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THE INTERPRETATION OF OBJECTIVE MEASUREMENTS ON THE STAGE BY MEANS OF THE CORRELATION WITH SUBJECTIVE DATA

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ABSTRACT

The aim of objective measurements, in the architectural acoustics context, is mainly to give an objective interpretation of the subjective perception of acoustical qualities. Nevertheless, the lack of a metrological basis for the subjective acoustic perception and of a defined correlation between objective measures and subjective evaluations, yields to significant difficulties in achieving univocal conclusions.

In particular, the interpretation of subjective results in absence of a metrological evaluation could be misleading and a methodology that validates the choice of the data for the correlation is necessary to avoid doubtful interpretations.

In this work, the concern is to identify the suitable objective measures to estimate the perception of the stage acoustics by musicians playing on it. Acoustical measurements are carried out on real stages and analysed with the aim to get a reliable connection with subjective data collected by means of a proper questionnaire. The subjective data are analysed with a metrological approach in order to evaluate features like reproducibility and bias that allow to get reliable results.

PREVIOUS SUBJECTIVE AND OBJECTIVE SURVEYS

In 1988 G. M. Naylor and R. J. M. Craik [1] conducted experiments with musicians in anechoic conditions judging the ease of hearing the others and themselves. For a musician the ability to hear the other players was well modelled by the modulation transfer function (MTF) for simple signal-to-noise level degradation, where the signal was the level of the other musicians, and the noise was the level of the self sound. The ability to hear himself followed a cumulative Normal distribution forms as the level difference was varied.

In 1985 and 1986, A. C. Gade [2] submitted a questionnaire to performers of classical music in 17 halls. In all the stages the same set of objective measurements was carried out (ST_{early}, ST_{late}, ST_2, EDT, T, Ts, EDTF, C80). Based on the subjects averaged data, corresponding to one “orchestra judgement” for each hall, he found that musicians judged hall acoustics primarily in two dimensions: the first was closely connected to all the aspects in the questionnaire except ‘Timbre’, which comprised the second dimension. In the first dimension, when orchestra players were familiar with the halls it was shown a sensible tendency towards the ‘Support’ judgements being related mostly to a parameter called ST_2, later slightly modified and replaced with St_{total}, whereas the ‘Reverberance’ and ‘Dynamics’ judgements seemed to be related to ST_{late}. ‘Support’ was initially described as the property which makes the musician feel that he can hear himself. In the case where the musicians were not familiar with the stage all the first factor scales were highly correlated with reverberation and clarity parameters. As far as the factor two is concerned, the ‘Timbre’ was always found to be correlated to EDTF, that is the low/high frequency ratio of EDT. In another survey with a resident orchestra in Copenhagen, in 1987, he had the possibility to investigate the effect of twelve configurations of stage and found a strong correlation between “Hearing others” and ST_{early}. In a paper of 1992 [3] he reported again this association together with the association between EDT and ST_{late}, both intended for measurement of reverberance, and introduced St_{total} for describing the support from the room of the sound from the musicians’ own instrument.

In 2003 Chiang *et al.* [4] investigated stage acoustics of five concert halls for solo and chamber music performances. They found that acoustical parameters associated with early reflected energy, like ST_{early}, or total energy, like G, were strongly inter-correlated, and also parameters associated with the late energy, like ST_{late}, C80, Ts, were strongly inter-correlated. T20 and EDT were correlated with acoustical parameters in both groups. The main finding of their work was that for chamber music performances, the parameters associated with early reflected energy were strongly and negatively correlated with 'Hearing oneself' and 'Overall impression'.

CASE STUDIES

Five orchestras, mainly composed by professional musicians, were the object of the survey. Three of them usually perform in Turin, on the stages of the "Lingotto" Auditorium (STG1), the RAI Auditorium (STG2) and the "G. Verdi" Conservatorium (STG3), one in Sanremo on the stage of Sanremo Casinò (STG4), and one in Parma on the stage of "N. Paganini" Theatre (STG5). Tables I and II list the main characteristics of the orchestras and the stages. All the orchestras had a long experience on the stage on which they were asked to answer and the musicians have been played in the same orchestra group for a quite long time. In the survey the dependence from musicians' position was partially taken into account, since all the musicians' responses were averaged on groups defined by the type of instrument (violins, violas, cellos, woodwinds, brasses).

