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OBJECTIVE AND SUBJECTIVE SURVEYS OF OPERA HOUSE ACOUSTICS: EXAMPLE OF THE GRAND THEATRE DE BORDEAUX

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This paper deals with the relationships between objective and subjective results of an acoustic survey in the historical opera house of Bordeaux, called the Grand Theatre de Bordeaux. The comparison of the ordinary listeners' answers with the objective results shows that the auditive sensations are fitting with the measured criteria obtained in the opera configuration with the opened pit and sceneries on the stage. The aim of this study was to test in real conditions of performance a questionnaire designed for ordinary listeners. The obtained results allow us to accord a good reliability to the questionnaire.

1. INTRODUCTION

The historical opera house of Bordeaux, called Grand Theatre de Bordeaux (GTB), was built between 1773 and 1780 by Victor Louis (1731–1792). Nowadays, it is used for concerts as well as for opera. This building has still its original stone wall structure and a wood roof structure. No important alterations have been made, even if many restorations have been executed in the last two centuries. Furthermore, it has never been damaged by fire and is almost the same as when it was built.

In 1990, the last restoration conducted by B. Fonquernie as architect and A. Y. Xu as acoustic consultant gives back to the building its early spirit, with its white, blue and gold main hall. The architectural modifications were the re-establishment of the depth of the Italian stage, the modernization of part of the machinery and the deepening of the pit. The number of seats (1200) remains the same, only the upholstered chairs on the wooden floor and the under part material of the suspended balconies were changed in order to improve the acoustics of the hall [1]. The total cubic volume is about 19 000 m^3, 13 773 m^3 of which are for the flytower. The surface of, respectively, the stage and the audience area is 576 and 156 m^2. The walls and the ceiling are made of painted wood with a lot of ornamentation. The hall has a horseshoe shape. Figures 1 and 2 display a plan and the long section and Figures 3 and 4 are pictures of the hall.

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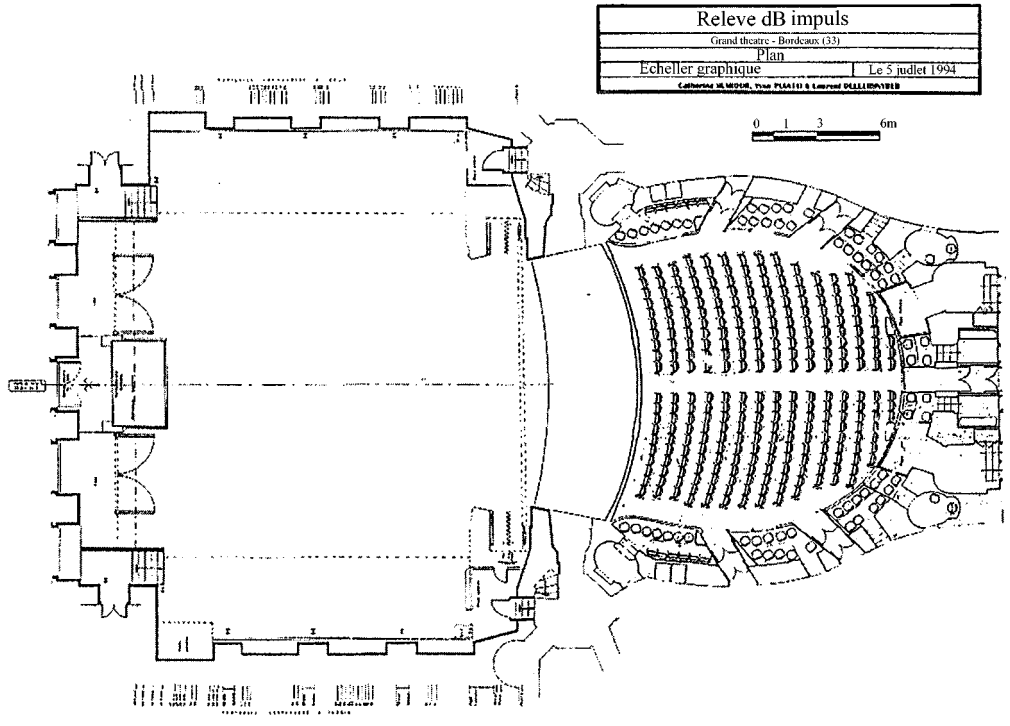

Figure 1. Plan at the level of the orchestra seats.

