EuroRegio2016
June 13-15, 2016
Porto ▪ Portugal

ACOUSTICS DESIRED FOR CHORAL MUSIC - USING VIRTUAL ACOUSTICS AND MDS METHODS

Paweł Małecki

Department of Mechanics and Vibroacoustics, AGH University of Science and Technology,
al. Mickiewicza 30, 30-059 Kraków
pawel.malecki@agh.edu.pl

Abstract
The article shows a virtual acoustic approach in determination of the best acoustic condition for multi-voice vocal a Capella music. Choral music has rich timbre and a sophisticated texture. A room response is an integral part of this kind of music. A reverberation influences both the performers and the listeners. The article presents research about the perception of choral music in a variety of reverberant conditions. The most significant factors of room impulse response, which were also the ones preferred by the listeners, were investigated. Ambisonics, altogether with VBAP, was used in the listening test. Multidimensional scaling was used in a statistical analysis of the results.

Keywords: choral music, MDS, ambisonics, auralization

PACS no. 43.66.+y

1 Purpose and motivation

Human voice belongs to one of the most beautiful means of expression and also, musical instruments if it be classified as such. In the event of multiplying human voice in a choir, the result is a timbre of uniquely rich texture. Reverberation is inextricably linked with architectural acoustics. Reverberation time is defined as the time after which, upon turning off the sound source in a room, its time decreases by 60 dB. However, reverberation is a broader concept and it is often referred to phenomena known as sound decay in any space (for instance in the forest or in the canyon); as to the sound engineering, it is one of the basic tools for creation of sound [1],[2]. The source of reverberation in recordings may be natural acoustics, the echo of any interior where recorded music is made. A common practice is, however, recording signals in a studio (often almost free field), with the additional use of close microphones to minimalize the reflected sounds. In such cases, reverberation is generated by electroacoustic devices or special algorithms. Less frequently plate and spring reverberators are used, reverberators based on complex delay lines are commonly used. The main function used to simulate rooms acoustics is the technique of convolution of the impulse response with the acoustic signal recorded in a free field conditions. Additionally, for recording of impulse responses, microphone systems, as well as 3D microphones [3],[4] based on ambisonic tehnique are applied.
Regardless of the kind of the technique used, it is essential to decide on the length of reverberation time in a particular recording. In the case of adding reverb in post-production, there is the ability to make experiments, as well as verify a number of variants. In the event of natural acoustics recordings, it is essential to decide on the room and, consequently, on the reverb. The decision is very important, as the

consequences are not possible to be changed in the process of mixing. Therefore, proper selection of the parameter is often essential to achieve the effect desired.
The aim of the study is an attempt to answer the question what is the optimal or preferred by an average listener length of reverberation time in choral music. As part of the study, sound samples of choral music that differed only by the reverb were made. The samples were tested using the procedures of mulitidimensional scaling.

2 Preparation of sound variants and listening stand

2.1 Recording of Choral Music in the conditions of free field

Choral music accompanies human history from its very beginning and it may be encountered in almost every culture. The largest importance of the music can be identified in western culture. The development of choral music over the centuries has been largely associated with the development of Christian religious music. At the time of Middle Ages and Renaissance, sacred music was practiced mainly in churches, Orthodox churches and monasteries, exclusively by male choirs. Despite the earlier development of classical polyphonic music, the beginning of polyphonic choir dates back to 1430 [5].
The recording position was prepared in an anechoic chamber in the AGH Department of Mechanics and Vibroacoustics. The object of the recordings was a chamber choir composed of eight choristers. In order to record, electroacoustic study transducers RME Fireface 800 and Rode NT5 microphones were used. The recordings were made with the use of a multi-track microphone technique. Due to the difficulty caused by poor audibility among individual choristers, each of them was equipped with personal listening system. Several recordings were made; for the study a sample was selected that is characteristic for its simple, concord chords, uncomplicated harmony and understandable words (the word "Alleluia" repeated three times). The recording was carried out with sampling frequency of 96 kHz and resolution of 24 bits.

