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A Comperative Study of Four Concert Halls in Istanbul: Correlation of Subjective Evaluation with Objective Acoustic Parameters

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The relation between the objective and subjective acoustic parameters, which define the impacts of a hall's physical acoustical qualities on the audience, has been reported in many studies. In this study, the objective parameters of four concert halls in Istanbul were examined in detail. The halls are used by many different performances, from concerts to ballet or opera. The purpose of this paper was to attempt a comparison of the objective measurements with the subjective impression of halls which were examined in a previous study. The results of the subjective evaluations have been reported at another congress. This paper presents (a) the rankings of the four halls given by ordinary concert-goers and musicians respectively, and (b) a comparison of the objective measurements with typical ISO 3382 values and the subjective ratings. The measured octave band quantities are RT, EDT, G, C80, TS and D50.

1 Introduction

Subjective evaluation studies, which have begun with Beranek [1], were followed by many studies, and as a result of these studies several parameters have been put forward. In conducting subjective judgment studies, the general approach has been to interview acoustic experts, musicians [1,2,3], and frequent concert-goers [4,5] because they have a better understanding of acoustics than ordinary concert-goers. Instead of only interviewing musicians, ordinary concert-goers were also included in the comparisons. Although each group gave different subjective ratings for each hall, they agreed on which concert hall was the best and which was the worst. As can be seen by the results of the comparisons of the subjective judgments, the objective acoustical measures reveal that the acoustic quality of the newer halls was better than that of the oldest one [6]. Of the measured six parameters, only the results of the RT, EDT, G and C80 values are presented in this paper.

2 Surveyed Halls

In order to be considered for evaluation, a concert hall had to have a minimum seating capacity of 800, hold performances regularly, and these performances had to be given by a large orchestra. Furthermore, the hall had to be in a location that was easily reachable by concert-goers. Four halls in Istanbul that fit these criteria were then selected for the study. The halls are used for many different performances, from concerts to ballet or opera. Short descriptions of the studied halls are given in Table 1. The range in volumes is from 5635 to 19016m^3 and shapes differ from rectangular to fan shape in general. The AKM has a proscenium stage and other halls have variable form stages. The CRR, AKM and LK feature balconies, while the IS hall has no balconies.

Hall	Year	V(m³)	Na (m²)	St (m²)	V/Na	V/St	L(m)	D(m)	W(m)	H(m)
IS	2000	5635	802	867	7.02	6.5	45.27	35.27	34	10.7
LK	1996	19016	1933	1809	9.84	10.51	43.9	28.3	26	10.8
CRR	1989	6332	844	1079	7.5	5.87	33	25.6	24.7	12.53
AKM	1977	12040	1304	1107	9.23	10.87	35.84	24.9	26	6.58

Table1. Architectural features of the studied halls

IS – IS Bank Performing Hall LK- Lutfi Kirdar Congress Center Hall

CRR-Cemal Resit Rey Concert Hall AKM-Ataturk Cultural Center

3 Objective measurements

3.1 Source and receiver positions

The measurements were carried out without audiences. Wherever possible up to four omnidirectional loudspeakers were placed on stage, near the conductor position S_1 on the center line of the hall. The number of receiver positions was determined by the symmetry, the size and the number of balconies. The architectural plan including receiver and source positions of each hall are given in Figure 1.