Table I: Orchestras and stages object of the survey.

Orchestra	Stage where the orchestra plays	Total questionnaires
RAI National Orchestra (OR1)	"Lingotto" Auditorium stage (STG1)	46
	RAI Auditorium stage (STG2)	35
Philharmonic Orchestra of Turin (OR2)	"G. Verdi" Conservatorium stage after restoration (STG3)	15
"G.Verdi" Conservatorium Orchestra (OR3)		17
Symphonic Orchestra of Sanremo (OR4)	Casino of Sanremo stage (STG4)	29
"G.Verdi" Orchestra of Parma (OR5)	"N. Paganini" Theatre (STG5)	15

Table II: Features of concert halls and stages judged by musicians.

Auditorium	Total volume	Seats	Stage area	T30 mid frequencies (unoccupied, empty stage)
Lingotto	26364 m^3	2000	244 m^2	2.0 s
RAI	14500 m^3	1311	268 m^2	1.9 s
"G.Verdi" Conservatorium	6718 m^3	686	260 m^2	2.1 s
Sanremo Casinò	about 3400 m^3	290	about 140 m^2	1.5 s
"N. Paganini" Theatre	15200 m^3	780	250 m^2	2.0 s

DESCRIPTION OF THE MEASUREMENTS

The following parameters were measured on each stage: 'Reverberation time' (T20), 'Clarity' (C80), 'Centre time' (Ts), 'Definition' (D50), 'Early decay time' (EDT), 'Early support' (ST_{early}), 'Late support' (ST_{late}), 'Total support' (ST_{total}), 'Early decay time vs. frequency' (EDTF), 'Bass ratio' (BR) and 'Treble ratio' (TR). BR and TR are defined respectively as the low/medium frequency ratio and high/medium frequency ratio of reverberation time. The parameters are partly defined in the ISO/DC 3382-1 [5] and in Literature [2,3].

For the three cases STG2, STG3 and STG4 an omni-directional B&K dodecahedron, mod. 4296, and a Schoeps microphone, mod. CMC 6U, with a Tascam US-122 soundcard were used. For STG1 and STG5 a different measurement equipment was employed [6]. The Dirac Room Acoustics Brüel & Kjær Software was used for the analyses. The source and the microphones were at a height of 1.3 m from the floor for all the measurement positions. The stages were equipped as in concert configuration with stands and chairs, and on two stages also with resident instruments, like celesta and percussions.

Eight source positions were chosen in order to represent the main instrumental sections of the orchestra playing on the stage, in particular the violas, the cellos, the violins, the double bass, the woodwind instruments, the brasses and the percussions. Figure 1 shows a general plan of the source positions, that were alternatively also microphone positions, describing all the adopted source-microphone setups as all the possible couples source-microphone. For the 'Support' measurements the microphone was placed 1 m away from the source, only in the case for which both the dodecahedron and the probe were at least 4 m from any reflecting surfaces and stands and chairs moved away from the transducers, in particular the positions S1, S2, S3, S4, S5 were considered.

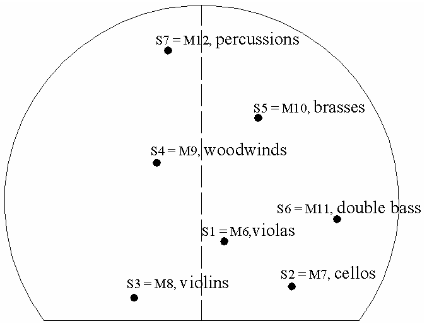

Figure 1 - Plan of the source-microphone positions.

QUESTIONNAIRE ADMINISTRATION

The questionnaire consisted of two parts [6]: the first was finalized to describe the musicians' perception during playing, the second was aimed at obtaining a priority classification of the acoustical subjective attributes, as felt by musicians [7]. For the first part continuous bipolar semantic differential scales were chosen as means to evaluate the acoustical attributes. Twelve acoustical subjective attributes were used in the survey: 'Overall Acoustic Impression' (OAI 'Clarity' (CLA), 'Reverberance' (REV), 'Ensemble' (ENS), 'Dynamics' (DYN), 'Sound Envelopment' (SENV), 'Sound Strength' (SS), 'Tempo' (TMP), 'Own Instrument Perception' (OIP), 'Low frequency balance' (LB), 'High frequency balance' (HB) and 'Timbre' (TBR). Each attribute was briefly described and an introduction giving instruction to fill in the questionnaire was added. Each scale, a segment of 70 mm length, was labelled at the two extremes with two opposite adjectives, and the score was decoded measuring the distance from the lower extreme to the mark. For the decoding the left extreme corresponded always to the negative or lower judgment. The musicians were asked to fill in the questionnaire referring to the stage where they rehearsed for about two hours.

