Objective and Subjective Evaluation of the Recording Acoustics of European Concert Halls: Results

(Objektive und subjektive Erforschung der Aufnahmeakustik europäischer Konzertsäle: Ergebnisse)

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Klaus - Hendrik LORENZ-KIERAKIEWITZ
PEUTZ GmbH, khl@peutz.de

Abstract

During the last VDT international convention in 2004 acoustical measurements of the main microphone positions of European concert halls were introduced (among these Wiener Musikvereinssaal, Jesus-Christ-Church Dahlem, Gewandhaus Leipzig, Stadtcasino Basel, Tonhalle Zürich, Concertgebouw Amsterdam, Royal Albert and Royal Festival Hall London) and the calculated acoustical parameters (EDT, T_{30}, T_{Center}, C_{80}, D_{50} and AL_{cons}) presented.

A first subjective listening test was performed with the auralised impulse-responses. Hereupon it succeeded to develop a new, concentradted listening test and to present it to the public in cooperation with a widespread magazine. The results of the evaluation of this second listening test are to be presented here and suggest, that no ideal or optimal acoustical conditions for recording acoustics, but rather different tastes (and therefore target groups) seem to exist. Based upon the evaluation of the judgements the results is interpreted and the relation of speech intelligibility and recording acoustics is analyzed.

1. Introduction

In the history of recording technique, some enclosures used for recordings of classical music turned out to have very special acoustical properties. Among these, especially have to be mentioned the Jesus-Christ-Church in Berlin-Dahlem (W. Furtwängler judged that this church could replace the old Berlin philharmonic hall destroyed in World War II at least for recordings), the Dvořák Hall of the Rudolfinum in Prague, the Klaus-von-Bismarck hall of the West German Radio in Cologne (WDR) and of course the golden hall of the Musikverein in Vienna, which is known also as one of the best concert halls of the world.[1,2] Moreover, every concert hall famous for its acoustical properties is used for music recordings, partly because artists (and potential record-buyers) prefer natural acoustics. Their sound is preferred by listeners of concerts and recordings and conserved by recording engineers.[3,4]

As any rooms designed for the performance of music, concert halls and recording venues can be seen as a kind of musical instruments; and in the case of historic enclosures, composers knew and took into account the acoustical conditions.

The question, why special rooms are preferred for the performance of music in general and for sound recordings in special can only be answered by correlation of subjective preference judgements to measured acoustical parameters.[5-15]

During the Ph.D. research project „Speech Intelligibility and 'Hörsamkeit' in European Concert Halls" at the university of Cologne, between 2000 and 2006 measurements were performed in 28 various (partly famous) concert halls and recording venues.[16-19]

The measurements provided monaural and binaural impulse responses (with almost identical equipment and settings) not only at typical listeners positions, but also two-channel responses at possible main microphone positions. These are regarded to be substantial for the possible sound of these rooms in recordings.

2. Target of the research

In this research work it was examined, if in concert halls and concert-hall like studios exist tendencies for an ideal or optimum recording acoustics or if several disjunctive tastes exist. Of course, every piece of music sounds best in the acoustical conditions the composer beard in mind.

Commonly subjective comparison listening tests[9-11,14] are used to clarify what makes a hall a good recording hall and which values or ranges of the acoustical parameters are preferred.

3. Measurement locations

In table 1, the 28 different measuring locations are presented.[12-14,17-21]

The choice of these rooms did not claim to be complete; it was attempted to include as many different historical or established halls in middle Europe; however, some very interesting (Philharmonic Hall Berlin, Liederhalle Stuttgart, Usher Hall Edinburgh, the „Glocke" Bremen) could not be measured until now.

The Dvořák Hall in Prague, the Gewandhaus in Leipzig and the Jesus-Christ-Church Berlin were included deliberately for their special sound in known recordings.[3,17] The sound of other halls was known by own recordings (Tonhalle Düsseldorf, Aula University of Cologne, St. Aposteln Cologne, Beurs Amsterdam, Studio MCO5 Hilversum) or concert visits (Klaus-von-Bismarck-Hall WDR Cologne).

