

PSYCHO-PERCEPTIVE JUDGEMENTS ON ACOUSTICAL QUALITIES IN OLD TURKISH MOSQUES

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SUMMARY

An experiment has been performed, in the European project CAHRISMA, using auralized sounds, in which some parameters have been modified; the variables are distance between source and receiver (2 levels), volume (2 mosques), Reverberation Time (7 RT's) and sound type (sermon and prayer). 56 different sounds have been presented and evaluated by a sample of 60 people, one sub-sample being Islamic, the other not.

The statistical analysis of the data allows the evaluation of the preferred RT, as well as the assessment of the relative weight of the perceived distance, RT, intelligibility-clarity and intensity in the global impression on the mosques acoustical qualities.

These data could be considered as requirements for the building of new mosques.

I INTRODUCTION

The project CAHRISMA consists in a revival of the cultural heritage represented by the old churches and mosques in Turkey, built during the Byzantine era and the Ottoman period (XVIth century).

Some of the aims of this European study, as a part of INCOMED program, consist in the assessment of the qualities of the sounds heard in these worship buildings and in the development of acoustical requirements for new mosques. The work has comprised 3 steps:

- a psycho-social survey among 120 users, to know their spontaneous opinion on the relative importance of acoustics, compared to architectural-historical value and decoration
- a set of 15 interviews of specialists in acoustics such as to give their impression on registered sounds in the historical mosques, as to select the main acoustical parameters of their judgment.
- an experiment in laboratory, that is the topic of this paper

II EXPERIMENTAL PROTOCOL AND SAMPLES

The aim of this part of the study is to find out the optimum acoustic properties of the rooms used as mosques, in order to develop a proposal of criteria , especially for reverberation time (RT) for the new mosques. The sound signals for subjective investigation were prepared by Technical University of Denmark, one of the partners of the project. The ODEON models of Sokullu (5700 m³) and Süleymaniye (115 000 m³) have been chosen as stimuli rooms. Taking as reference the measured RT's of the mosques and following scaling factors 0.5, 0.63, 0.8, 1.25, 1.59 and 2, seven different reverberation times are obtained for each of the mosques. Two anechoically recorded signals are chosen as stimuli (song – prayer and speech –sermon-). Furthermore two receiver positions are chosen in each model, giving a total of $2*7*2*2 = 56$ stimuli signals (Table 1).

The experimental protocol was based on the headphone listening, in a quiet room, of 56 different sounds, by two different groups (30 Muslims and 30 non-Muslims). Each person is characterized by one's age, profession, relative worshipping, and understanding of the language used for the prayers and sermons. The auditory sharpness was controlled through an interview.

For each sound the answerer had to bring out characteristics on a non-graduated scale of 10 cm. For each sound, the distance from the speaker, the intelligibility of the sermon or clarity of the prayers, sound intensity and overall impression were evaluated separately. At the end of the 45 minutes listening of the 56 sounds, each person was asked to give a personal opinion on the whole protocol (comfort, habit and stress).

The Muslim sub-sample is on the whole fairly older. The non-Muslim sub-sample may be characterized by a fairly low worshipping frequency , as opposed to the Muslim panel who have been selected directly on the public worship place of the Lyon Mosque. The experimental protocol was generally judged somewhat more customary , appeasing and pleasant by the Muslims as they can understand both sermons and prayers, as opposed to the non-Muslims

Table 1. Sound features – Description of the observed variables
SOKULLU Mosque

sound	speech	Distance	RT
1	Prayer	4,33	1,80
2			2,12
3			2,58
4			2,92
5			3,39
6			4,19
7			4,94
8		12,89	1,90
9			1,97
10			2,54
11			2,95
12			3,38
13			4,17
14			4,83
15	Sermon	4,33	1,80
16			2,12
17			2,58
18			2,92
19			3,39
20			4,19
21			4,94
22		12,89	1,90
23			1,97
24			2,54
25			2,95
26			3,38
27			4,17
28			4,83

