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OUR EXPERIENCE IN SUBJECTIVE PERCEPTION IN CONCERT HALLS

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A. Giménez[1]; R. Cibrián[2]; J. Romero[1], S. Cerda[1], J.L. Miralles[3]; J. Segura[1]
[1] Grup d´Acustica Arquitectònica, Ambiental i Industrial, E.T.S.I.I., Univ. Politécnica de Valencia, agimenez@fis.upv.es
[2] Facultad de Medicina. Universidad de Valencia, Rosa.M.Cibrian@uv.es
[3] Facultad de Psicología. Universidad de Valencia. Blasco Ibáñez, 21, Valencia, mirallel@uv.es

ABSTRACT
Numerous objective parameters have been proposed by different investigators for studying musical perception. These create different ways of tackling such study, depending on the fundamental attributes to be considered. A selection of these parameters is necessary due to musical audition requirements in our sociocultural environment. In this article we present our work in this regard, studying the dependence or independence between the parameters most commonly used and their correlation with subjective perception. To carry out the study halls were selected following typological, functional, constructive, patrimonial, capacity, etc., criteria. Numerous measurements were determined in these halls and a survey was completed by an audience and a group of experts regarding their subjective responses, which covers the whole area of audition. This study is part of the research coordinated project (BIA2003-09306-C04)[1] of the Ministry of Science and Technology of Spain. We are carrying out this project together with research groups from the Public University of Navarre, University of Seville, Polytechnic University of Catalonia, and Polytechnic University of Valencia.

INTRODUCTION
In order to perform the study of the musical audition requirements in concert halls a measurement and analysis of objective acoustic parameters, **physical study**, should be done. The physical study encompassed both the characteristic/architectural factors of the concert hall and factors of the source of music itself. Likewise, a **psychological study,** which analyse the subjective perception that audition produces in people, was performed. This study is based on variables that are very difficult to quantify and standardize and can only be performed by means of the listeners' responses to the questions in a survey. These questions had to be easy to understand and related, directly or indirectly, to the acoustic parameters measured in the physical study.

Knowledge of the radiant body is mandatory for the physical study, but in the case of concert halls, dependency on the multi-factor "music source" makes this study difficult, which is why certain directives were established and are set out in norm ISO 3382 [2]. The psychological study is especially complicated due to the diversity of musical compositions, the complexity of the audition mechanism, and particularly factors that influence audition. This complexity justifies the existence of numerous objective parameters proposed by different authors to study musical perception. Consequently, there are different ways to undertake such study, depending on the fundamental attributes to be considered.

The aim of this article is to present the work we are performing in which we study the dependence or independence of the parameters most commonly used, to select the most necessary parameters considering the requirements of music audition in our sociocultural surroundings, and to analyze their correlation with subjective perception. This study is part of the above-mentioned coordinated investigation project, although here we present exclusively our results regarding concert halls in the Valencian Community (VC).

MATERIAL AND METHODOLOGY

The fundamental point of this study is to determine the correlations between the objective measurements in theatres and concert halls by means of impulse response (IR), following the directives of norm ISO 3382[2], and the answers to the subjective perception of listeners, determined by means of a survey. This survey comprises 58 questions divided into 6 sections[3]. **Section A: "General aspects of the hall":** Background noise, visibility of the orchestra, comfort of the seating, architecture and décor, etc. **Section B: "Detailed acoustic perception":** Characteristics of psychoacoustic quality are assessed in this section. **Section C: "Global acoustic perception"** includes items about the global orchestra perception, global orchestra balance, and evaluation of global acoustic perception in the hall. **Sections D**, **E** and **F**: **"Sociological data"**, **"Musical preferences"** and **"Commentaries"** present a total of 6 questions.

In order to establish the correlation between the objective and subjective parameters, the "acoustic zones" with geometric, typological, and acoustic criteria have been defined in all the halls, each zone obtaining mean values of the ISO-3382 parameters in addition to **bass ratio** and **brilliance**. The parameters selected for musical audition are shown in the table below:

Parameter	Calculation
Reverberation Time (TR_{30})	$TR_{mid} = \frac{1}{2}\left(TR^{500\,Hz} + TR^{1\,kHz}\right)$
Bass Ratio	$BR = \frac{TR^{125\,Hz} + TR^{250\,Hz}}{TR^{500\,Hz} + TR^{1\,kHz}}$
Brilliance	$Br = \frac{TR^{2\,kHz} + TR^{4\,kHz}}{TR^{500\,Hz} + TR^{1\,kHz}}$
Early Decay Time	$EDT_{mid} = \frac{1}{2}\left(EDT^{500\,Hz} + EDT^{1\,kHz}\right)$
Central Time	$T_C = T_{C1kHz}$
Musical Clarity	$C_{80} = \frac{1}{3}\left(C_{80}^{500\,Hz} + C_{80}^{1\,kHz} + C_{80}^{2\,kHz}\right)$
Speech Clarity	$C_{50} = 0.15 \cdot C_{50}^{500\,Hz} + 0.25 \cdot C_{50}^{1\,kHz} + 0.35 \cdot C_{50}^{2\,kHz} + 0.25 \cdot C_{50}^{4\,kHz}$
Strength	$G_{mid} = \frac{1}{2}\left(G^{500\,Hz} + G^{1\,kHz}\right)$
Lateral Energy Fraction	$\begin{cases} LF_4 = \frac{1}{4}\left(LF^{125\,Hz} + LF^{250\,Hz} + LF^{500\,Hz} + LF^{1\,kHz}\right) \\ LFC_4 = \frac{1}{4}\left(LFC^{125\,Hz} + LFC^{250\,Hz} + LFC^{500\,Hz} + LFC^{1\,kHz}\right) \end{cases}$
Interaural Cross Correlation (Early)	$IACC_{E3} = \frac{1}{3}\left(IACC_E^{500\,Hz} + IACC_E^{1\,kHz} + IACC_E^{2\,kHz}\right)$

RESULTS AND DISCUSSION

Analysis of the survey[3,4], performed with statistical package SPSS v14 of the items in sections B and C, shows high reliability (Alpha of Cronbach 0.929) and the possibility of grouping the 45 items in these two sections into 9 factors (reduction of variables method, with Varimax rotation):

Section A: F5 and F6 explain 7% of the variance.
Section B: F1, F3, F7, F8, F9 explain 40.37% of the total variance of the survey, F1 being the sensation of pleasant sound in the hall, which alone explains 26% of the variance.
Section C: F2 and F4 explain 15% of the variance, factor 2 explaining 10%.

As Section B contains the majority of the questions for grading concert halls, we focused on this section exclusively in this report. We reduced the number of factors further to study their correlation with the objective parameters measured in the halls.

We focused our study on the concert halls in the Valencian Community where 392 surveys were answered, 65 by music experts and 326 by members of an audience who attend concerts: eight concerts held in four concert halls were analyzed.

Table I.- Generic name of the factors that are obtained when the reduction of variables is applied to the items in the survey. The order of the factors indicates decreasing contribution to the explanation of the variance of the results in the survey.

F1: Pleasantness of the sound in the hall
F2: Perception and discrimination of instruments
F3: Unpleasantness of the sound in the hall
F4: Perception of the orchestra as a whole
F5: Hall comfort
F6: Noise in the hall
F7: Global perceptive discrimination
F8: Spaciousness of the hall
F9: Predominance of the sound

The factors analysis in this case, which only considers the items in Section B, shows that 48.9% of the variance of this section could be explained by three factors, two of which are particularly weighty. The first would explain 27.3% of the variance, the second 14% of same, and the third, providing a less important contribution to the explanation of the variance, only 7.6%. The rest of the factors contribute less than 7%, which is why we have decided to use only three factors.

Table II shows how the questions in Section B are grouped in each component as well as the weight of each question in the factor. Positive weight of some questions (b01, b11 and b21) can be observed in component 1 and the significant negative weight that these questions have in factor 3, which clearly indicates that high values of these questions increase factor 1, whereas they would diminish factor 3 and are therefore opposite factors:

If we analyze the corresponding questions, we could term the factors obtained as follows:
Factor1 (F1) “perceptive harmony and clarity”;
Factor2 (F2) “perceptive asynchrony” and
Factor3 (F3) “unpleasantness”.

The great importance of F1, apart from the fact that it grouped questions that answered two different concepts, “perceptive harmony” and “perceptive clarity”, induced us to corroborate if the method of extraction of factors applied to the questions in this factor would allow a division into two sub-factors.

Table III shows the results: there are no significant negative values that imply that one is the inverse of the other. They are, therefore, independent factors that contribute to the perceived pleasantness. Questions about perceptive clarity could be included in sub-factor F1_1 and those of perceptive harmony in F1_2. Sub-factor F1_1 has a greater weight.

We can include Section B questions thus:
F1: F1_1 “perceptive clarity” plus F1_2 “perceptive harmony”: 12 questions
F2: “perceptive asynchrony”: 7 questions
F3: “unpleasantness”: 4 questions
These are the factors we correlated with the objective parameters of the hall and with the listener’s assessment of such hall in question 31 of Section C.