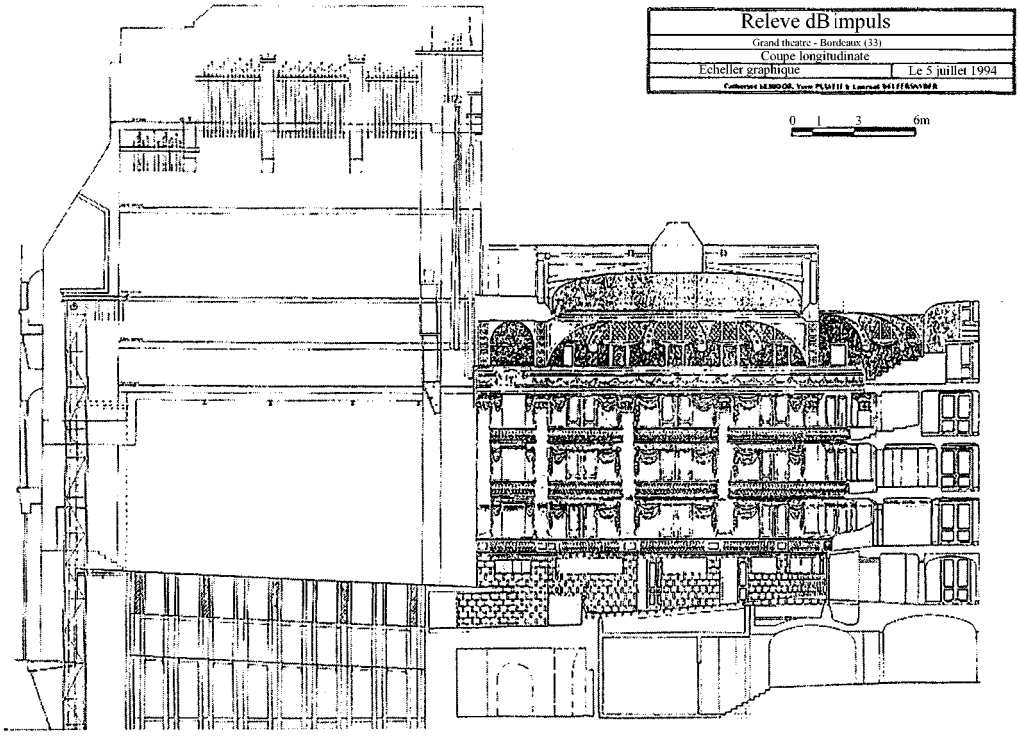

Figure 2. Long section.