DATA ANALYSIS

Subjective results present well known problems of accuracy. One method proposed for having a metrological management of the problem was to establish significant relationships with the objective measures [2 and 8 as examples]. Functional relationships connecting one or more objective measures with each subjective acoustical attribute can be identified; in this way, being estimable the uncertainty of the objective variables, the accuracy of subjective ones can be assessed. This method should be applied to an adequate number of experimental data to give fully significant results, nevertheless it is here applied on five different stages for a total of about 25 orchestra sections in order to show its capability, not to propose defined numerical models that should be agreed in an extended cooperation among researchers.

For each case study both objective and subjective values were evaluated to give an information for the different instrumental sections. Differences among the stages, directly evaluated by objective variables, were considered the main systematic variation factors. Subjective variables contain the same systematic effects, but also other possible biases like differences of assessment among the orchestras and among the different sections.

The first step for establishing a relationship between objective variables, taken as independent variables, and each of the subjective variable, requires to understand if the objective variables are intercorrelated. The relevant correlation matrix of the objective data, showed in Table III, puts in evidence that there are three separate groups of variables significantly correlated:

- C80, Ts and D50 are strongly correlated and form a first group, that includes the parameters typically connected with the 'Clarity of the sound' for a listener in a hall.
- ST_{early}, ST_{late}, ST_{total} and EDT are strongly correlated and constitute a second group that, according to Gade [2, 3], gives information about the quality of sound for a musician. In this second group it is possible to include also T20 e BR, even though for them the correlation with EDT is lower.
- BR, TR e EDTF are strongly correlated and form a third group which gives information about the frequency content of the impulse response. BR is also correlated with all the variables in the second group and TR is also correlated with EDT.

It shall be clear that correlation between objective variables does not means that they are equivalent for describing a subjective acoustical attribute, but only that the identification of functional relationships should involve each time only one variable for each separate group to avoid higher difficulty.

Table III. Correlations of objective data. Significant correlation coefficients are showed. Two stars** and bold value indicate that the correlation is significant at the 0.01 risk level. One star* indicates that the correlation is significant at the 0.05 risk level.

	C80	Ts	D50	T20	EDT	ST_{late}	ST_{early}	ST_{total}	BR	EDTF	TR
C80	1.00										
Ts	**-0.88****	1.00									
D50	**0.60****	**-0.70****	1.00								
T20				1.00							
EDT				0.41*	1.00						
ST_{late}				**0.60****	**0.87****	1.00					
ST_{early}				**0.70****	**0.76****	**0.84****	1.00				
ST_{total}				**0.68****	**0.82****	**0.95****	**0.91****	1.00			
BR				**-0.67****	-0.44*	-0.49*	**-0.65****	**-0.60****	1.00		
EDTF									**0.60****	1.00	
TR					0.53*				**-0.72****	**-0.75****	1.00

The second step consists of evidencing the objective variables more connected with each subjective variable; this can be done producing the correlation matrix of subjective-objective data, as shown in Table IV. For CLA, DYN and TMP, the tendency is to be correlated with Ts, a parameter of the first group of objective data, and with one, EDT, or more parameters, ST_{late}, ST_{early} or ST_{total}, of the second group, without T20 and BR. ENS is only correlated with EDT, which takes part of the second group. Other variables like OIP, REV, SENV, SS, TBR are connected with the second group of correlated objective variables including T20 and/or BR. REV and TBR show also a slight correlation with the first group, respectively with C80 and Ts, and OIP and TBR with the third group by BR. The reason of the positive correlation between REV and C80 cannot be easily understood, but in literature [8] one can clearly see that REV is a complicated subjective variable. LB and HB are connected with the third group, even if HB can be considered to have some connections also with the second group through EDT and BR.