In the enclosures, at possible main microphone positions (1 m behind and 1 m above conductor's head) two-channel impulse responses were measured in all 28 halls in unseated condition. In addition, eleven rooms were measured also in a condition were audience was simulated by application of stripes out of special polyester cloth spread over the seats, showing an absorption comparable to chairs seated with average audience.[16,22]

City	Hall	Date	Audience*	Microphone	Distance r/m	# seats	V /m³	V Spec m³/#
Nijmegen	De Vereeniging	06-06-00	U	4007	6,4	1200	12000	10,0
Haarlem	Concertgebouw	29-06-00	U	4007	9,5	1200	8000	6,7
Berlin	Jesus-Christus-Kirche	26-07-00	U	M296	9,0	≈ 300	10000	30,0
Berlin	Konzerthaus	27-07-00	U	M296	7,4	1575	15000	9,5
Leipzig	Gewandhaus	28-07-00	U	M296	4,4	1900	21000	11,1
Düsseldorf	Tonhalle	29-07-00	U	M296	3,9	2135	15000	7,0
London	Royal Albert Hall	06-08-00	U	M296	11,0	6080	86650	14,3
Köln	Aula Universität	16-03-01	U	M93	4,8	1100	ca.8000	7,3
Köln	St. Aposteln	16-03-01	U	K4	6,2	≈ 600	>30000	>40,0
Köln	WDR, Gr. Sendesaal	18-03-01	U	K4	≈ 5,0	700	6800	9,7
Hamburg	Musikhalle	27-03-01	U	M93	5,3	1993	11700	5,9
Amsterdam	Concertgebouw	03-08-01	PS, U	4007	4,6	2037	18780	9,2
Wien	Musikvereinssaal	20-08-01	S, U	M93	5,2	1598	15000	9,4
Basel	Stadtcasino	23-08-01	PS, U	M93	3,1	1448	10500	7,3
Duisburg	Mercatorhalle	24-08-01	PS, U	M93	4,8	1800	12500	6,9
Wermelskirchen	Ev. Stadtkirche	27-10-01	U	K4	5,1	700	ca.4000	5,7
Prag	Dvořák Hall	04-08-02	PS, U	M93	4,5	1104	10000	9,1
Zürich	Tonhalle	06-08-02	PS, U	M93	4,5	1546	11400	7,4
München	Herkulessaal	07-08-02	U	4007	3,6	1321	13950	10,6
Hilversum	Studio MCO5	19-11-02	U	M93	5,0	≈ 200	16000	80,0
Bochum	Audimax Universität	10-02-03	U	4007	4,8	1995	45000	22,6
Bad Kissingen	Regentensaal	22-07-03	PS, U	K4	4,5	936	ca.8000	8,5
Wiesbaden	Kurhaus	23-07-03	PS, U	K4	4,2	1310	12000	9,2
Rotterdam	De Doelen	07-11-03	S, U	K4	4,6	2242	24070	10,7
London	Royal Festival Hall	25-11-03	PS, U	M93	5,4	2901	21950	7,6
Amsterdam	Beurs van Berlage	18-12-03	PS, U	M93	3,8	≈ 1200	30000	25,0
Amsterdam	Muziekgebouw aan 't Ij	23-05-05	U	4007	4,3	730	7000	9,6
Düsseldorf	Neue Tonhalle	15-04-06	S, U	K4	≈ 5,5	1835	15850	8,6

*Table 1: Measured recording and concert halls, *Seating state: S = audience simulation (more than ca. 90%), PS = audience simulation (ca. 65-85 %), U = unseated*

4. Measurement technique, positions and execution

In the halls, 2-channel impulse responses were measured using a PC-based Maximal Length Sequence measuring system with almost identical components, amplifications and settings (MLS of degree 17B {18B for St. Aposteln}, Fs=44.1 kHz, resolution 16 Bit).[17]

The microphones were placed near the critical distance at possible main microphone positions at a height of 3,85 m above the parquet, ca. 1 m in front of the stage in the hall.

The two microphones were set up in AB (time of arrival) stereophony. An evaluation of the room-acoustical parameters requires omni-directional microphones to take into account the acoustical contribution of all room parts. The stereo base **b** varies in dependence of the maximum angle of sound incidence, if a uniform distribution of the entire orchestra all over the stereo basis between the loudspeakers is desired.[9] **b** results for a reproduction on precise loudspeakers (*Δt = 0,8* ms)[23] to (27 to 38 cm were used here):

$$\Delta t = \frac{\Delta l}{c} = b \cdot \frac{\sin\alpha}{c} \Leftrightarrow b = \frac{\Delta t \cdot c}{\sin\alpha} \qquad \text{(eq. 1)}$$

The chosen distances **r** of the left measuring microphone to the omni-directional sound source placed in the middle of the stage are given in table 1 and 2. A dodecahedron loudspeaker was used as sound source (omni-directional for frequencies below 2 kHz).