SULEYMANIYE Mosque

sound	speech	Distance	RT
29	Prayer	6,00	3,86
30			4,57
31			5,35
32			6,25
33			7,50
34			8,95
35			10,34
36		32,58	3,96
37			4,75
38			5,47
39			6,35
40			7,52
41			8,81
42			10,21
43	Sermon	6,00	3,86
44			4,57
45			5,35
46			6,25
47			7,50
48			8,95
49			10,34
50		32,58	3,96
51			4,75
52			5,47
53			6,35
54			7,52
55			8,81
56			10,21

The consistency of the answers of each subject for every scale was tested under the hypothesis that the data were distributed according to the normal law. Consequently a few subjects were removed because of their deviant answers. The analysis lays upon perceptive judgments of both samples, then a quantitative approach out of which we may extract some prospective psycho-acoustic law.

III A COMPARATIVE ANALYSIS OF PERCEPTIVE JUDGEMENTS FROM DISTINCT GROUPS

3.1 Definition and building up of the mean scores for each sound

The chosen approach has allowed to obtain a set of grades for each subject. The method retained leads to the calculation of a mean score for each sound as well as for each of the 5 scales measured by both panels.

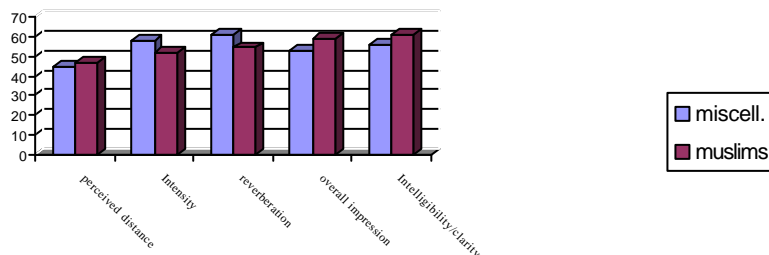


Figure 1. Mean scores on the various scales of perception for both panels

The slight differences between the panels cannot be regarded as statistically significant. What can only be noticed is a slight overestimation of intensity and reverberation for non-Muslims as well as a slightly superior overall impression and intelligibility for Muslims, the latter being explained by their better understanding of the language. The perceived distance gets similar judgments from both panels.

Comparisons depending on the mosque

Whatever the panel, the results do show a feeling of proximity and a better intelligibility and clarity in the Sokullu mosque. In much the same way the reverberation time is assessed as shorter and the general impression better than in the Suleymaniye mosque.

Comparisons depending on prayer or sermon

For both sub-samples again there are no significant differences in judgments whether prayers or sermons were heard. It is only to be remarked a slightly superior score for prayers, yet it remains non-significant.

Comparisons depending on real distance

Real distance had a statistically significant influence on all perceptions and ensuing judgements. Scores are better for shorter distances (4,33 or 6 meters). They deteriorate (intelligibility, clarity, intensity and overall impression) for a longer distance (32,58 meters).

The perceived reverberation is shorter for both distances in Sokullu (4,33 ; 12,89 meters)

The perceived reverberation is higher for both distances in the second mosque (6,00 ; 32,58 meters)

The overall impression is slightly deteriorated for a short distance (4,33 or 12,89 meters) in Sokullu.

Conversely, the overall impression is deteriorating with a longer distance (6,00 or 32,58 meters) in the second mosque. These results are equivalent for Muslims and non-Muslims.

3.2 Comparisons of the scores in the perceptive scales depending on the physical values of RT (7 sounds for each class)

The perceived distance increases along with an increase in RT.

Intelligibility and clarity decrease with an increase in RT.

Intensity does not vary according to RT. The latter result, being fairly surprising, will be further analysed in next chapter.

The perceived reverberation does vary according to the variations in real reverberation. It will be noted that the difference observed takes place with values inferior to 2,54.sec

The overall impression deteriorates with an increase in RT. It is optimal for reverberation times inferior to 2,54 sec (for non-Muslims) and 3,38sec (for Muslims). Apart from the latter point the results obtained with Muslims

and non-Muslims are widely identical. It may only be observed that a longer reverberation time is tolerated by the Muslims without a consequent deterioration of the overall impression.