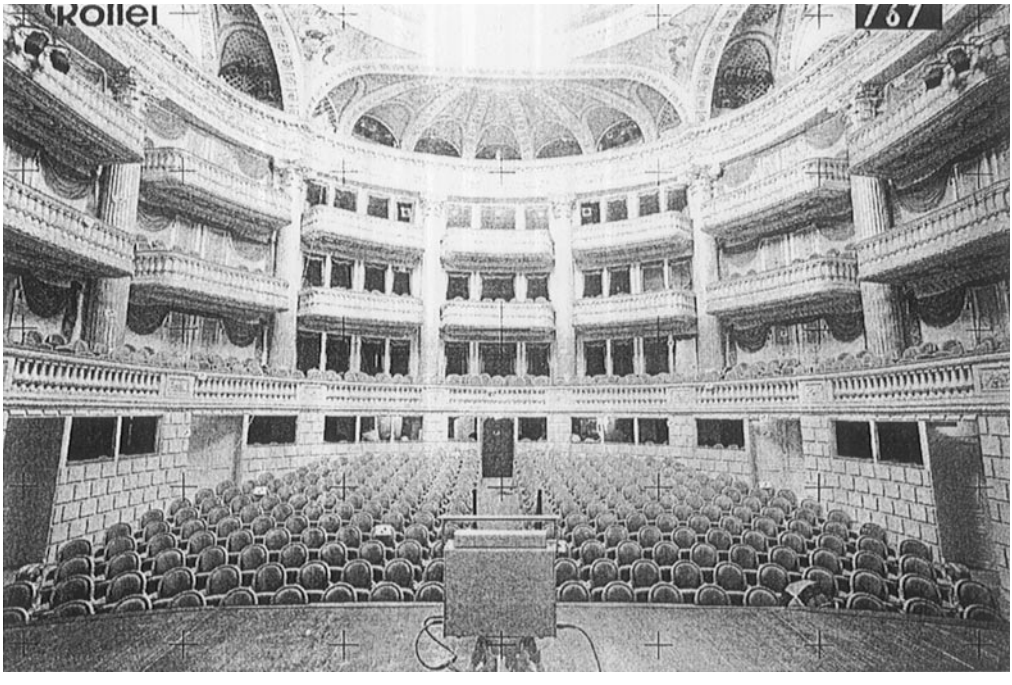

Figure 3. The interior from the stage. At foreground the back side of the source.

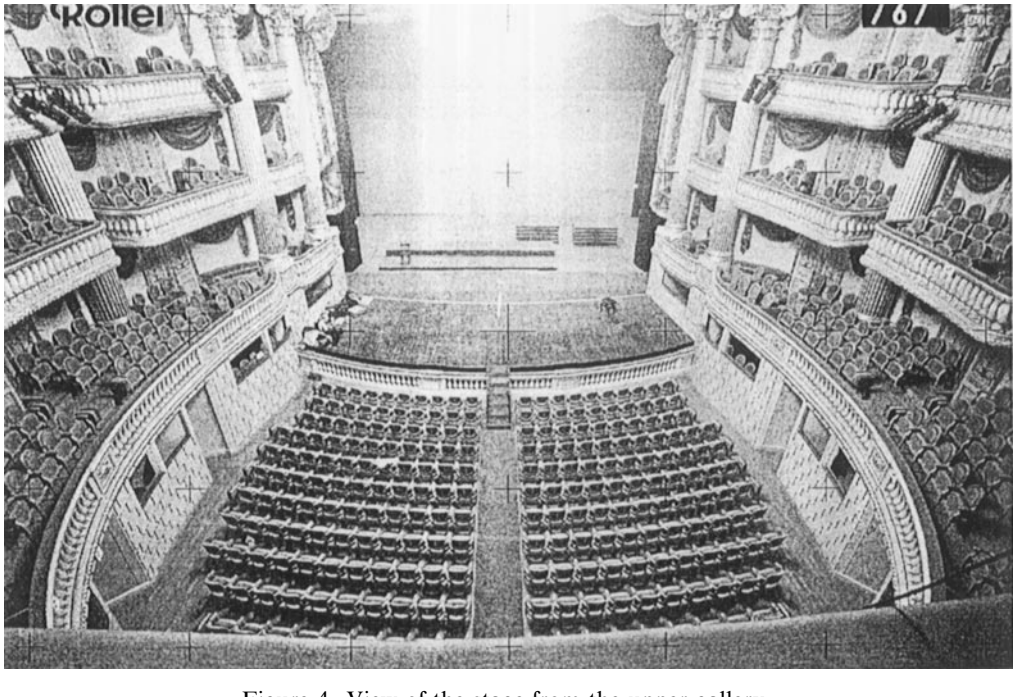

Figure 4. View of the stage from the upper gallery.