5. Evaluation of the objective parameters

By help of a specially written computer program, the acoustical parameters T_{30} (reverberation time), EDT (Early Decay Time), T_{Center}, C_{80} (Clarity), D_{50} (Deutlichkeit),[20] STI (Speech Transmission Index)[24] and AL_{cons} (Peutz 1988, Articulation Loss of CONSonants)[24,25] of the left microphone channel were evaluated for the octave bands with mid-frequency 63 to 8000 Hz. The results averaged over the octave bands with mid-frequencies 125 to 4000 Hz are shown in table 2, sorted by the measured values of AL_{cons}. STI and AL_{cons} were calculated from the omni-directional impulse response (Q_{source} = 1) instead of the for speech intelligibility measurements commonly used directional source with a directivity factor of Q= 2,5 for the human voice. As examples for the performed analyses the resulting graphs (ETC and EDT/T_{30} in dependence of the frequency) are presented in figure 1 and 2 for the two rooms Dvořák Hall in Prague and Klaus-von-Bismack Hall (WDR) Cologne.

Hall*	City	Seated chairs	V /m^3	T_{30} /s	EDT /s	BR (RT)	C_{80} /dB	D_{50} /%	T_{center} /ms	STI	r /m	AL_{Cons} P_{88}/%
Royal Festival Hall	London		21950	1,5	1,1	0,9	7,8	76	39	0,76	5,4	3,7
Gewandhaus	Leipzig		21000	2,1	1,2	0,9	6,2	75	54	0,73	4,4	4,0
Alte Tonhalle	Düsseldorf		15000	1,6	1,5	1,1	3,6	64	63	0,70	3,9	4,3
R. Festival Hall, PS	London	1900	21950	1,4	1,0	0,9	7,3	68	45	0,72	5,9	4,3
Musikhalle	Hamburg		11700	2,0	1,8	1,2	5,0	68	70	0,70	5,3	4,6
Stadtcasino, PS	Basel	1400	10500	2,1	1,9	1,1	5,1	70	64	0,68	3,2	4,7
De Doelen, PS	Rotterdam	1800	24070	2,1	1,3	0,9	6,9	76	48	0,74	4,4	4,8
Neue Tonhalle, S	Düsseldorf	1800	16500	1,7	1,5	1,1	5,5	67	57	0,70	5,5	5,1
De Doelen	Rotterdam		24070	2,2	1,7	0,9	5,7	71	59	0,71	4,6	5,2
Audimax Universität	Bochum		45000	2,2	1,9	0,9	6,0	62	69	0,71	4,8	5,2
Tonhalle, PS	Zürich	1200	11400	2,4	1,9	1,1	4,3	64	83	0,68	4,1	5,3
Stadtcasino	Basel		10500	2,3	2,2	1,1	4,4	66	75	0,68	3,1	5,4
Dvořák Hall, PS	Prag	750	10000	2,5	1,5	0,8	7,3	80	53	0,72	4,5	5,4
Beurs van Berlage	Amsterdam		30000	3,2	1,8	1,4	5,5	72	82	0,71	3,8	5,5
Regentensaal, PS	Bad Kissingen	800	8000	1,4	1,2	0,7	3,4	57	66	0,63	4,5	5,7
Neue Tonhalle	Düsseldorf		16500	2,0	1,8	1,0	4,6	64	97	0,67	5,0	5,7
Beurs van Berlage, S	Amsterdam	1000	30000	2,8	1,6	1,3	5,8	70	76	0,70	4,0	5,8
Concertgebouw, PS	Amsterdam	1400	18780	2,2	2,3	1,1	4,0	66	81	0,65	4,6	5,8
Muziekgebouw	Amsterdam		7000	1,9	1,6	1,1	4,6	60	72	0,64	4,3	5,9
Regentensaal	Bad Kissingen		8000	1,5	1,3	0,7	3,2	56	70	0,62	4,5	6,1
Herkulessaal	München		13950	2,1	1,7	1,0	5,1	71	64	0,68	3,6	6,2
Dvořák Hall	Prag		10000	2,7	2,5	0,7	3,3	63	94	0,60	4,5	6,7
Mercatorhalle, PS	Duisburg	1500	12500	2,4	2,0	1,1	2,6	59	94	0,60	5,2	7,3
Musikvereinssaal, S	Wien	1598	15000	2,4	2,0	1,1	2,6	59	94	0,60	5,2	7,3
Mercatorhalle	Duisburg		12500	2,6	2,6	0,8	2,6	56	107	0,58	4,8	7,4
Kurhaus, PS	Wiesbaden	1000	12000	1,9	1,8	1,0	2,5	53	90	0,58	4,2	7,5
Studio MCO5	Hilversum		16000	2,5	2,0	1,0	3,6	64	91	0,60	5,0	7,8
Kurhaus	Wiesbaden		12000	2,0	2,0	1,0	2,1	52	99	0,57	4,2	8,0
Tonhalle	Zürich		11400	3,1	2,8	1,1	2,1	53	126	0,60	4,5	8,0
Concertgebouw	Amsterdam		18780	2,6	2,6	1,0	0,4	44	138	0,54	4,6	8,7
Konzerthaus	Berlin		15000	2,7	2,3	1,1	1,5	43	121	0,55	7,4	8,8
Aula Universität	Köln		8000	2,1	1,5	0,9	2,6	47	92	0,57	4,8	9,6
WDR, Sendesaal	Köln		6800	1,7	1,8	0,9	-0,5	40	118	0,50	5,0	9,8
Ev. Stadtkirche	Wermelskirchen		4000	2,3	2,1	0,9	1,3	49	117	0,56	5,1	9,8
Musikvereinssaal	Wien		15000	2,9	2,4	1,0	1,7	54	118	0,58	5,2	9,9
Royal Albert Hall	London		86650	2,5	1,7	0,9	2,9	45	96	0,58	11,0	9,9
De Vereeniging	Nijmegen		12000	2,2	2,2	1,2	-0,8	26	144	0,48	6,4	11,1
Concertgebouw	Haarlem		8000	2,4	2,5	1,1	-2,5	26	168	0,45	9,5	13,6
Jesus-Christus-K.	Berlin		11700	2,5	2,8	0,7	-0,9	31	156	0,50	9,0	13,9
St. Aposteln	Köln		30000	7,7	6,3	1,2	-3,1	29	309	0,40	6,4	24,5