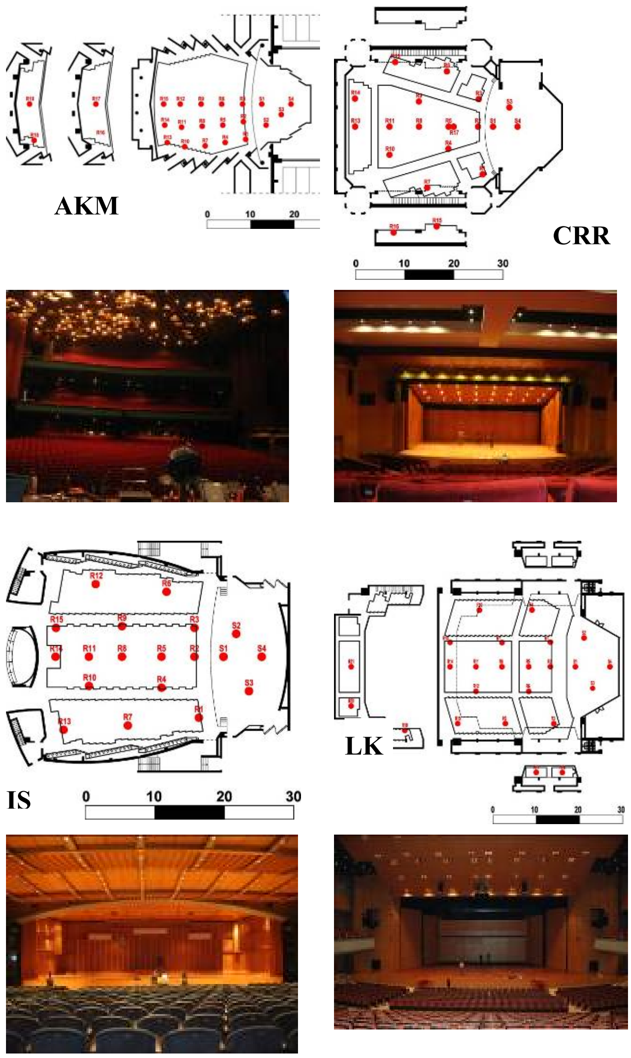

Figure 1. The number of source and receiver positions

3.2 Measuring systems

Six acoustical parameters – reverberation time, RT, early decay time, EDT, clarity C80, strength, G, center time TS and distinctness, D50 were measured in six frequency bands following the procedures of ISO 3382 [7]. The sources were put 1.5m and the microphones 1.2m above the ground. For the measurements, the 'DIRAC' software installed on a personal laptop, a sound source, a power amplifier, microphones and a sound pressure level meter were used. The measuring system was calibrated for measuring G values [8]. The setup is shown in Figure 2.

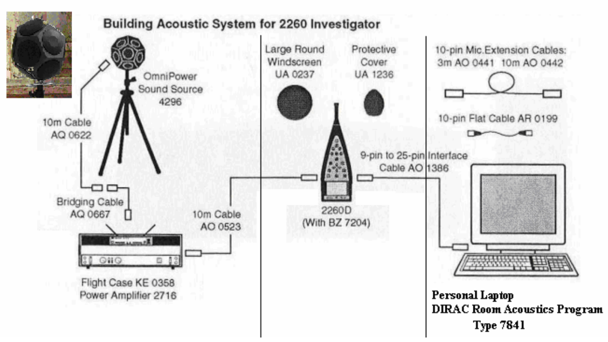

Figure 2. The equipment used in the measuring process

4 Subjective analysis

4.1 Participants of the study

A total of 331 people (184 female (56%) and 147 male (44%) participated in the survey. 261 (78.9%) questionnaire forms were filled in by ordinary concert-goers and 70 (21.1%) by the musicians who also answered the musicians' questionnaire. The age of the audience ranged from 15 and 89 years. Most of the ordinary respondents (82%) had attended at least 1 or 2 concerts in the hall that was being surveyed and nearly all ordinary respondents (88%) had attended at least 1 or 2 concerts in another hall in the previous year. A musical experience was also found among ordinary respondents with 28% being able to play a musical instrument, and 6.5% playing or singing in a classical music group. Moreover, 51 % of the ordinary respondents owned a recording of at least one of the pieces being played and so would bring experience and knowledge of the works being performed.

The questionnaire was completed by a total of 96 musicians, 43 (44.8%) of them being female and 53 (57%) of them being male. The occupational experience of the musicians in years was as follows: 2-5 years, 0.1%; 6-10 years, 11.46%; 11-15 years, 36.46% and (>16), 47.9%. From this data we see that 85% of the musicians have more than 10 years of experience. Of the musicians that were interviewed, 55.2% played a string instrument, 28.14% played a woodwind instrument, 5.2% played a percussion instrument and 4.16% played the piano.

