CORRELATION BETWEEN SUBJECTIVE DESCRIPTORS AND OBJECTIVE PARAMETERS OF THEATRES AND AUDITORIA ACOUSTICS SIMULATED WITH BINAURAL SOUND SYSTEMS

Andrea Capra*[1], Marco Binelli[1], Daniela Marmiroli[2], Paolo Martignon[1] and Angelo Farina[1]

[1]Industrial Engineering Department, University of Parma, Italy
[2]Faculty of Medicine, University of Parma, Italy
andrea.capra@ied.unipr.it

Abstract

Getting older, our auditory system looses functionality: the level and the frequency range of the perceived sounds decrease. A large part of people who habitually assist to shows of lyric and classical music has an age older than forty years: it is therefore assumed that these persons have a loss of perception in high frequencies, beside other typology of auditory disturbances. In most of cases, who has consciousness of his deficiency wears hearing aids, but they are set for a better intelligibility of speech. Because all of these things the largest part of who seats in theatres or in auditoria don't perceive correctly the sound generated from the performer (singers, orchestra, single musician, etc…). In order to find a possible correlation between objective parameters and subjective descriptors, and so to perform meaningful listening tests, we need to comprehend what is the perception of the medium customer and take it into account. The first step of our research was the distribution of a questionnaire in Regio Theatre (Parma) and Paganini Auditorium (Parma) to know the age, study degree, preferences, authority on music. The second step was a listening test on subjects recruited with the mentioned questionnaires. They were performed in "La Casa della Musica" (Parma – Italy), in a listening room with an acoustic treatment, using Stereo Dipole as system of test. The complete test was composed by three parts: an audiometric test, a listening test without hearing aids and the same test with hearing aids, set with a correction only in the case of a hearing deficit. Therefore this paper shows the preparation, the development and the results of this particular session of listening tests.

INTRODUCTION

Correlation between subjective descriptor and objective parameters is fundamental for the design of new theatres and concert halls: if we knew that a positive judgment on the acoustic of a theatre correspond to a set of values of principal acoustical parameters (T60, C80, Lateral Fraction, etc…) we will be able to project new theatres close to listeners expectations. The main problem is that most of the people who frequent theatres do not listen to the music with the right perception in all the frequency range. In fact, getting older, our perception of the sounds changes for a natural loss in high frequencies due to the ageing of our auditory system. Also the increasing of sound pollution is a possibly cause of damages of our auditory perception. In most of cases the loss is gradual, the brain gets used to its new equalization and the person is convinced of his capability in hearing sounds.
The aim of the particular listening tests here presented was to investigate changes in correlation between subjective and objective acoustic parameters with and without a correction of auditory deficits.

TEST SESSION

We recruited subjects for the listening tests during Opera Season of Regio Theatre and Concert Season of Paganini Auditorium, both in Parma (Italy). To have a representative sample of population of the listeners, a questionnaire was distributed asking age, number of concerts and operas attended per year, degree and possible musical studies. 919 questionnaires were collected giving a large subjects availability for the test . We choose for the test 30 subjects, representative of the theatregoers, distributed as shown in *Figure 1*:

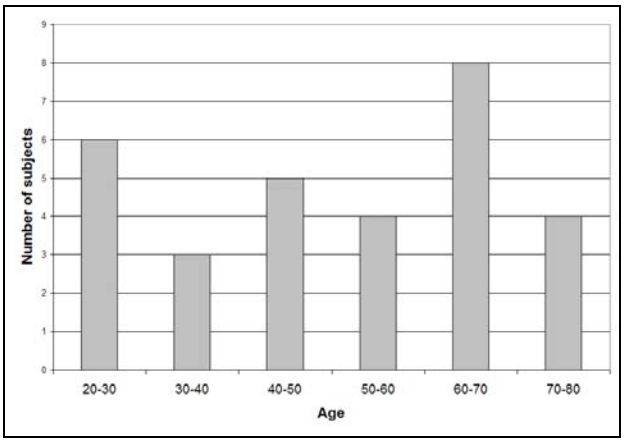

Figure 1 – Details of subjects under test

The test was divided into three parts. The first, an audiometric test, was executed with a portable audiometer (*Interacoustic AS7)*, in the listening room; the aim of this