*Table 2: Evaluation results of the measured recording and concert halls left main microphone positions: shown are averages over the 6 octave bands with mid frequencies 125 to 4000 Hz, sorted by AL_{cons} [*Seating state: S = audience simulation (more than ca. 90%), PS = audience simulation (ca. 65-85 %), U = unseated]*

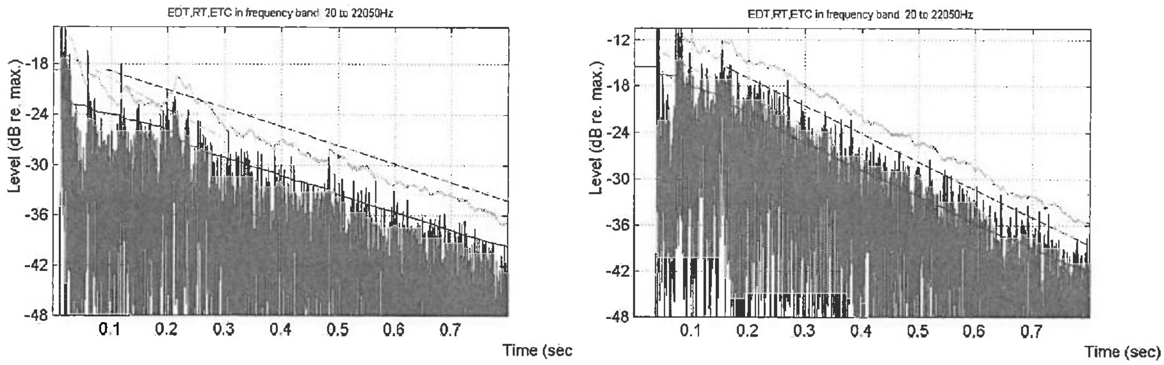


Figure 1: Broad-band ETCs of the left main microphone position in Dvořák-Hall Prague (left) and Klaus-von-Bismarck Hall WDR Cologne (right)

6. Judging subjective quality of recording acoustics by comparison tests

The 38 measured two-channel impulse responses of the main microphone positions out of the 26 halls (in total 37 situations) were now available for a subjective quality judgement of recording acoustics by comparison listening tests.[6-10,13-14]
Preferences for music recordings are tested best with musical stimuli as source signals.
So it was chosen to perform the preference listening tests with the impulse responses convolved with non-reverberant recorded music rather than pure impulse responses, for one has to gain some experience to judge impulse responses without being convolved with music. Earlier experience with quality judgement listening comparison tests revealed, that the maximum stimulus length is about 15 sec. in order to be able to identify small timbre changes in direct comparison and to avoid an overflow of the short-time memory.[9,10]
Because the test listeners did not have any information over the identity of the stimuli, these tests are true blind comparison tests.
In spite of the fact that the impulse responses were measured with a single sound source, a fair auralisation of the sound in the venue is possible with reproduction by loudspeakers.
Every test person was asked to judge the stimuli listening by their own stereo-equipment to ensure that every test person was able to listen under his/her well-known listening conditions (they normally use to judge the sound quality of recordings). If the equipment used has any effect on the sound of the stimuli, the effect is constant for every sample.
Strictly speaking, results gained from these kinds of listening tests are valid only for the piece of music chosen as stimulus. However, it was tried to select a piece which is the least characteristic for a special style or epoch among the non-reverberant recordings available at that time. Therefore we excluded vocal, high romantic, ancient and contemporary music. Such a limitation to only one selected piece of music will ever be a compromise. An alternative is to repeat the same kind of tests with different pieces of music from different styles and times to be able to find the listeners' ideals for the stimuli.[9,10]
The evaluation of the listeners' judgements should be correlated with the analyzed parameter values from the measured impulse responses.[6] To gain some statistical relevance, a large number of test persons is needed.