Table IV. Correlation between objective and subjective data. Significant correlation coefficients are showed. Two stars** and bold value indicate that the correlation is significant at the 0.01 risk level. One star* indicates that the correlation is significant at the 0.05 risk level. Lower correlations are indicated in italic red character to give more information.

	C80	Ts	D50	T20	EDT	ST_{late}	ST_{early}	ST_{total}	BR	EDTF	TR
CLA		*-0.31*			-0.45*	*-0.32*		*-0.31*			
ENS					*-0.33*						
DYN		-0.43*			-0.42*	**-0.56****	*-0.33*	-0.48*			
TMP		*-0.32*			*-0.32*						
OIP				**-0.57****	-0.48*	-0.50*	-0.51*	**-0.56****	**0.54****		
REV	*0.38*			**0.55****			*0.39*				
SENV				**0.50****	0.42*	0.46*	0.47*	0.48*			
SS				0.40*			*0.34*				
TBR		*-0.35*		**-0.66****	**-0.50****	-0.50*	**-0.63****	**-0.53****	**0.57****		
LB									*0.35*		**-0.63****
HB					*-0.34*				**0.61****	**0.51****	**-0.56****

The third step consists of identifying by linear regression some possible models describing the systematic variations of the subjective data in function of the objective variables, taking into account the correlations in Table IV. In Table V the results of some of the best regression analyses are collected. As said before, the selected regression models and the values of identification coefficients should be considered only indicative, but they are important to underline the metrological meaning of residuals. In fact, if it is acceptable that regression represents the systematic relationship between each subjective variable and some objective variables, the residuals can give a rough indication of the reproducibility of the relevant subjective variable. The residuals contain also the effect of systematic differences in the subjective evaluations, and it is possible therefore to analyze if such systematic differences are due to a biases of the orchestras or instrumental sections. This is evidenced when the differences between the subjective evaluations averaged on orchestra-stage or on instrumental section are not justified by random variations. The results are slightly different for each different subjective variable, but the analysis outcome can be summarized in an unitary way: systematic effects due to both the instrumental sections and the orchestra groups happen rarely. There is evidence of absence of biases due to this two factors, with the exception of one specific case, nearly always present: a strong difference on the evaluations made by OR1 on STG1 and STG2. For CLA this systematic difference is shown in Table VI and Figure 2. This situation is very interesting, because indicates that generally the compatibility of subjective evaluations can be considered good and well connected with the relevant objective measures, but also that strong interaction orchestra-stage effects can happen, may be due to psychological reasons, as it was indicated in the open comments of musicians written on the questionnaires.

Table V. Some of the best regression formulas obtained for each subjective variable based on the more strictly correlate objective ones, together with the relevant values of the standard error of residuals, the coefficient of determination R^2 and an index of robustness roughly taken from the confidence level of significance of the regression coefficients.

Subjective variable	Regression model	R^2	Standard deviation of residuals	Model robustness
CLA	= 149-51 EDT	0.20	18	very good
REV	= -40 + 3.49 C80 + 41.25 T20	0.36	14	good
ENS	= 121.4 – 37 EDT	0.11	19	good
DYN	=26.8 - 0.492 Ts – 3.98 STlate	0.41	17	good
SENV	= -33.4 + 44.7 T20	0.25	16	good
SS	= 117.6 – 76.9 TR	0.14	19	good
TMP	= 140.8 -0.384 Ts – 31-85 EDT	0.18	19	medium
OIP	= 192.3 – 75.39 T20	0.33	22	very good
TBR	= 170 - 60 T20	0.44	14	very good
TBR	= -64.3 +112.7 BR	0.32	15	very good
LB	= 161- 131 TR	0.40	15	very good
HB	= -89 + 131 BR	0.38	16	very good

Table VI. Evaluation of bias due to orchestras and instrumental sections related to the regression model for CLA. Italic red characters represent the values not justified by random variations.