2.2 Adding reverberation

The next stage of the study is adding diversified reverberation to the material recorded in free field conditions. In order to do this, measurements of spatial impulse responses in several dozens rooms of qualified acoustics were made. On the basis of the acoustic parameters measured in the particular rooms, eleven of the most diverse ones were selected. The selection of eleven objects was the consequence of time constraints determined by listening tests. To determine the spatial impulse responses and create convolutions, MATLAB and EASERA 1.2 PRO softwares were applied. The measurement chain was configured with the use of first order ambisonic microphone Soundfield ST350 and an active speaker column JBL EON 515. The distance between the measuring point and the source was constant for all the impulse responses and it amounted to 6.5 meters. Selected acoustic and geometric parameters of the measured spaces were presented in Table 1.
Apart from the reverberation time of the rooms, Table 1 presents their space and the following parameters of the rooms' acoustics (defined and described in detail i.a. in [6]): C80 – Clarity for music, LEF – Lateral Energy Fraction, STI – Speech Transmission Index, G – Sound Strength, BR – Bass Ratio, TR – Treble Ratio. Convolutions of spatial impulse responses were made individually for each choir voice.
B-Format signals obtained by a convolution of individual choir voices with spatial impulse responses of the selected rooms were decoded for a multi-channel loudspeaker setup in AGH Department of Mechanics and Vibroacoustics. The system is composed of sixteen-channel system put on Genelec 6010 speakers. Distribution of individual voices in the space was obtained by applying the technique of vector based amplitude panning method (VBAP). Apparent sources of sound, that is individual voices, were

placed in front of a listener in positions natural for the choir. Horizontal angles of the successive votes were chosen assuming a distance of 6.5 metres between the listener and the sources, as well as typical distance between the voices.

Table 1 – acoustic and geometric parameters of the selected spaces.

Recording no.	RT [s]	CBM [m3]	C80 [dB]	LEF	STI	G	BR	TR
1	1,07	750	6,9	0,51	0,68	4,7	1,08	0,73
2	1,17	900	7,7	0,46	0,68	5,2	0,75	0,88
3	1,82	1700	4,6	0,21	0,61	3,3	1,1	0,7
4	1,83	1650	4,2	0,47	0,58	7,3	0,88	0,76
5	2,09	2400	2,6	0,57	0,58	6,6	1,21	0,68
6	2,2	1500	0,7	0,76	0,51	7,7	1,03	0,68
7	2,87	3050	3,4	0,25	0,58	3,8	1,34	0,6
8	4,59	6050	3,9	0,1	0,56	3,7	1,04	0,66
9	4,74	6400	3,9	0,14	0,56	5,8	1,35	0,5
10	6,14	5950	0,9	0,27	0,46	5,7	0,96	0,61
11	6,53	9500	0,2	0,22	0,49	6,6	0,98	0,63

3 Listening tests

The aim of the listening tests was to establish how different variants of reverberation affected the perception. Due to the complexity of the phenomenon of reverberation and the applied method of convolution with response impulses, appropriate testing procedure was to be adjusted. In order to answer the question what reverb conditions are preferred by the listeners and what reverb parameters influence this dependency to the greatest extent, interdisciplinary method of multidimensional scaling MDS was applied [7]. MDS method enables estimation determining the number of space dimensions, the factors influencing the perception of the listeners.

Figure 1 – The position of listening tests with a multi-channel system installed in the anechoic chamber.

The concept of multidimensional scaling is based on the study of distance between the objects representing examined impulses on the basis of the examined relations between them. Mostly, the person evaluating a set of objects (e.g. by comparing pairs, triads, alignment etc.), estimates how much the objects differ from one another. In order to collect data describing preferences of audience in the current experiment, the method of comparing pairs was applied. The cardinality of the set of all possible pairs for eleven objects without repetitions was 55. Each test series consisted of two consecutive sound sequences (with the length of 15s), prepared for each room individually. The task of the listeners was to answer the following question: In which of the rooms presented as to the sounding would you prefer to listen to this kind of sounds? To define the question further, the following part was also added: Which of the examples presented you like the most? The experiment belonged to a group of preferences tests [8]. The listeners answered the questions using touch interface on a tablet computer. A listener stayed inside the speaker system in the sweet spot, and the test operator outside the system (as shown in Figure 1). The test lasted about 40 minutes, halfway a mandatory interval took place. Each example was announced by a lector and the listeners could repeat playback of each test series any number of times. A listening group consisted of twenty people aged 20 to 35 years, including 6 women. The listeners differed in terms of education and experience in working with music. All of the listeners were characterized by audiologically normal hearing.

4 The results

Having received the answers, it was calculated how the evaluations of individual listeners were correlated. The average value of the Pearson correlation coefficient calculated for the conducted test of preferences amounted to 0.38 for n=20. The null hypothesis assuming no correlation between the results of the particular listeners was not rejected in as much as 40 cases out of 180 possible, at a significance level of 0.95. Therefore, there was no foundation to accept an alternative hypothesis of significant correlation between the responses of all the listeners. In order to enable additional analysis of correlation between the responses of individual listeners, the correlation matrix was calculated and analyzed. Two clusters of strongly correlated results were found, which in some way explains the lack of significant correlation between the results of the preferences test. The results suggest the necessity of performing separate analyses for each of the groups (clusters), indicated schematically with I and II.