Listening test one

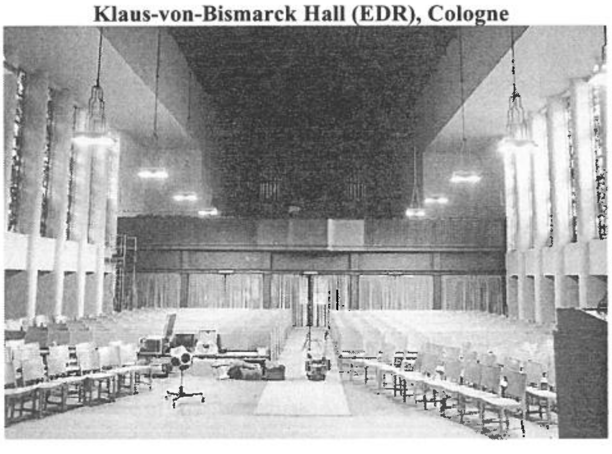
A first Test CD was distributed during the last international conference of audio in 2004 in order to reach a broad public of professionals. The non-reverberant music, a piece out of the overture of the opera "Ruslan and Ludmilla" by the Russian composer M. Glinka was taken from a Deonen-CD containing recordings of the Osaka Philharmonic Orchestra in a room which was made almost completely absorbing.[26]
The test listeners were asked to sort the 37 samples to their favorite order of quality – by far not an easy task - and to note this order on the supplied questionaire. However, the very low number of responses did not allow an evaluation of any statistical relevance. Therefore, a completely improved test was designed, taking into account the comments on the first test: it turned out to be a much too long and difficult task, even for listeners keen on the matter to sort 37 samples in a order of quality without a guiding strategy.

Listening test two

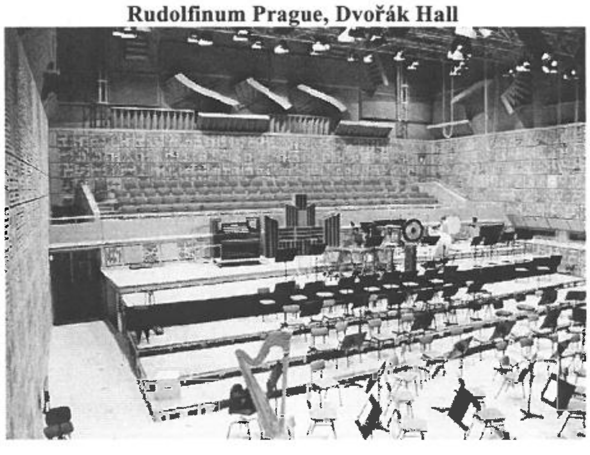
Therefore the number of samples was reduced from 37 to a selection of four different typical recording venues: the Klaus-von-Bismarck Hall (WDR) Cologne, the Dvořák Hall Prague, the Jesus-Christ-Church Berlin and the Studio MCO5 Hilversum.

Klaus-von-Bismarck Hall (EDR), Cologne

Rudolfinum Prague, Dvořák Hall



Jesus-Christ-Church Berlin



Studio MCO5 Hilversum

Figure 2: Inner views of the four recording halls selected for listening test two