4.2 Questionnaire design

Participants were asked to rate the acoustic qualities of each hall on a scale from 1-10. The parameters that were evaluated were clarity, reverberation, envelopment, intimacy, loudness, warmth, balance (low-mid fre.), balance (mid-high fre.) and balance (orchestra-soloist). The meaning of each value in the rating scale is given below.

1	2	3	4	5	6	7	8	9	10

POOR MEDIOCRE REASONABLE GOOD VERY GOOD

In addition to having participants evaluate the above-mentioned acoustic qualities, participants were also asked to rate the overall acoustic impression on a scale of 1-7 in order to express their impression with more precision. The explanation of overall acoustic impression ratings is given below.

1	2	3	4	5	6	7
VERY POOR	POOR	MEDIOCRE	REASONABLE	GOOD	VERY GOOD	EXCELLENT

4.3 Results of the subjective evaluation

The results of the ordinary concert-goers' survey and the musicians' survey were analyzed separately. The data were statistically analyzed using SPSS ver.15.0 (Statistical Package for Social Sciences). Acoustical attributes that were analyzed in the subjective part of the study are given in Table 2.

Acoustical Parameter	Musician	Audience
Clarity	X	X
Reverberation	X	X
Envelopment	X	X
Intimacy	X	X
Loudness	X	X
Support	X	
Warmth	X	X
Ensemble	X	
Adaptation	X	
Visual Impression	X	X
Balance(low-mid fre.)	X	X
Balance(mid-high fre.)	X	X
Balance(orchestra-soloist)	X	X
Overall Enjoyment		X
Overall Acoustic Impression	X	X

Table 2. Analyzed acoustical parameters

The results of the overall acoustic impression of musicians and ordinary concert-goers of each hall are summarized in Figure 3 and Table 3. The ordinary concert-goers rated the acoustic qualities of each concert hall higher than the musicians. Although each group gave different ratings for each concert hall, they agreed on which concert hall was the best and which was the worst. AKM received the lowest score while CRR received the highest score from both groups. Correlation of overall acoustic impression with 9 variables for each hall resulted in the correlation matrix set out in Table 4.