preliminary test was the characterization of the subjects to find out possible auditory problems.
In the second part, after the audiometric test, the subjects performed a listening test evaluating the acoustic characteristics of two opera houses (*Regio Theatre* in Parma, *Valli Theatre* in Reggio Emilia), two auditoria of comparable dimension (*Auditorium Paganini* in Parma, *Sala Petrassi* of Parco della Musica in Rome) and an historic theatre (*Olimpico Theatre* in Vicenza). The comparison between the five room was made through auralization, convolving the measured impulse responses [1] with the anechoic Overture of "*Le nozze di Figaro*" (Mozart), performed by *Osaka Philarmonic Orchestra (Denon)*. We choose binaural impulse responses recorded using the *Neumann KU100 Dummy Head* placed approximately at the same distance source-receiver in every room (~14 m); the source used for the test signal was a dodecahedron with a subwoofer, placed on the stage on the left and on the right. We prepared tracks for the test making convolution between anechoic stereo track and binaural impulse response with source placed on the left, making convolution between anechoic stereo track and binaural impulse response with source placed on the right and making a mix of the two stereo tracks.
From recent studies [2] stereo dipole [4] seems to be a good reproduction system in terms of realism and spatiality, in spite of a small sweet-spot. This binaural technique, on the contrary of headphones, doesn't cause the unpleasant effect of a generation of the sound from the centre of the head but it places the listener in a more comfortable, "head locking" free sound space. For the stereo dipole reproduction system a couple of monitors Genelec S30D was used, placed with an angle of 30° and with a distance of 1.5 m from the listener chair. Implementation of inverse filtering [5] was performed through the plug-in "*Inverse Kirkeby*" of *Aurora Plug-ins* (A.Farina) and *Voxengo Pristine Space* inserted in *Plogue Bidule* host.
The listening test was made by means of a dedicated software: the user had the capability to switch in real time between the five room within interrupting the play of the track, evaluating and saving the judgements. The evaluation of the acoustics was made through nine couples of adjectives identified [3] as the most suitable for this type of characterization: *pleasant-unpleasant, round-sharp, soft-hard, diffuse-localizable, detached-enveloping, dry-reverberant, treble boosted-treble reduced, bass boosted-bass reduced, quiet-loud* .
The third part of the test consisted in the same listening test of the second part wearing an *Oticon Tego* auditory aid on both ears, set to compensate the frequency deficit, shown from the audiometric test, on the subject.

RESULTS

Audiometric Test

From the analysis of audiometric tests emerges (Figure 2) that only the first two classes of age, from 20 to 40 years, had an auditory system without corruption: a small loss of level but no evident loss in particular bands of frequencies. The high

frequencies loss is proportional to the increase in age, with an heavy deficit in middle-high frequencies for subjects from 70 to 80 years. Subjects from 50 to 80 years, in most of cases, don't hear correctly the sound of an orchestra: they are unable to hear the sound of a *piccolo*, the last octave of a piano or the last notes of a violin, because they hear an unbalanced sound with lack of high frequencies. From the 912 questionnaires collected emerges that 59.3% of regulars theatergoers has an age included in this range; this means that only 40.7% seems to hear correctly the sound. This result match with most of the results present in literature [6].

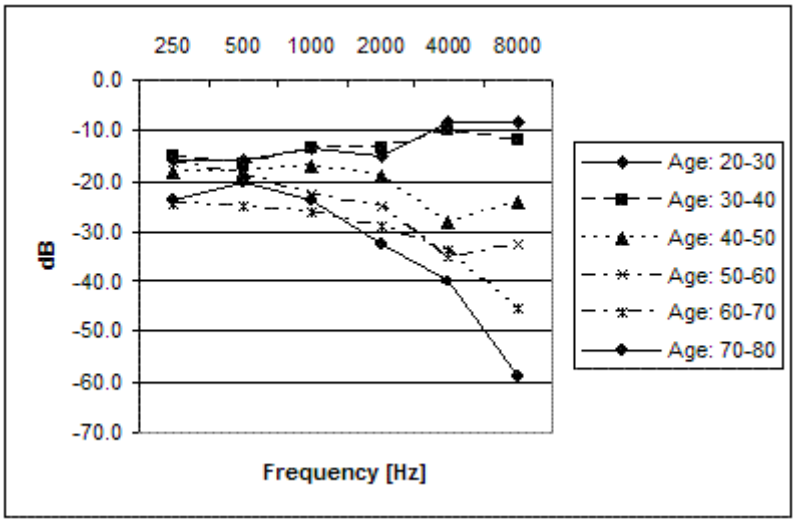

Figure 2 – Average of the auditory system loss for listening test subjects

On the 30 subjects tested there was only a case of a person with an audiometric test perfectly linear. For the subjects with an age between 20 to 40 years there's a sound level, heard on basses, lower than the one heard in high frequencies: the test was made in winter and this phenomenon is due to possible colds of the season.