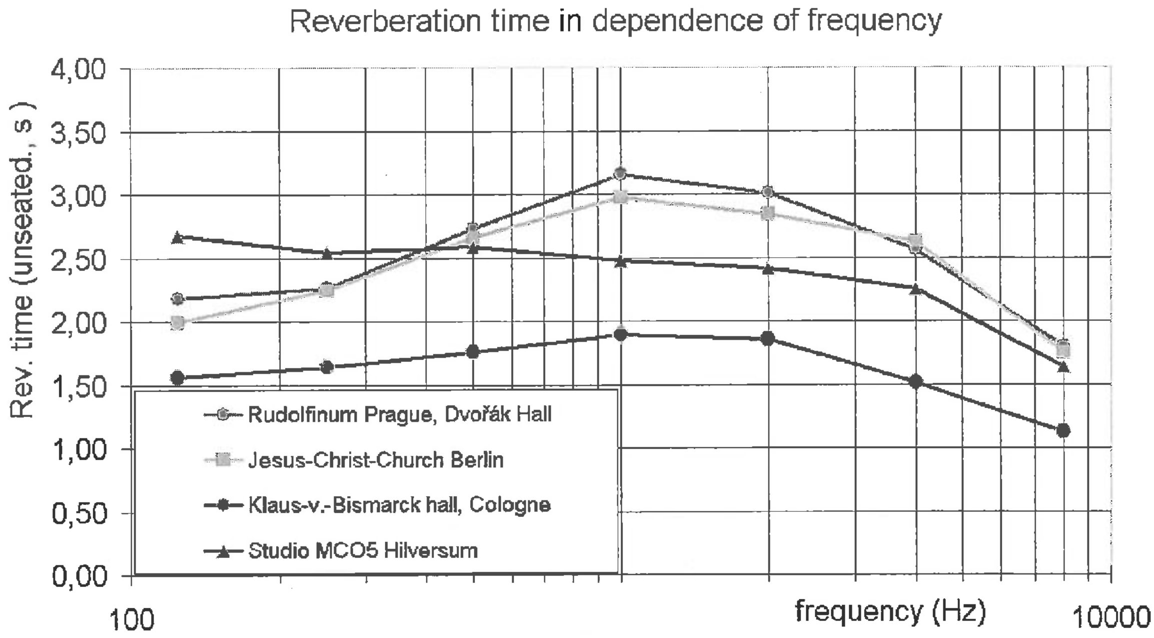


Figure 3: Reverberation time T_{30} in dependence of the frequency for the left main microphone position in the four recording locations in listening test 2

Halls (unseated)	City	V /m³	T_{30} /s	EDT /s	BR (RT)	C_{80} /dB	D_{50} /%	T_{center} /ms	STI	r /m	AL_{Cons} P_{88}/%
Dvořák Hall	Prag	10000	2,7	2,5	0,7	3,3	63	94	0,6	4,5	6,7
Studio MCO5	Hilversum	16000	2,5	2,0	1	3,6	64	91	0,6	5,0	7,8
WDR, Sendesaal	Köln	6800	1,7	1,8	0,9	-0,5	40	118	0,5	5,0	9,8
Jesus-Christus-K.	Berlin	11700	2,5	2,8	0,7	-0,9	31	156	0,5	9,0	13,9

Table 3: Acoustical parameters of the recording halls selected for test two

This concentration on four famous and typical recording halls allowed to give the test persons a pre-defined randomly found order of 15 (including three identical) pairs, for which the test-listeners were asked to decide, whether the first or the second stimulus in the current pair was the most favorable to them. The test came along with the following questionnaire:

In this listening test the recording sound of the halls is to be judged by loudspeakers. Therefore you are presented 15 pairs of sound samples for comparison. Please decide for every pair, if you like the first sample within the pair like best or sthe second sample. Example: pair 11 = A. Global questions: Age: _____; gender: __; nationality: ____ Native language: _______; profession:_______	Musical experience: ____________________________ pair: A B A B A B A B pair 01: ☐ ☐, pair 02: ☐ ☐, pair 03: ☐ ☐, pair 04: ☐ ☐ pair 05: ☐ ☐, pair 06: ☐ ☐, pair 07: ☐ ☐, pair 08: ☐ ☐ pair 09: ☐ ☐, pair 10: ☐ ☐, pair 11: ☐ ☐, pair 12: ☐ ☐ pair 13: ☐ ☐, pair 14: ☐ ☐, pair 15: ☐ ☐.

Figure 4: Questionnaire for listening test two (translated from the German original)

To reach much broader public, the test was distributed in co-operation with a widespread German Hifi-Magazine on a CD.[19] But therefore the right to copy the non-reverberant music had to obtained. However, our request was rejected by the new copyright owner (another Japanese company recently bought all rights of Denon-recordings). They even refused permission of scientifically publishing excerpts of the non-reverberant recordings CD, originally made for scientific purposes. So another non-reverberant recording had to be used: we kindly asked for the right to use an excerpt from the "Jupiter" Symphony of W. A. Mozart recorded in 1969 by the BBC with the English Chamber Orchestra under the conductor Kenneth Montgomery in an non-reverberant room[27] and were allowed to use it.

7. Evaluation of the subjective judgements

Until now, 50 test persons contributed to this last listening test. The evaluation and the results are to be presented here. At first, it was tried by re-arranging the test-persons and order of questions to identify possibly existing groups of listeners, having judged the questions similarliy.

It turns out, that the judgement patterns are mostly not of random nature: they reveal characteristic judgements of *four* different taste groups, 'A' – 'D'.