In each survey, we calculated the value of each factor through the value of the answers of the corresponding items (an unanswered question was not considered as a value). Consequently, in order to avoid obtaining a value of a factor with few answers, which would be unreliable, only the surveys that had at least half of the questions answered, that integrate a factor have been considered. Thus, to determine F1_1 and F1_2 it was necessary that in each case at least 3 of

the 6 possible questions in the survey had been answered; to determine F2 at least 3 of the 7 questions had to be answered, and to determine P3, 2 of the 4 questions had to be answered.

Table II.- Matrix of components rotated for the questions in Section B. The specific weight of each question in the factor is shown, and the sign of the value of the weight indicates the type of correlation of the question with the factor

	Factors		
	F1	**F2**	**F3**
b01	**,584**	,105	**-,338**
b11	**,429**	,010	**-,301**
b21	**,682**	,109	**-,329**
b041	-,022	**,534**	,335
b042	,067	**,467**	,292
b043	**,676**	,255	-,050
b051	,115	**,815**	-,103
b052	,150	**,722**	,025
b053	,147	**,834**	-,120
b061	,020	,450	**,555**
b062	-,121	,004	**,663**
b063	**,450**	-,021	,569
b064	,399	**,473**	,136
b065	**,615**	,188	,153
b066	**,727**	,148	-,093
b067	-,161	,176	**,712**
b071	**,703**	-,002	,150
b072	,116	,396	**,393**
b073	**,738**	,171	-,100
b074	,222	**,412**	,178
b075	**,779**	,049	,048
b076	**,644**	,047	,167
b081	**,637**	,359	-,025

Table III.- Matrix of components rotated for the questions of Factor 1. The specific weight of each question in the sub-factor is shown, and the sign of the value of the weight indicates the type of correlation of the question with the sub-factor

	Subfactors	
	F1_1	**F1_2**
b01	**,802**	,039
b11	**,642**	,038
b21	**,711**	,115
b043	**,538**	,393
b063	-,146	**,650**
b065	,404	**,520**
b066	**,566**	,474
b071	,176	**,720**
b073	,473	**,585**
b075	,502	**,595**
b076	,145	**,643**
b081	**,530**	,407

Consequently, the value of the factor obtained was multiplied by the specific weight accorded it by the number of questions each factor was made up of. So the mean of F1_1 was multiplied by 6/23, the mean of F1_2 by 6/23; the mean of F2 by 7/23, and the mean of F3 by 4/23. Obviously, F1 is the addition of both sub-factors.

Table IV shows the coefficients of the linear regression between question c31 in the survey "How would you rate the hall globally?" and the three factors obtained (F1, F2 and F3) of Section B in the above-mentioned survey. The correlation coefficient r= 0,547 indicates, considering the meaning of r^2, that 30% variation of the evaluation of the hall can be justified by the variation of the score of the questions of these factors.

It can be observed that IC95% of the intercept includes zero, that is why we did not need to include this value in the regression equation (1):

$$\text{Evaluation of the hall} = 1{,}4 * F1 + 0{,}9 * F2 - 0{,}7 * F3 \quad (1)$$

Once again, F1 is the factor of greatest weight; in fact, if regression is considered only between c31 and F1 the correlation coefficient decreases only slightly to 0.523. It is, therefore, the most important factor.

Table IV. Values, standard error and confidence interval of 95% of the coefficients of the linear regression, between variable C31 and factors F1, F2 and F3 in the survey.

	Coefficients	Standard error	CI95%
(Cte)	-0,11	0,28	-0.647 , 0.435
F1	1,41	0,13	1,149 , 1,662
F2	0,94	0,21	0.518 , 1,358
F3	-0,66	0,29	-1,223 , -0,087

With the aid of the surveys gathered in the VC, Figure 1 shows the correspondence between both evaluation methods: the qualification of the hall obtained by means of the factors (ec.1) and the global qualification of the hall obtained by means of question c31 in the survey.

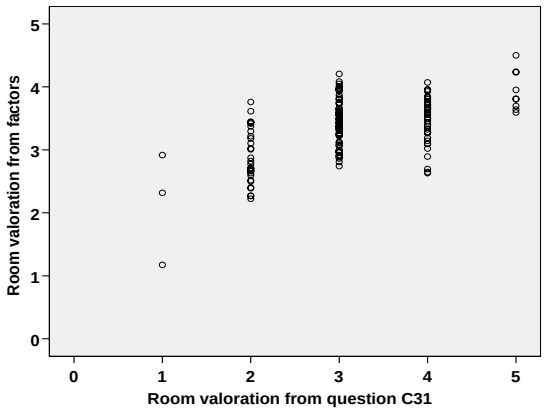

Figure 1.- Correspondence between the evaluation of the room from the value of question 31 of thesurvey and the score calculated from the items in Section B in the survey.