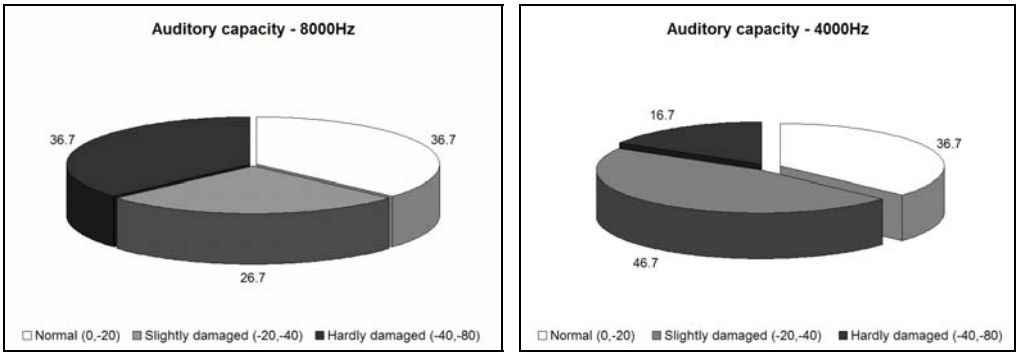

Figure 3 – a)Auditory capacity in the band of 8000Hz for the tested subjects
b) capacity in the band of 4000Hz for the tested subjects

Most of the theatergoers were sure of their capability in hearing every frequency distinctly: the 85.7% declared a normal auditory capacity, the 11.9% declared a slightly damaged capacity and only the 2.4% supposed an hard damage of his capacity. The real capacity, showed from the audiometric test, is quite far from the previous percentages (Figure 3): the 16.7% of subjects has an hardly compromised auditory system on the 4000 Hz and even the 36.7% has a big deficit on the 8000 Hz. Is emblematic the case of a subject, suspended 15 years ago from his job for hypacusia due to an auditory trauma, who declares that he hears "*every sound, also the highest notes of violins played very quiet*"; this is impossible because his audiometric test reveals a big loss, from 40 dB to 70 dB, on medium-high frequencies.

Listening test

For the analysis of possible correlations between subjective descriptors and objective parameters of acoustics, nine parameters for every room, showed in Table 1, were chosen: reverberation time (T20 and T30), clarity (C50 and C80), definition (D50), energy barycentric time (Ts), early decay time (EDT), bass ratio (BR), tonal balance (TB), inter-aural cross-correlation coefficient (IACC) and lateral fraction (LF). All the values were measured from 2002 to 2005 by Prof. Angelo Farina and his staff.

	A.P.	**T.O.**	**T.R.**	**R.700**	**T.V.**
C50 [dB]	2.00	1.21	2.86	-1.51	0.51
C80 [dB]	3.92	2.94	6.49	1.30	6.37
D50 [%]	54.36	56.24	59.89	41.25	52.45
Ts [ms]	110.64	94.49	75.12	122.51	67.52
EDT [s]	2.12	1.77	1.34	1.71	1.15
T20 [s]	1.99	1.86	1.32	1.80	1.36
T30 [s]	2.03	1.85	1.28	1.84	2.08
Lateral Fraction	0.48	0.44	0.41	0.62	0.44
IACC	0.49	0.42	0.57	0.40	0.65
Tonal Balance	0.08	-0.04	0.11	0.14	0.13
Bass Ratio	1.13	0.77	1.34	0.99	1.33

Table 1 – Objective parameters (A.P.=Auditorium Paganini, T.O.=Olimpico Theatre, T.R.=Regio Theatre, R.700=Sala700, T.V.=Valli Theatre)

A first comparison between the two test (with and without auditory aid) on the descriptor "*pleasant-unpleasant*" shows as, in subjects with a "normal" auditory capacity, the aid doesn't modify the judgment: the only little gain doesn't seem to affect the right perception of sounds.
From a multivariate analysis, performed with software *SIMCA P11*, comes out a correlation of "*pleasant-unpleasant*" with four subjective descriptors (Figure 4). The four couples, "*soft-hard*", "*round-sharp*", "*detached-enveloping*" and "*dry-reverberant*", seems to be the most important to forming a judgment on the

pleasantness. This result is strengthened from its observation in both cases, with and without auditory aid.
For the statistic analysis the *Last Squared Method* was used, finding out a linear regression coefficient for every coupling objective-subjective parameters. The absolute value of 0.3 was chosen as a limit between a sufficient and a bad correlation.
One of the most significant results is that an increase of the balance between middle and bass (*Tonal Balance*) seems correlated with the couple *round-sharp* in both cases, with (r = -0.39) and without (r = -0.36) aid (Figure 5). The same objective parameter affects the pleasantness (r = -0.33) wearing the aid: the overemphasizing of bass frequencies in subjects, which are not used anymore in such equalization, makes unpleasant the sound.