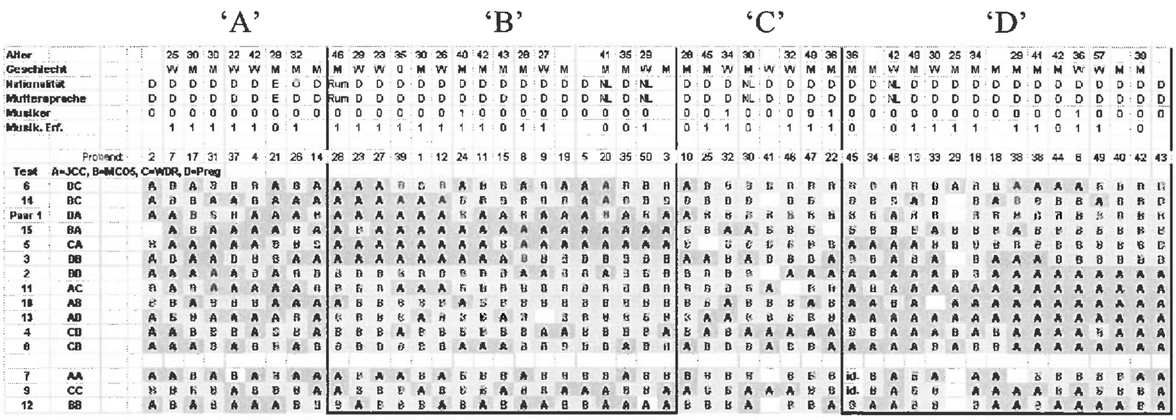


Figure 5: Map of the judgements sorted by the four taste groups 'A', 'B', 'C', 'D'

Every two groups have about the same size: 'A': 18%, 'C': 16%, 'B': 34%, 'D': 32%.
The largest groups 'B' and 'D' gave almost diametrically opposed ratings in the test.

Deeper analysis shows characteristic properties in the groups:

Preferred order	Halls (unseated)	City	D_{50} /%	AL_{Cons} P_{88}/%	T_{center} /ms	C_{80} /dB	STI	V /m³	BR (RT)	T_{30} /s	EDT /s
1	WDR, Sendesaal	Köln	40	9,8	118	-0,5	0,5	6800	0,9	1,7	1,8
2	Studio MCO5	Hilversum	64	7,8	91	3,6	0,6	16000	1	2,5	2,0
3	Jesus-Christus-K.	Berlin	31	13,9	156	-0,9	0,5	11700	0,7	2,5	2,8
3	Dvořák Hall	Prag	63	6,7	94	3,3	0,6	10000	0,7	2,7	2,5
	Correl.coeff. with order		**0,09**	**0,14**	**0,20**	**0,22**	**0,30**	**0,34**	**-0,75**	**0,90**	**0,93**

Table 3a: Preferred order of the 4 halls in test 2 for taste group 'A'

Preferred order	**Halls (unseated)**	**City**	**BR** (RT)	**V** /m³	**EDT** /s	T_{30} /s	**STI**	C_{80} /dB	T_{center} /ms	D_{50} /%	AL_{Cons} P_{88}/%
1	Dvořák Hall	Prag	0,7	10000	2,5	2,7	0,6	3,3	94	63	*6,7*
2	Studio MCO5	Hilversum	1,0	16000	2,0	2,5	0,6	3,6	91	64	*7,8*
3	WDR, Sendesaal	Köln	0,9	6800	1,8	1,7	0,5	-0,5	118	40	*9,8*
4	Jesus-Christus-K.	Berlin	0,7	11700	2,8	2,5	0,5	-0,9	156	31	*13,9*
	Correl.coeff. with order		**-0,09**	**-0,14**	**0,20**	**-0,41**	**-0,89**	**-0,90**	**0,92**	**-0,93**	**0,96**

Table 3b: Preferred order of the 4 halls in test 2 for taste group 'B'

Preferred order	**Halls (unseated)**	**City**	**BR** (RT)	**V** /m³	**EDT** /s	T_{30} /s	**STI**	C_{80} /dB	T_{center} /ms	D_{50} /%	AL_{Cons} P_{88}/%
1	Jesus-Christus-K.	Berlin	0,7	11700	2,8	2,5	0,5	-0,9	156	31	*13,9*
2	WDR, Sendesaal	Köln	0,9	6800	1,8	1,7	0,5	-0,5	118	40	*9,8*
3	Studio MCO5	Hilversum	1,0	16000	2,0	2,5	0,6	3,6	91	64	*7,8*
4	Dvořák Hall	Prag	0,7	10000	2,5	2,7	0,6	3,3	94	63	*6,7*
	Correl.coeff. with order		**0,09**	**0,14**	**-0,20**	**0,41**	**0,89**	**0,90**	**-0,92**	**0,93**	**-0,96**

Table 3c: Preferred order of the 4 halls in test 2 for taste group 'D'

In the target group ('B') the order of preference correlates best with increasing values of speech intelligibility indicator AL_{cons} resp. the inverted order in group 'D'.