4.1 Preferences of the listeners

The results were interpreted in two ways. Firstly, the method of last squares by Thurstone-Mosteller was applied [8]. The results are based on analysis of probability of selection of the objects compared in pairs. The probability is determined by the number of cases, when a object *i* is selected as the preferred one, in relation to another object *j*. Scaling was made for two groups of listeners, the results between the listeners were significantly correlated with each other. Based on the graphical interpretation of the results shown in Figure 2, it may be concluded that the fundamental difference between the preferences of individual groups appears for extreme objects (with the shortest or the longest reverberation time). For group I, objects 1 and 2 are more preferred than 9, 10 and 11; for group II - conversely. For both groups reverb from the range 2-3 s is preferred the most out of all the other examples.

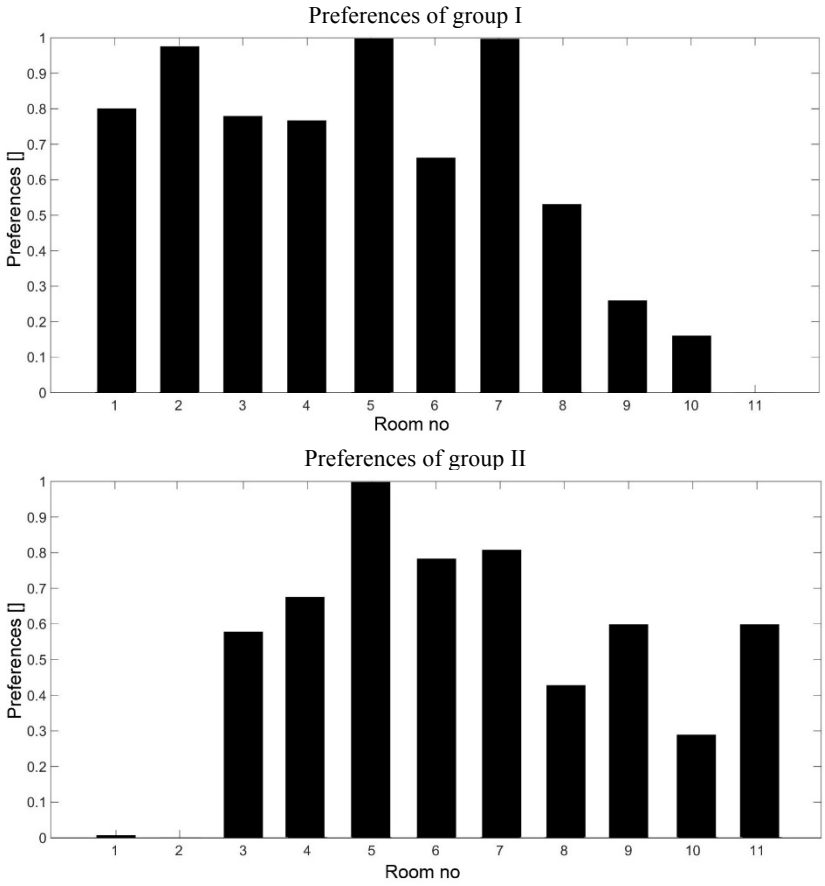

Figure 2 –Preferences of the listeners as to the samples tested, based on the comparison in pairs, according to the least squares method by Thurstone-Mosteller

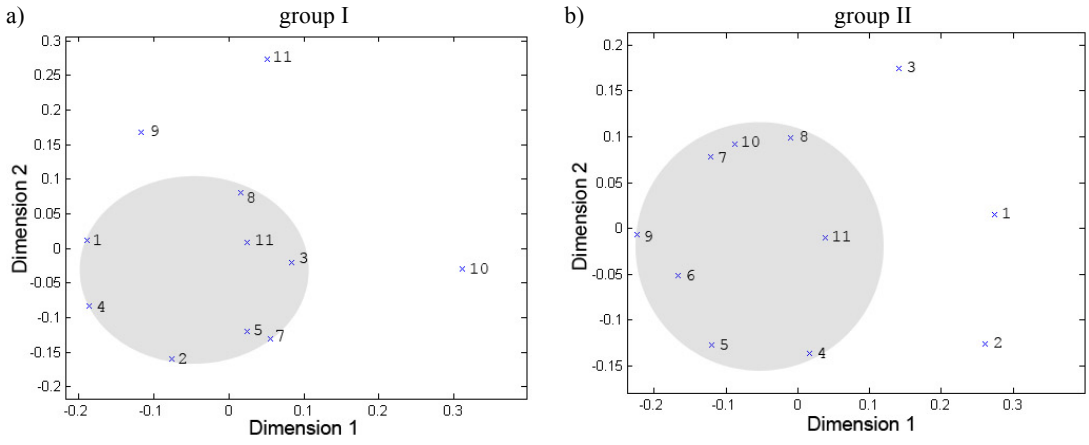

Figure 3 - Preferences of the listeners according to non-metric MDS method

In the second case, non-metric multidimensional scaling was made again, where the probability of occurrence of preference of one answer over the other was converted into the distance between them, according to the formula [7]:

$$\delta_{ij} = |P_{ij} - 0{,}5| \quad (1)$$

Where δ is the distance, and P is the number of instances when the subject i is preferred more than the subject j, divided by the number of listeners. Graphic interpretation of preferences for both the groups of listeners made using nonmetric MDS is presented in Figure . For both the graphs in Figure 3 objects grouping geometrically in a circle and objects definitely differing from the groups can be distinguished. In the case of group I, the objects have the longest reverberation time; in the case of group II, the objects have the shortest reverberation time. On the basis of the interpretation it may be concluded that the groups of listeners that have been distinguished differ in terms of what they definitely do not prefer. In the next stage, analysis was made on the correlation of the results concerning the perception of space with both the reverberation time and other acoustic parameters of the tested impulse responses. The results were shown in Table 2.

Table 2 – Coefficients of correlation of characteristics concerning the compared impulse responses with MDS dimensions for preference test. In bold are correlations relevant for the level of significance 0.95.

Group I	RT	C_{80}	BR	LEF	G
Dimension 1	0,56	**-0,62**	0,01	-0,25	-0,14
Dimension 2	**0,69**	-0,42	0,16	-0,44	0,12
Group II					
Dimension 1	-0,45	**0,70**	**-0,61**	0,07	-0,36
Dimension 2	0,34	-0,12	0,28	**-0,64**	**-0,75**

A significant correlation of preferences with the reverberation time was determined only for group I. In the case of group II, the correlation is also high, but below the 0.95 level of significance. The results of group I are also strongly correlated with Clarity C80, but there was no correlation with the other parameters. The results of group II show even stronger correlation with the Clarity C80, but they are additionally strongly correlated with all the other parameters analyzed: Bass Ratio, Lateral Energy Fraction LEF connected with spatial dimension and Sound Strength G.
On the basis of the results, there may be an attempt to draw the following conclusion: the listeners of group II paid much more attention to sound nuances independent of the length of reverberation. Moreover, the reverberation time was of least importance to them in the process of evaluating particular sounds; however, the group clearly identified objects of the longest reverb as non-preferred.

5 Summary and Conclusions

The study presents the progress and results of comparison of eleven sound samples which differed by the reverb. MDS method of multidimensional scaling was applied in the analysis, the listening was made with the use of ambisonic technique. The results were further analyzed statistically. During the analysis two groups of listeners were distinguished, the results of which were significantly correlated. The analysis of the results was made for each group independently. The conducted analyses showed that the most preferred reverberation time for choral music lies between 2-3 s. An interesting conclusion of the study is that the two groups referred extremely to reverberation times that were much longer or shorter than the preferred one. It other words, it may be stated that the groups differed in what they definitely do not prefer – it may be thus concluded that in the case of choral music, reverberation time that would be much shorter or much longer than about 2.5s is undesirable. However, the further conclusion is that the length of the reverberation time is not a crucial parameter in the case of choral music. For all the

listeners, the most relevant issue is the clarity of sound for music; however, some of the listeners defined parameters of timbre, space and power of sound as the most important ones.

References

[1] Izhaki, R. *Mixing Audio,* Focal Press, Londyn, 2008.

[2] Case, A. *Mix Smart: Pro Audio Tips For Your Multitrack Mix*, Focal Press, London, 2011.

[3] Azzali, A.; et al, *Reproduction of auditorium spatial impression with binaural and stereophonic sound system*, AES 118th Convention in Barcelona, In CD-ROM, 2005.

[4] Woszczyk, W.; Ko, D.; Leonard, B. *Convolution-based virtual concert hall acoustics using aural segmentation and selection of multi-channel impulse responses*, INTER-NOISE 2009, 4545-4552.

[5] Unger, M. P. *Historical Dictionary of Choral Music*, Plymouth (Great Britain), The Scarecrow Press Inc., 2010.

[6] Dunn, F.; et al, *Springer handbook of acoustics*, Springer, 2015.

[7] Borg, I.; Groenen, P. J. F. *Modern multidimensional scaling: Theory and applications*, Springer Science & Business Media, 2005.

[8] Kingdom, F. A. A.; Prins, N. *Psychophysics: a practical introduction*, London, Academic Press, 2010.

[9] Tsukida, K.; Gupta, M. R. *How to analyze paired comparison data*, Seattle, Washington Univ Seattle Dept of Electrical Engineering, 2011.