2. THE OBJECTIVE SURVEY

In order to have relevant data to correlate with subjective responses, measurements are conducted with the opened pit and sceneries on the stage, but unfortunately without people in the audience area. The first source position is on the middle of the stage, the second one in the middle of the pit (see Figure 5). There are three receiver points (circled in black in Figure 6) on the floor level (N1) (coloured in deep grey in Figure 6), four at first and second balconies (N2) (in grey) and four at third balcony and in the upper gallery (N3) (in white).

The objective criteria measured by the MLS system and pinked interrupted noise technique are the usual ones [2]: reverberation time $RT60$, measured between -5

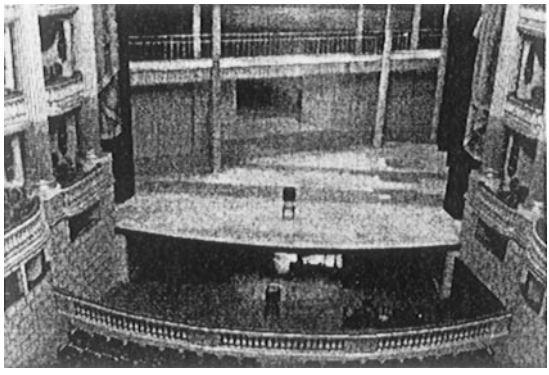

Figure 5. The source positions on the stage and in the pit.

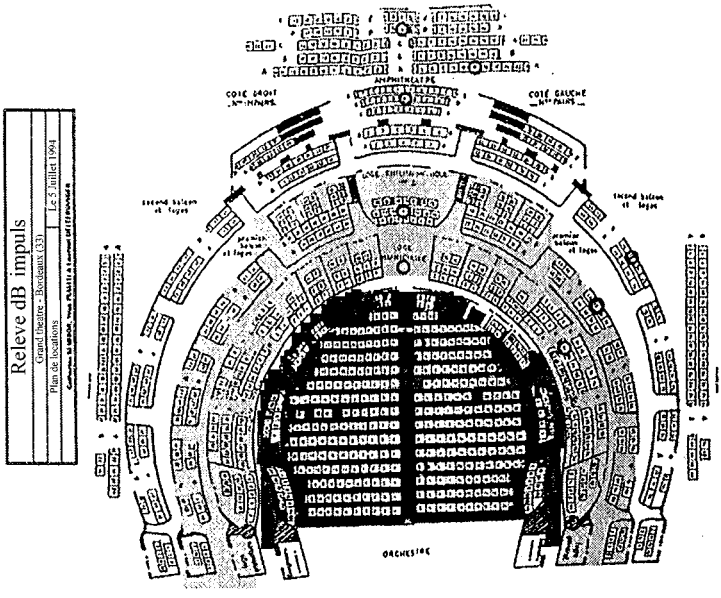

Figure 6. Seat plan.

and -35 dB, early decay time EDT, objective clarity C_{80}, definition D_{50}, strength index in low- and mid-frequency calculated as G equals sound pressure level (L_p) minus power level measured in an anechoic room (L_w), Speech transmission index (STI) and Rapid speech transmission index ($RASTI$). Unfortunately, because of the lack of apparatus, it is not yet possible to proceed to spatial-binaural measurements, and to accede to criteria such as interaural cross-correlation ($IACC$) or lateral energy fraction (LE).

In Table 1, it is obvious that the intelligibility is a little higher, everywhere in the audience area, when the source is on the stage, rather than when it is in the pit. The values are weaker at the first and second balconies (level N2) than at the other levels N1 and N3. As expected the strength index is close to the optimal value [3] on the floor level, but even at levels N2 and N3 the values are quite correct.

The curves of $RT60$ (see Figure 7) show values rather weaker than the optimal ones, but Xu has obtained the same ones in the empty hall [1], which corroborates our results. Because of the good agreement between these values, it is possible to base the comparison of this criterion with the correspondent subjective indicators on the results of his measurements carried out in the occupied hall which are nearly 1 s for all the frequencies bands. EDT curves (see Figure 8) have the same shape with smaller values.