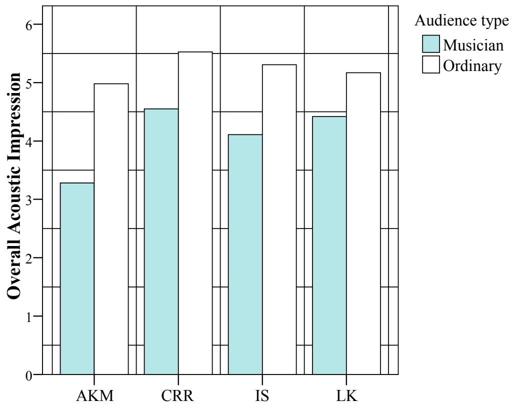

Figure 3. Ratings of overall acoustic impression by different audience groups

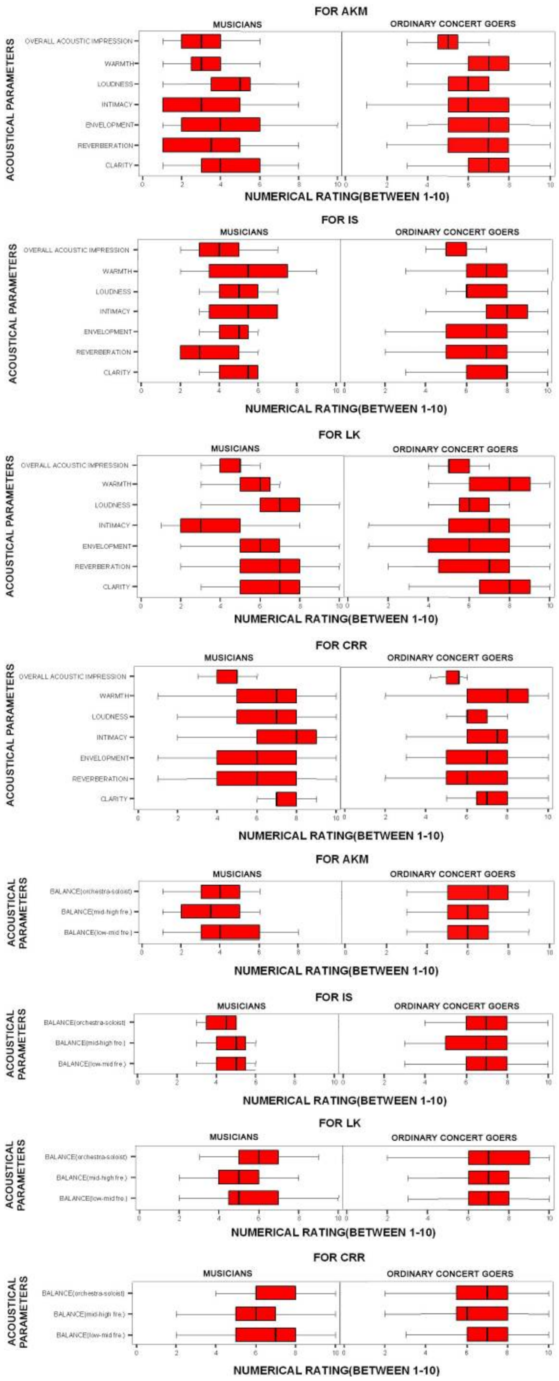

Table 3. Max., min. and median values of acoustical parameters

MUSICIAN		ORDINARY CONCERT GOERS	
↑	BALANCE CLARITY WARMTH REVERBERATION LOUDNESS ENVELOPMENT INTIMACY	↑	CLARITY BALANCE WARMTH ENVELOPMENT REVERBERATION INTIMACY
CRR LK IS AKM	↑ **Good** **Mediocre**	CRR IS LK AKM	↑ **Very good** **Good**

Table 4. Acoustical quality ratings of halls by two audience groups

5 Findings based on the objective measurements

5.1 Results of the objective measurements

The complete set of measurements of RT, EDT, C80, G, TS and D values is listed in Table 5. The suffix "L", "Mid", "3" and "mean" designate the average over 125 and 250, 500 and 1000, 500, 1000-2000, 125-4000 Hz, respectively.

	AKM	IS	LK	CRR
EDTlow	1,44	1,04	1,54	1,19
EDTmid	1,27	1,11	1,59	0,99
EDT3	1,25	1,11	1,56	0,96
EDTmean	1,29	1,06	1,49	1,01
RTlow	1,39	1,07	1,56	1,18
Rtmid	1,21	1,19	1,67	1,11
RT3	1,18	1,23	1,65	1,11
RTmean	1,22	1,16	1,57	1,11
Glow	13,76	16,50	13,27	15,72
Gmid	13,37	16,21	14,51	15,53
G3	13,17	16,21	14,32	15,30
Gmean	13,11	15,97	13,53	15,14
Clow	11,02	5,69	11,36	5,54
Cmid	9,47	4,25	11,11	3,68
C3	9,60	4,15	11,07	3,73
Cmean	9,84	4,56	10,75	4,27

Table 5. Average objective acoustical parameters of the halls

In this study objective measurements of C80, EDT, RT and G have been used as the predictors of subjective opinions clarity, reverberance and loudness respectively.

5.2 Hall average values

The combination of acoustic measurements at different parterre and balcony positions can result in a large amount of data that may at first hide the important acoustic features. In order to overcome this situation to some extent, the acoustic parameter values in Table 5 have been evaluated separately for the balcony and parterre positions (Figure 4). In the individual halls the number and distribution of receiver points were as follows (Table 6): AKM, fifteen parterre, two on first balcony, two on second balcony; the balcony measuring points were analysed together. CRR, fifteen parterre, two on the balcony; the balconies are placed on the sides of the hall. LK, fifteen parterre, six on the balconies, with two on the side and four on the rear balcony. As in the case of the AKM, independently of their position, all balcony points were included in the average.. IS, fifteen parterre; this hall has no balconies. For comparison purposes, the receiver points are indicated in the figures above.