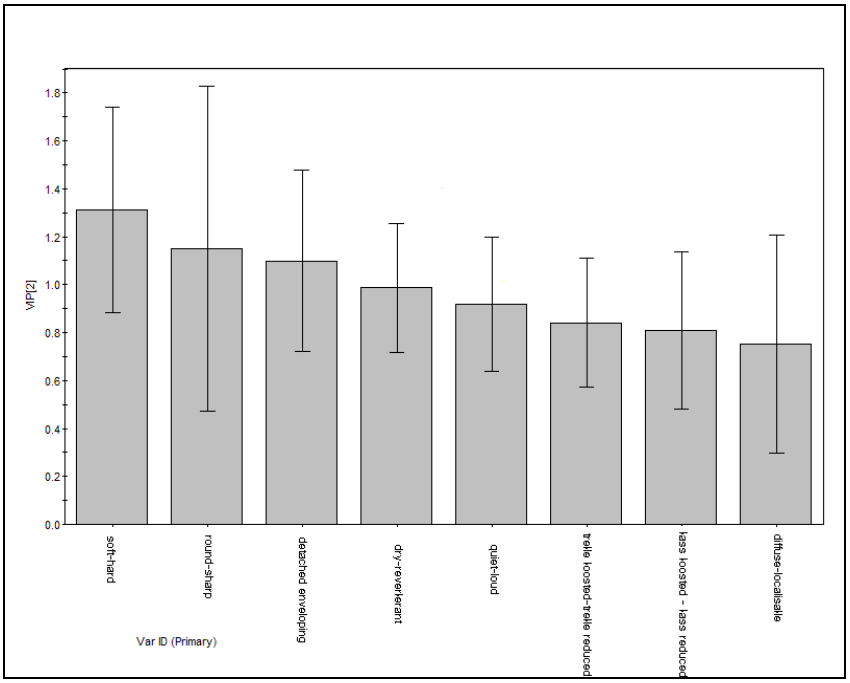

Figure 4 – Scale of importance of the subjective descriptors contributing to "pleasant-unpleasant"

An other relevant objective parameter is the Baricentric Time (Ts): its improving seems correlated with the sensation of bass accentuation (r = -0.39). The reverb time *T20* shows a correlation only with *"quiet-loud"* (r = -0.31) and only in the case of absence of auditory aid.
We noted unexpected results as the lack of correlation between the two spatial parameters *Lateral Fraction* and *IACC* with the subjective descriptors "*diffuse-localizable"* and "*detached-enveloping"* or as the small influence of reverb parameters on subjective judgements.

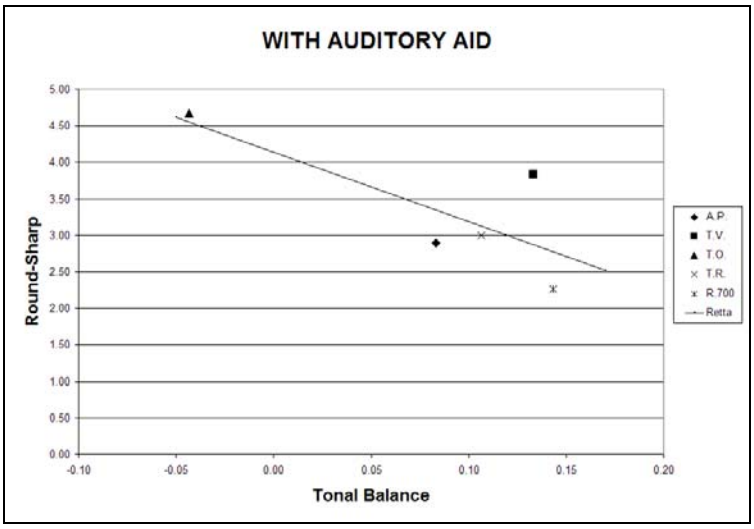

Figure 5 – Linear regression of Tonal Balance and "round-sharp" wearing auditory aid

CONCLUSIONS

The listening test points out the importance of taking into account auditory capability of theatergoers for an accurate evaluation of theaters, concert hall and listening room: people are sure of their capability in hearing sound but, in most of the cases, their deficit, due to auditory traumas or natural aging, doesn't allow a correct perception.
The test must be improved with a more accurate statistical analysis because of a too scant linear correlation between single subjective and single objective parameters. The next step will be the research on these data, with a multivariate analysis, of a mathematical model representing the descriptor "*pleasant-unpleasant*" in dependence of objective parameters.

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