This proves that the sound field is quite diffused and the quantity of absorption is rather important, which is in accordance with the architectural parameters of this

TABLE1

Intelligibility index results

	Source on the stage				Source in the pit			
Level	STI	$RASTI$	G_{low}	G_{mid}	STI	$RASTI$	G_{low}	G_{mid}
N1	0·58	0·62	−30	−29	0·52	0·56	−28	−30
N2	0·48	0·53	−33	−32	0·47	0·52	−34	−34
N3	0·55	0·61	−33	−33	0·51	0·59	−35	−33

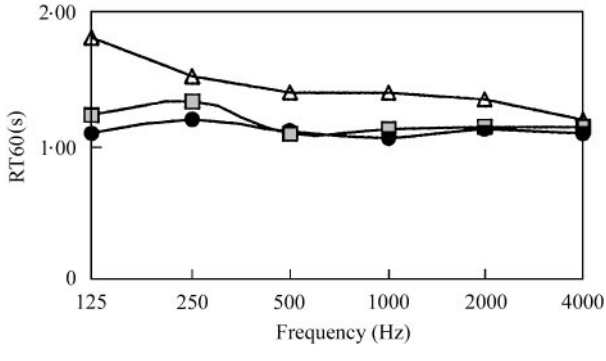

Figure 7. Reverberation time. —□—, Stage; —●—, Pit; —△—, Optium RT.

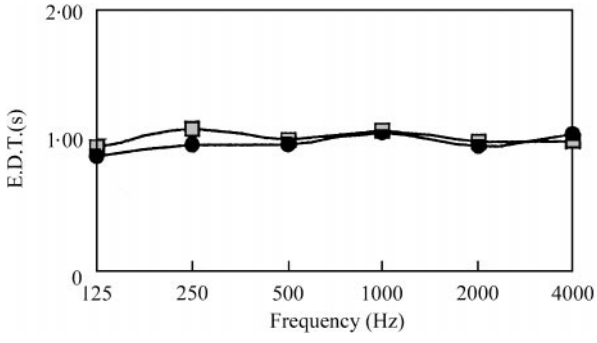

Figure 8. Early decay time. —□—, Stage; —●—, Pit.

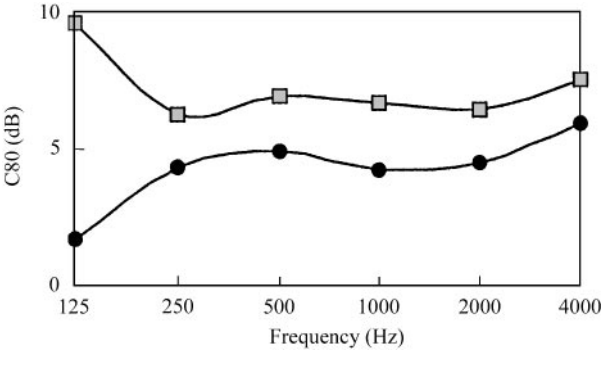

Figure 9. Objective clarity. —□—, Stage; —●—, Pit.

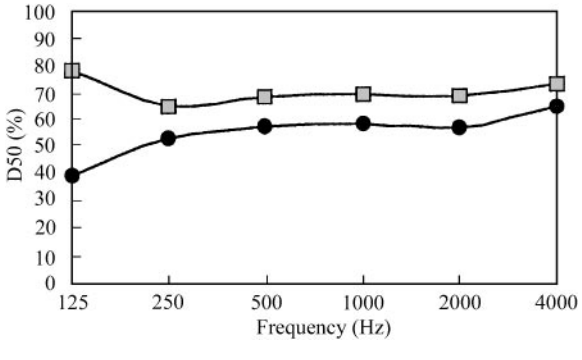

Figure 10. Definition. —□—, Stage; —●—, Pit.

hall: a lot of columns all around the audience area, the front of the balconies ornamented with balusters, velvet upholstered seating, presence of boxes with some velour cutrains in the back part of the balconies.