Variable	**Model**				
CLA	**CLA = 149-51 EDT**				
Analysis of residuals					
For orchestra			For instrumental section		
	Average	St. dev. of the average		Average	St. dev. of the average
OR1_STG1	*-14.8*	3.1	Violins	-4.5	7.1
OR1_STG2	*22.0*	3.2	Violas	-1.7	8.5
OR2_STG3	-0.8	3.8	Cellos	*12.2*	5.8
OR3_STG3	-2.5	11.4	Woodwinds	-7.8	4.9
OR4_STG4	*-13.9*	6.5	Brasses	-0.8	9.8
OR5_STG5	3.7	5.2			

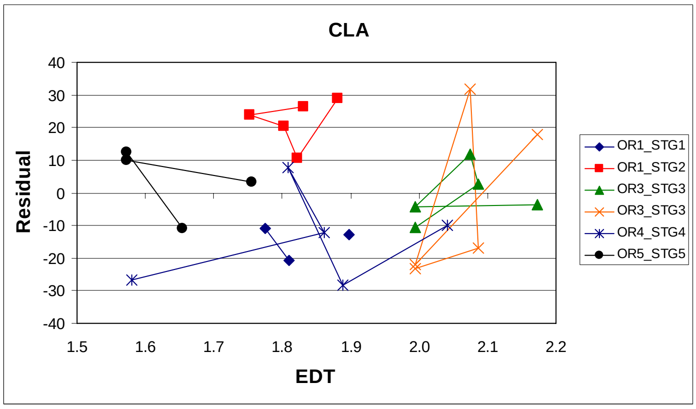

Figure 2 – Residuals of the regression model for CLA. It is evident that OR1_STG2 has a clear systematic effect. For OR1_STG1 and OR4_STG4 systematic condition is not so visible as one shall consider the averages against the relevant variability.

CONCLUSIONS

The correlations between objective data show that the measured parameters are not always independent, but three groups of correlated measures, not completely separated, were found. The first group includes C80, Ts and D50, the second EDT, ST parameters, T20 and BR, and the third EDTF, BR, TR.

From the correlations between objective and subjective data it is evident that EDT and/or 'Support' parameters are correlated with all the subjective aspects, even if for some of them is more important EDT and for other are more important the 'Support' parameters. The first objective group, usually representing the 'Clarity of the sound', seems to be important for the subjective aspects connected with the good playing, like CLA, DYN and TMP. As stated from the interviews 'Clarity' have been interpreted as the good articulation of the music played by the orchestra. T20 seems important for the subjective aspects that are connected with the acoustics of the stage, like OIP, REV, SENV, SS. TBR is correlated to the first and the second group, included T20, and to the third group by means of BR, as it would express the overall quality of the stage, while the frequency balance measures EDTF, BR and TR clearly express the balance between frequencies.

The analyses of residual of the regression models between subjective and objective data, show that subjective evaluations have large random variations, as can be seen by the standard deviations of residuals, but also that the connections with objective values is quite strong, as demonstrated by the generally good level of robustness of the regression models. This method of analysis can also evidence possible biases between orchestras or instrumental sections and it is interesting to consider that such systematic effects were not so frequent in the presented observations.

References

[1] G. M. Naylor, R. J. M. Craik, "The effect of level difference and musical texture on ease of ensemble", Acustica, vol. 65, N. 2, 95-100 (1988).

[2] A. C. Gade, "Investigations of Musicians' Room Acoustic Conditions in Concert Halls, II: Field Experiments and Synthesis of Results", Acustica, Vol. 69, 249-262 (1989).

[3] A. C. Gade, "Practical aspects of room acoustic measurements on orchestra platform", Proc. 14th ICA, Vol. 3, Beijing, China (1992).

[4] W. Chiang, S. Chen, C. Huang, "Subjective assessment of stage acoustics for solo and chamber music performances", ACTA ACUSTICA UNITED WITH ACUSTICA, Vol. 89, 848-856 (2003).

[5] COMMITTEE DRAFT ISO/CD 3382-1, Acoustics – Measurement of the reverberation time – Part 1: Performance spaces.

[6] A. Astolfi , M. Giovannini , S. Geroso, L. Dellatorre, "Assessment of the acoustic perception of musicians", Proc. 6th International Conference on Auditorium Acoustics, Copenhagen, (2006).

[7] G. Genta, M. Giovannini, A. Astolfi, G. Barbato, "The subjective investigation of acoustic perception of musicians: a proposed method for interpretation of results", Proc. 19th ICA, Madrid, (2007).

[8] M. Barron, "Subjective study of British symphony concert halls", Acustica 66, 1-14 (1988).