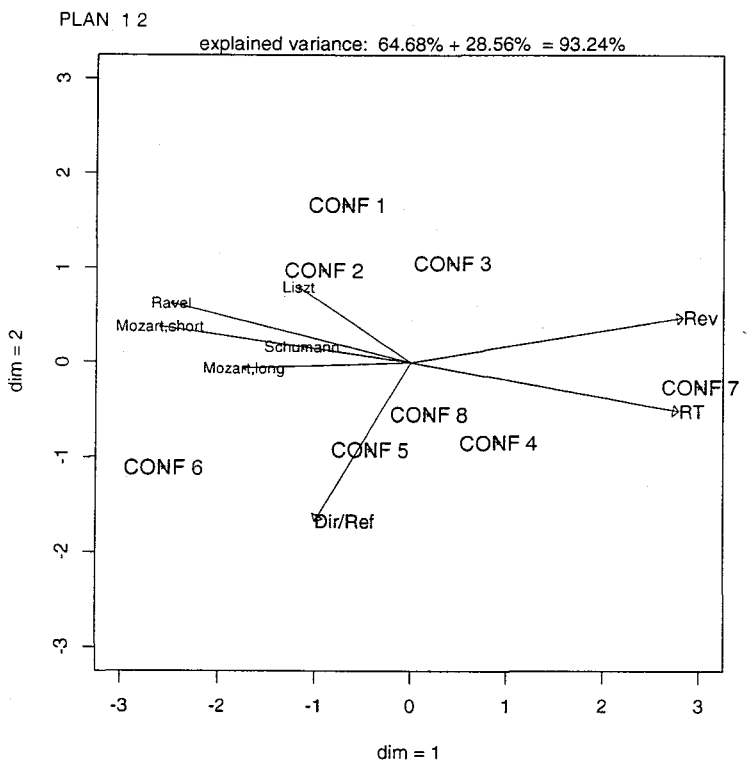

Figure 1: Principal components analysis derived from the objective characterization of the configurations, using the four construction criteria. Vector projection of (1) the objective criteria RT, Rev, Dir/Ref, and (2) the interpretation parameter "global intensity", for different musical excerpts.

criterion	CONF 1	CONF 2	CONF 3	CONF 4	CONF 5	CONF 6	CONF 7	CONF 8
RT	1193 ms	1189 ms	1502 ms	1837 ms	1501 ms	1116 ms	2789 ms	1830 ms
Rev	-13.36 dB	-14.95 dB	-13.38 dB	-13.59 dB	-15.04 dB	-17.08 dB	-10.69 dB	-13.49 dB
Dir/Ref	9.66 dB	10.18 dB	9.64 dB	12.25 dB	12.84 dB	14.08 dB	10.99 dB	12.53 dB
ΔRTBF	0.59 dB	0.05 dB	-0.69 dB	-1.57 dB	-0.82 dB	0.7 dB	-1.58 dB	-0.39 dB

Table 1: Values of the acoustical criteria for the eight configurations, corrected to take into account the directivity of the piano.