3.3 Correlations between the scales of perception

The correlation matrix shows close relations between real distance and

estimated distance (+)	clarity/intelligibility (-)
intensity (-)	overall impression (-)

Thus real distance was well estimated and its increase entails a deterioration of clarity/intelligibility and overall impression. What may also be observed is significant relations between measured RT and estimated RT, as well as between intensity and clarity/intelligibility(+) and overall impression(+). So, the overall impression does deteriorate with an increase in reverberation. Lastly, the overall impression is almost in confusion with intelligibility or clarity. The relations observed are comparable with both groups.

3.4. Preferences in sounds

For each sound one may observe the mean score obtained for the assessment scale from the 30 subjects and its possible differentiation from the average on the 56 sounds. The mean assessment scores obtained for each sound allow to select those which are over or under-valued (at least two standard errors above or under the average). Some variations may be observed between the two panels yet there is no wide deviation (a sound which has been under-estimated in one group will not be overestimated in the other)

The most preferred signals are 3 (which is for prayer), 15 and 16 (which are for sermon) for Sokullu.

The least appreciated sounds are 41 (prayer) and 50 to 56 (sermon) for Süleymaniye. All of them are distant positions. However for sermon the results are the same for all RT values, whereas for prayer the least appreciated sound has an RT of 8,81 sec.

No sound was then « preferred » by one group while being « rejected » by the other sub-sample.

IV STUDY OF PERCEPTIONS DEPENDING ON THE PHYSICAL PROPERTIES OF THE SOUNDS

4.1 Correlations between RT-1000 Hz, overall impression and intelligibility/clarity

Each sound is characterized by 8 values in reverberation time per octave. The correlation matrix shows that :

- the RT per octaves are highly correlated between themselves
- the 8000 Hz band is slightly less correlated to the other values of RT , except for the 1000 Hz band which stands out as better correlated to that 8000 Hz band
- the value of RT which comes out as best correlated to the general impression of intelligibility/clarity is around 8000Hz.

It may be noted that in Suleymaniye, the value of RT at 1000 Hz (selected so far) is far less correlated to the overall impression than the value of RT for 8000 Hz.

Comparison of the mean values of the 56 sounds depending on the mosque

It has been observed that the sounds simulated in the two different mosques are not acoustically comparable, in terms of perceptions linked to the physical characteristic of the reverberation times. Whatever the frequency band, the reverberation times are, on the average, longer in Suleymaniye while the judgements are better for Sokullu (proximity, intelligibility :clarity, overall impression) for both groups.

4.2 Correlations and regression lines between overall impression (y) and the values of RT (x)

- for non-Muslims $y(\text{impression}) = -3,36x + 69,5$ $\ll r \gg = 0,507$
- for Muslims $y(\text{impression}) = -2,94x + 73$ $\ll r \gg = 0,48$

The overall impression is linked to the reverberation time at 1000 Hz and declines with its increase. Both panels allow us to observe that the relationship between overall impression and RT is much less scattered, and hence closer and more linear for low values of RT. The relationship between overall impression and RT is closer for simulated sounds in Sokullu. These links x/y being very close for both groups, a united analysis may be built.

4.3 Study of regression and overall impression depending on volume and distance

The volume of the rooms has been estimated as a ratio of 1 to 20 between the two mosques

- Simple correlations overall impression/volume = - 0,32
- overall impression/distance = - 0.78

4.4 Complementary Analyses

The graph in Figure 2 illustrates quite clearly, whatever the panel, a definite decline in the overall impression with an increase of the reverberation time (threshold at 3,38 sec). A test was made on a panel of Turkish listeners; it will be analysed in a future paper.