Hall name	Receiver points: Main floor	Receiver points: Balcony	Source positions
IS	15	-	4
LK	15	6	4
CRR	14	2	3
AKM	19	4	3

Table 6. Source and receiver positions

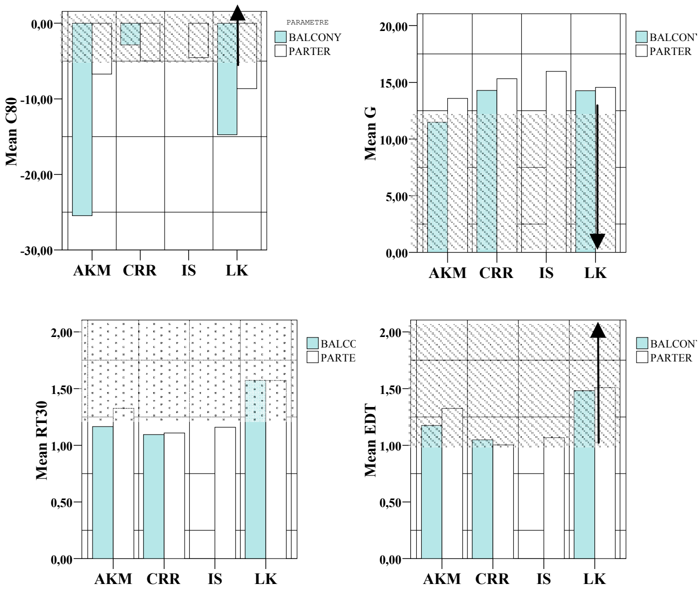

Figure 4. Mean values measured in parterre and balcony positions. The dashed area indicates the typical values of ISO 3382

In comparative studies of different halls, variance analysis is often used for room acoustics. With this analysis, the significance of the "F" values of the acoustic parameters calculated for different points in the four concert halls were checked in a confidence interval of 0.01. If the calculated "F" values exceed the critical "F" value, the deviation is considered to be significant within the chosen confidence interval.

Comparison of the balcony and parterre receiver positions reveal a significant difference only for the C80 parameter. (Table 7). The large difference in the C80 parameter for balcony and parterre points strongly suggests that an analysis on the basis of an average value for this parameter would not yield a correct result.

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	3500,60	3	1166,86	17,86	,000
Within Groups	9144,46	140	65,318		
Total	12645,0	143			

Table 7. Significance check of the C80 parameter difference

Comparison of the acoustic parameter values with the typical values published in ISO 3382 (Table 8) shows that the average C80 values for AKM and LK are far outside the typical values. However, if the balcony receiver points are not considered, the values for C80 and EDT are close to the lower limit of the typical values and the G values close to the upper limit. In all halls, the first reverberation energy is low and problems with the clarity of sounds are a certainty. As most of the halls are multipurpose buildings, EDT values near the lower limit of the typical values may be considered acceptable.

Subjective listener aspect	Acoustic quantity	Single number frequency averaging (Hz)	Just Noticeable Difference (JND)	Typical range[a]
Subjective level of sound	Sound Strength, *G*, in dB	500 to 1000	1 dB	-2 dB; +10 dB
Perceived reverberance	Early Decay Time, EDT, in s	500 to 1000	Rel. 5 %	1,0 s; 3,0 s
Perceived clarity of sound	Clarity, C_{80}, in dB	500 to 1000	1 dB	-5 dB; +5 dB
	Definition, D_{50}	500 to 1000	0,05	0,3; 0,7
	Centre Time, T_S, in ms	500 to 1000	10 ms	60 ms; 260 ms
Apparent Source Width, ASW	Early Lateral Energy Fraction, LF or LFC	125 to 1000	0,05	0,05; 0,35
Listener Envelopment, LEV	Late Lateral Sound Level, LG, in dB	125 to 1000	Not known	-14 dB; +1 dB

[a] Typical range is for frequency averaged values in single positions in non-occupied concert- and multi-purpose halls up to 25 000 m³.