Objective clarity and definition (see Figures 9 and 10) are greater when the source is on the stage than when is it is in the pit. This fact correlates well with opera

performances for which the signers voices must be distinct and the music must produce a blend sensation.

3. THE SUBJECTIVE SURVEY

The investigations are conducted with an original questionnaire [4] proposed by our research team to provide ordinary opera-goers during four performances of "Traviata" with the same orchestra and conductor, in order to have valid statistical answers. The results of an earlier experiment [5] carried out with a test-questionnaire made up of simple words, which explain the sensations of the listeners, have shown that the questions are correctly understood.

For this reason we decided to use it with a large audience and to validate the results by comparison with the measured objective criteria.

The questionnaire consists of 30 questions, in six parts, assessed using a linear four-point scale concerning different themes about the needs and expectations of the listeners: the listener: use of specific entertainments; general appreciation of the opera house: needs and expectations according to physical aspects of comfort (acoustics, visibility, temperature, space around the seats etc.), aesthetic aspects; neutralization of the performance effect; appreciation of the GTB: evaluation of social and physical comfort; the hall and sound: evaluation of the acoustical comfort (among 16 times are found: qualities of sound (clean attack, distinct and natural sound, strength, frequency balance, etc.) balance between the different instruments, the musicians and the singers echo impressions, disturbing noises, etc.); the classical descriptors of conditions.

The analysis is made of 430 questionnaires distributed at the entrance of the hall and returned by the end of the performance. Half of the participants were subscribers, the majority of respondents were in the 21–65 years age range, 53% were male and 38·5% female. They were well distributed in the audience area: equally on the left and right side of the hall, most of them 44%, on the floor level (N1), 34% on the upper one (N3), and 22% in the middle part (N2).

From the answers it seems that on the whole the more important attributes are good acoustics, good vision of the stage and comfortable chairs; the less important ones are temperature and size of the hall.

Among acoustical attributes, all the propositions of hearing sensation descriptors to have a "good" hall seem to be equally important. The only point were the answeres differ in opinion, concerns the perference to be surrounded by sound: 47% have this preference and 45% have not. Baron [6] has produced the same results with expert listeners.

With regard to the acoustical qualities of the GTB, the sound seems clear, according to the values of C_{80} and D_{50} (see Figure 11), and coming directly from the stage (no surrounding by sound sensation) which may disagree with the preference of a part of the listeners (see Figure 12).

In this case, only binaural measurements, which could not yet be conducted, would justify the answeres of the listeners. The criteria that describe the spatial impression are also necessary to explain why opinion is divided about the

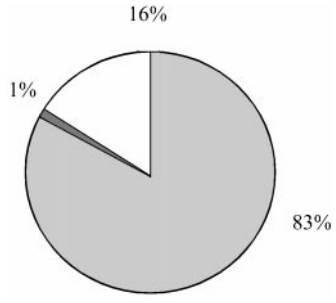

Figure 11. Preception of clarity. ⊡, Clear; ▭, Not clear; □ No answer.

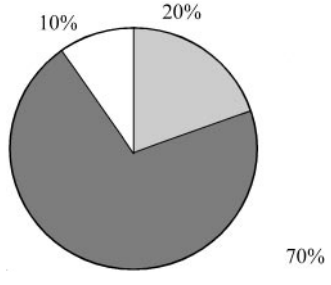

Figure 12. Sensation of envelopment by sound. ⊡, to be surrounded by sound; ▭, Sound coming directly from the stage; □ No answer.

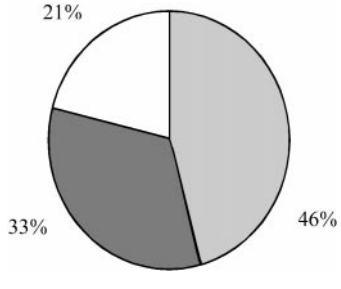

Figure 13. Emergence of some sounds. ⊡, Yes; ▭, No; □ No answer.

emergence of some sounds (see Figure 13). The fact that people hear some sounds louder than others through the G values are almost the same in mid- and low-frequencies, may effectively be linked on the one hand to the strength index, but also on the other hand to frequency balance (coloration), though the curve criteria does not reveal here any particular spectral resonance, and spatial effect [7].