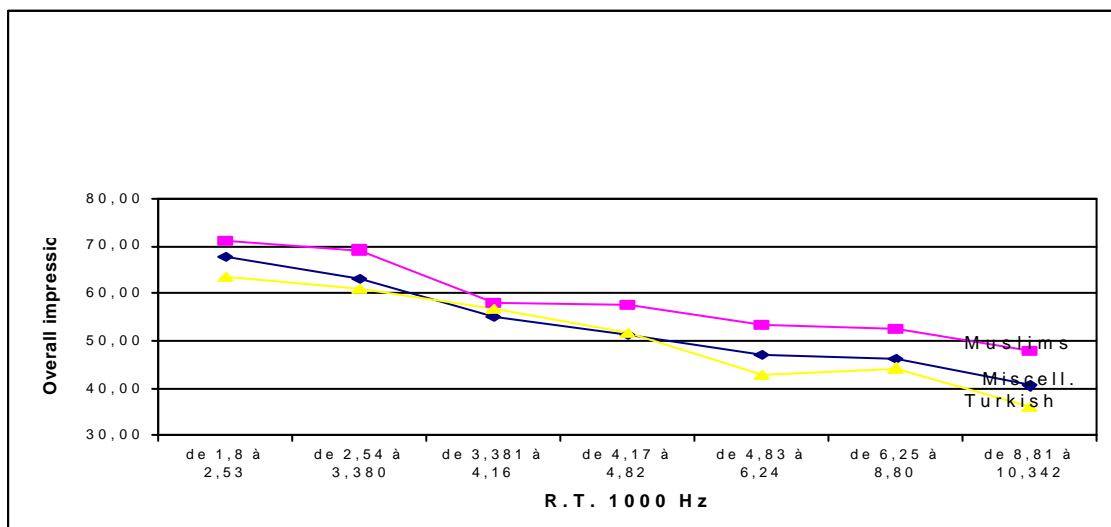


Figure 2. Mean overall impression with RT 1000 Hz

For each mosque: mean overall impression depending on distance and RT

For both mosques one may observe a decline in overall impression linked to the increase of distance as well as to an increase in RT.

Sokullu ; closer sounds : the mean overall impression remains statistically superior down to a value of RT of 2,92 sec for closer sounds.

Sokullu ; distant sounds : the mean overall impression remains statistically superior down to a value of RT of 2,54 sec.

For this mosque , the effect of distance on the overall impression is partly compensated by the decrease in RT.

Süleymaniye ; closer sounds : the mean overall impression remains superior down to a RT value of 5,3 sec.

Süleymaniye ; distant sounds : the mean overall impression remains statistically superior down to a value of 4,75 sec. However the decline in overall impression linked to the increase in distance is less compensated by the decrease in RT.

4.5 Specific study of reverberation and perceived intensity

Optimum : first value of RT associated to a perceived reverberation approximately equal to 50 on the scale of perception (graduated from 0 to 100). So it appears to be the real value of reverberation associated to a median perception.

Significant deviation : couple of values of real reverberation associated to the higher variance in perception (sensitivity index)

Reverberation perceived depending on prayer or sermon, for each mosque

Sokullu

Sounds 1 to 7 : Sokullu – prayer – 4,33 meters

The optimum is between 2,92 and 3,39 sec. The more significant deviation is around these two values.

Sounds 15 to 21 : Sokullu – sermon – 4,33 meters

The optimum is between 2,92 and 3,39 sec. The more significant deviations are around 2,92 and 4,19 sec.

Sounds 8 to 14 : Sokullu – prayer – 12,89 meters

The optimum is around 2,95 sec. ; the more significant deviations are around 1,97 and 2,95 sec

Sounds 22 to 28 : Sokullu – sermon – 12,89 meters

The optimum is between 2,54 and 2,95 sec. yet the more significant deviations are around 3,38 and 4,17 sec.

Süleymaniye

Sounds 29 to 35 : Süleymaniye –prayer- 6 meters

The optimum is around 4,57 sec. The more significant deviation is between 3,86 and 4,57 sec.

Sounds 43 to 49 : Süleymaniye – sermon- 6 meters

The optimum is around 3,96 sec. The more significant deviation is between 3,86 and 4,57 sec.

Sounds 36 to 42 : Süleymaniye – prayer – 32,58 meters

The optimum is around 3,96 sec. The more significant deviation is between 3,96 and 4,75 sec.