The judgements in 'A' are less consistent than in 'B' and 'D'; the order of preference correlates best with decreasing values of EDT and T_{30}.

The ratings of group 'C' are not consistant at all, so it was not possible to extract a reliable preference order for this group. A correlation of the acoustical parameters on the judgements of these group therefore seems doubtful.

Being aware of the danger of misinterpreting the data because of the small numbers of tests subjects, a statistical basic analysis was tried on the given data.

Pref. Nr.	**A**	**B**	**C**	**D**
1	WDR,	Prag	?	JCC
2	MCO5	MCO5	?	WDR
3	Prag	WDR	?	MCO5
4	JCC	JCC	?	Prag
Fraction of test persons (%)	18	**34**	*16*	32
Averaged age (years)	*30*	34	36	**38**
Gender (100: m, 0: f)	*57*	63	63	**73**
Nationality (0: German, 100: other)	**29**	19	13	*6*
First language (0: German, 100: other)	14	**19**	13	*6*
Prof. musician (100: yes, 0: no)	*0*	6	**25**	6
Musical experience (100: yes, 0: no)	**86**	79	71	*67*

Table 4: Statistical data for the different groups

Whereas in the largest group 'B' there is the highest fraction of not german as first language speaking listeners, the mostly german and german speaking members of 'D' show the highest averaged age. Less women belong to 'D' than to the other groups as well as subject judging themselves as musically experienced.

In 'A', the statistically youngest group, there is the highest fraction of not german listeners, and there are the least professional Musicians, but more people than in the other groups claim to have musical experience. Moreover, almost as many female as male test participants are in that group.

The inconsitently rating group 'C', the smallest of the four, astonishingly shows the highest percentage of professional musicians.

8. Results of the study

All recording halls examined, including the four examined in test two in more detail, are well-established recording venues. Thus it was not expected, that it would be trivial to the test listeners to judge the differences in the auralizations.

However, the results prove, that the rating patterns are mostly not of random nature. The judgements of the 50 listening test persons prove also, that obviously there is no uniform ideal or optimum about what recording venues are preferred within a group of good ones.

The answers of the test persons rather suggest that for this circumstances of test two (concentrated to four halls the test persons provided with a randomly defined, but fixed sequence of stimuli pairs) split up into 4 groups there exist 4 different goups of listeners and thus at least 3 different tastes – and target groups, two smaller and two larger ones. The larger pair of groups rates the given stimuli pairs diametrically opposed.

In two of the the target groups the order resp. the inverted order of preference correlates best with encreasing values of speech intelligibility indicator AL_{cons}, in one other group the order of preference correlates best with decreasing values of EDT (T_{30}).

These results suggest a strong correlation of the preference of these recording locations with decreasing EDT (T_{30}) for one and decreasing/encreasing AL_{cons} for other tastes.

A last group obviously made so contradictory judgements, that it was not possible to extract a consistent preference order for this group, so an influence of the acoustical parameters on the judgements of these group seems doubtful.

With proper caution, some statistical data are given for every of the taste groups.

9. Future prospects

The four recording halls in test two provide not unsimilar acoustical properties. Although, in this study it was possible to distinguish the test-listeners into four different groups of taste. However, a further listening test should be used to investigate whether additional room samples with more extreme values (e.g. T_{30} in the range of 1,0 to 4,0 sec.), if the tendencies described above converge at optimum values.

Further tests have to reveal, if the statistical data given for the taste groups will turn out to be characteristical.

Beyond, it would be interesting to extend the focus of this investigation to the reception of the recording acoustics of music of different cultures, styles and epochs (world music, choir music) to enlight a possible correlation between acoustical parameters like speech intelligibility and audience preferences for recording venues.

Some intermediate results of this study influenced the acoustical consulting of the refurbishment of the Tonhalle Düsseldorf, which opened in november 2005 with great success and will be used for classical concerts as well as recordings.[28]

To avoid juridical complications and to have a state-of-the-art non-reverberant recording at disposal for future listening tests, a new, multi-channel high resolution (24 bit, 96 kHz) non-reverberant recording was made. A recording session of the Aachen student orchestra took place in the Institute of technical acoustics of the RWTH Aachen in July 2005[29] resulting in some high-quality non-reverberant samples of the Carmen-Suite by Bizet, which can be used as raw auralisation material in listening tests in the future.

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