The sound attack impression is very clear, which is well correlated by the resonance values of reverberation time and EDT (see Figure 14).

There is a good hearing perception of the singers on the stage and of the musicians as an ensemble in the pit (see Figures 15 and 16).

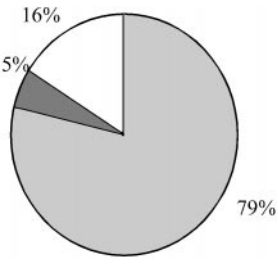

Figure 14. Sound attack impression. ⊡, Clear; ■, Not clear; □ No answer.

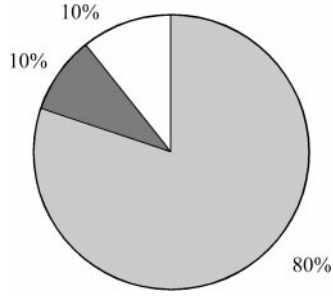

Figure 15. Sensation of well hearing singer anywhere on the stage. ⊡, Yes; ■, No; □ No answer.

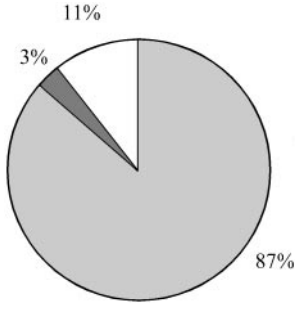

Figure 16. Sensation of well hearing musicians as an ensemble in the pit. ⊡, Yes; ■, No; □ No answer.

Perhaps these results have to be linked with the study conditions: that is live performance; the listeners were watching the singers on the stage and the musicians in the pit.

Indeed, the answers, regarding the general appreciation of physical comfort in an opera house, show that a good view of the stage is one of the most important aspects (93% of respondents put this opinion in second position of order of importance, just after "acoustics"). That could be correlated with the fact that environmental perception is due to all the senses. Some authors [7] have discussed the complexity of global human sensations in relation to the physical environment.

However, the results of the last part of the subjective survey on the subject, were insufficient to show that the view of the stage had a great influence on sound perception in the GTB. In fact, the uniformity of answeres regarding this point was very great because only 30% of the respondents found they had a bad view of the stage. But it did not seem to affect the opinion about the acoustical qualities of the hall, which was unanimous. The statistical crossing between the items was not meaningful.

Concerning the estimation of this hall (GTB), the results show clearly that the great majority of the involved audience had a favourable judgement (pleasing to the eye, quiet, clean, etc.). In spite of comfort defects due to the age of the opera house, such as the lack of space between the salts, the Grand Theatre de Bordeaux is very well appreciated.

We must remember that this hall is famous for its architecture. It is worth noting that, even in bad acoustical conditions (wind, traffic noises, etc.) such as can be found in Greek or Roman theatre opera performance — as, for example, in the town of Orange (France) — the feeling of participating in an exceptional event is more important than any physical comfort criteria.

4. CONCLUSION

Because many studies investigating the subjective response of listeners were conducted with subjects having expert knowledge of sound [6, 8], it is interesting to consider the point of view of the general public who represents the typical audience.

For that reason, the aim of this study was to test a questionnaire destined to ordinary listeners in order to know their needs and their expectations in matter of performances in the opera house. In such investigations in more difficult part is always to answer the technical questions. The significant correlation between subjective responses and measured objective criteria allows to record a good reliability to this questionnaire.

The social questions contribute to a better and complementary understanding of what makes a "good" hall. This information, not only on acoustical comfort, is very useful to architects for their design method.

ACKNOWLEDGMENTS

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