This good correlation is greater between the experts than the general audience, as Figures 2a and 2b show respectively, but in both cases the tendency is maintained.

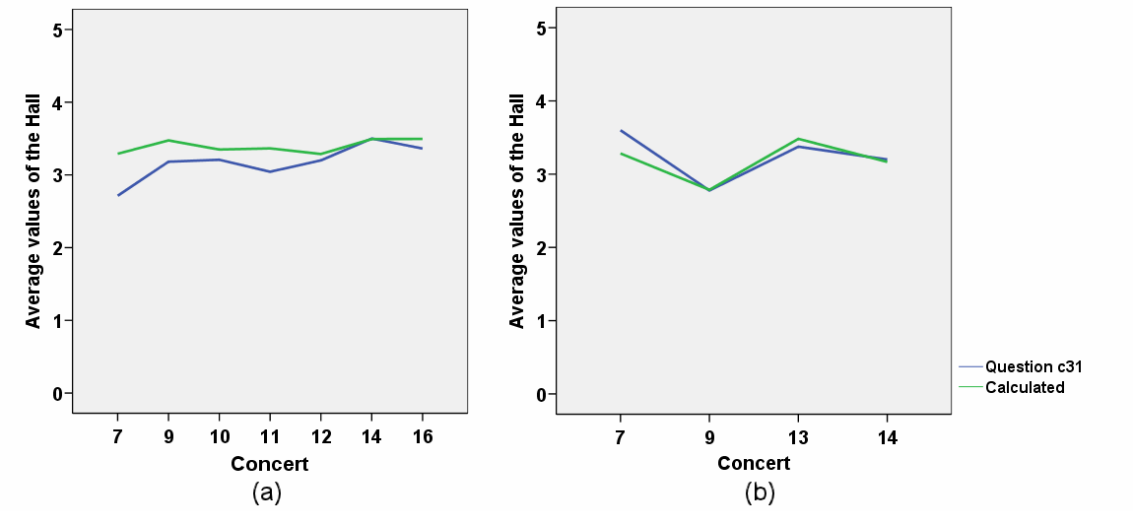

Figure 2.- Average values of the halls in the VC of the concerts surveyed, considering the evaluation corresponding to question 31 of Section C of the survey and the evaluation obtained from the questions in Section B of the same survey. (a) Audience (b) Expert.

With regard to the second of the objectives of this study, we sought correlations existing between the objective parameters measured in the concert halls of the VC and the factors obtained from the survey. Table IV shows these correlations.

In view of the low number of halls analyzed to obtain these correlations, but the high values of r obtained, we believe it would be possible to increase the number of significant correlations in a study with a greater number of halls.

Table IV: Correlation coefficients between objective (horizontal) and subjective (F1, F2, F3) parameters of the concert halls in the VC that were analyzed (significant correlation: *p< 0.05: ** p< 0.01)

	LF	LFC	G	C_{50}	T_{C1kHz}	C_{80}	BR	Br	TR_{mid}	EDT_{mid}	$IACC_E$
F1	**-0,849 ***	**-0,825 ***	**-0,911 ***	0,754	-0,780	0,720	0,638	-0,121	-0,670	-0,650	-0,235
F2	0,108	0,783	0,498	-0,670	0,766	-0,593	**-0,910 ***	**-0,827 ***	**0,886 ***	0,623	-0,649
F3	0,674	**0,964 ***	0,635	**-0,981 ***	**0,993 ****	**-0,953 ***	**-0,821 ***	-0,327	**0,983 ***	**0,954 ***	-0,526

As can be seen in all the objective parameters, except iacee, the correlations with F1 are opposite to those obtained with F2 and F3, again marking the different sensations that include the three factors. F1: clearly pleasant items, F3: clearly unpleasant, and F2: unpleasant items, but not so unpleasant as F3.

CONCLUSIONS

The survey provided a good scale of subjective measurement of evaluation of the concert halls, with high reliability and good correspondence with the global evaluation of the hall rated by the audience, experts and general public at the concerts.

The subjective factors bear a strong correlation with the objective parameters measured in the respective halls. F1 correlates negatively with If, Ifc and g; F2 negatively with Warmth and Brillo and positively with trmid, and F3, the unpleasantness perceptive correlates positively with Ifc, tc_1000, trmid and edtmid and negatively with c50, c80 and Warmth.

References: [1] Proyecto de investigación "Establecimiento de parámetros acústicos determinantes de la calidad percibida en salas de concierto y auditorios. Propuesta para su aplicación en proyectos de nueva planta o rehabilitación" BIA2003-09306-C04, Plan Nacional de I+D
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