Table 8. Typical values in ISO 3382

5.3 Within hall variations

In order to determine the change in acoustic parameters as a function of the source distance, graphics were prepared that show the parameter distribution in receiver points placed along the central axis of the hall (Figure 5) . Examination of the decay parameters reveals that in general the reverberation time curve is distance-independent in all halls and of a linear character. The EDT value, however, drops as the sound proceeds to the halls` rear which results in very different reverberance in the rear seats. These results confirm the evaluation of the musicians.

The evaluation of the results leads to the general conclusion that acoustic parameters are systematically related to the source receiver distance. The results once again indicate that variations within halls provide a more complete understanding of the acoustics of hall stage parameters.

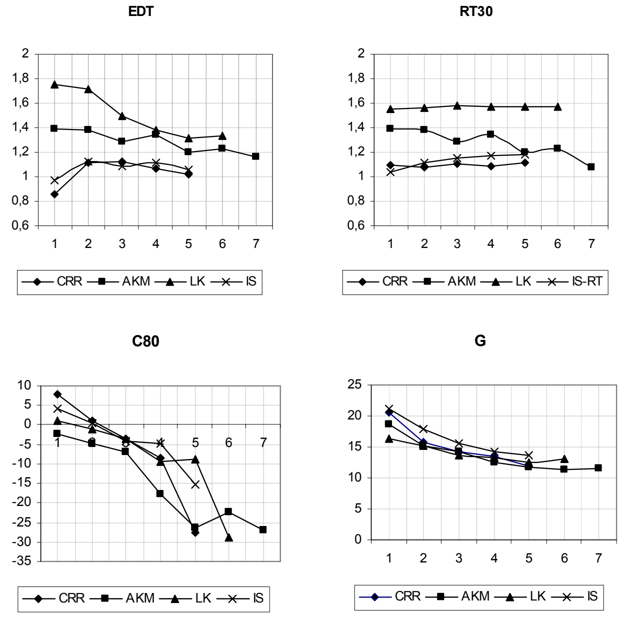

Figure 5. Variation of acoustic parameters with source distance.

5.4 Stage parameters

The results of stage parameter mean values as a function of source positions on stage are given in Figure 6. Table 9 shows the typical values given in ISO 3382. As can be seen in the figure, the measured values for all halls fall within the typical value range. The questions pertaining to the subjective analysis of the stage parameters were not included in this study as they were asked in the musicians` survey.

Subjective listener aspect	Acoustic quantity	Single number frequency averaging (Hz)	Just Noticeable Difference (*JND*)	Typical range
Ensemble conditions	Early Support, ST_{Early} (dB)	250 to 2000	Not known	-24 dB; -8 dB
Perceived reverberance	Late Support, ST_{Late} (dB)	250 to 2000	Not known	-24 dB; -10 dB

Table 9. Typical stage parameter values

6 Conclusion

A grouping of the analysed halls places CRR and IS in one group and AKM and LK in the other. Comparison of the measurement results with the subjective evaluation given in Table 4 reveals better conformity with the ranking of ordinary concert goers. However, the evaluation of the halls` acoustic quality as good and very good is a sign of the musicians` more selective appreciation, and their evaluation better reflects the actual acoustic conditions. More advanced analyses of the receiver points will yield even better results in the determination of concert halls` acoustic qualities.

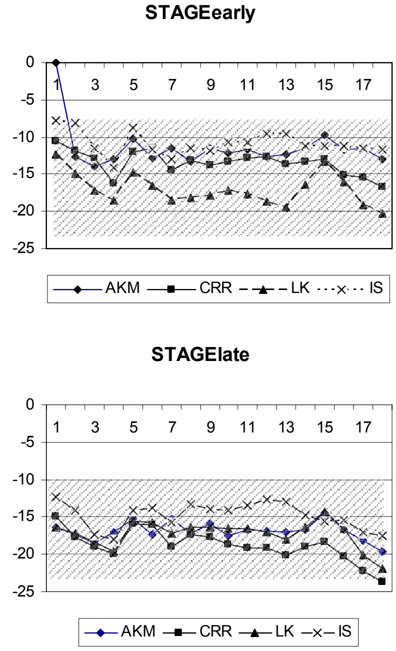

Figure 6. Variations of stage parameters. Dashed areas indicate the typical range defined in ISO 3382

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