Sounds 50 to 56 : Süleymaniye – sermon- 32,58 meters

The optimum appears to be under 3,96 sec yet the more significant variation is between 4,75 and 5,47 sec.

These results display little variation , in both mosques , with prayer or sermon. However , they display a higher variation according to distance :

Sokullu : the optimal values are between 2,92 and 3,39 sec. for « closer » sounds and between 2,54 and 2,95 sec. for more distant sounds.

Süleymaniye : the optimal values are around 4,57 sec for « closer » sounds and below 3,96 sec for distant sounds.

Reverberation perceived depending on distance, for each mosque

This second statistical approach of perceived reverberation depending on real reverberation lays the emphasis on the variations entailed by the distance and the type of mosque (as the preceding analysis has concluded to a very low effect of the difference between prayer and sermon)

Session 1 : short distance –Sokullu mosque

The optimum is around 3,39 sec. . The more significant deviation is between 2,92 and 3,39 sec.

Session 2 : short distance – Süleymaniye mosque

The optimum is around 4,57 sec. The more significant deviation is between 3,86 and 4,57 sec.

Session 3 : longer distance – Sokullu mosque

The optimum is around 2,95 sec. The more significant deviations are between 1,97 and 2,95 sec.

Session 4 : longer distance – Süleymaniye mosque

The optimum is around 3,96 sec. ; The more significant deviation is between 4,7 and 5,4 sec.

For the first three sessions , the perceived reverberation did vary according to real RT in a linear and rising mode. For longer distances in Süleymaniye (session 4), the perceived reverberation has undergone a lesser variation (a lower value of F-test). In most cases a decrease in the values of RT compensates for an increase in distance, except for huge mosques in which things are clearly more complex. The latter observation allows us to use these results, coming from the cultural legacy of ancient Turkish mosques, for the building of new modern mosques.

VI CONCLUSIONS

The analysis of the quantitative results of this psychoacoustic experiment on auralized sounds shows a slight difference between the Muslim group and the non-Muslim group; yet these slight differences cannot be held as statistically significant. What was observed was merely a slight overestimation of intensity and reverberation for non-Muslims in parallel with slightly superior overall impression and intelligibility for Muslims , which is easily explained by their knowledge of the language. The perceived distance was judged in similar terms by both groups.

The overall impression appears to be closely linked with distance and RT, and deteriorated with an increase in these parameters. The indications of the advisable RT values for a practice of prayers and sermons display an optimal value which varies according to the distance between the speaker and the listener :

- for a volume of some 5000 to 6000 m³ (Sokullu mosque= 5700), the optimal RT is between 2,9 and 3,4 sec., a short distance (4m), and it is identical for prayer and sermon ; for a distance of 13 m , the optimum is between 2,5 and 3 sec. for prayer, with a critical value between 1,97 and 2,95 sec. , hence it appears advisable, at that distance, not to exceed 2,5 sec. At the same distance optimum RT for sermon is between 2,54 and 2,95 sec, with a critical value between 3,86 and 4,6 sec.
- for a much bigger volume (Süleymaniye mosque=115000 m³), the optimum for prayer and sermon is around 4,6 sec. for a distance of 6 m; the critical point here is between 3,86 and 4,6 sec , hence it appears advisable to remain definitely below 4,6 sec. For a longer distance, such as 32 m, the optimum is 4 sec. for prayer and sermon, with an inflexion between 4 and 4,8 sec for prayers, and between 4,8 and 5,5 for sermon.

The analysis of the findings of this work, together with the measurement results and the literature values, will help in the development of clearer data which will be proposed as requirements for new mosques.

The simulation of sounds coming from the cultural legacy of ancient mosques built in Turkey in the 16th century did provide, after some experiments, indications to be followed for the building of new mosques ; the acoustic treatment through architectural means will be central to the project. This basic treatment will have to be completed with electro-acoustic devices so as to take into account the number of worshippers , which may vary from one day to another , and which modifies in great proportions the values of acoustic absorption , hence the acoustic quality of sermons or prayers.

REFERENCES

- Karabiber Z: A new approach to an ancient subject: CAHRISMA project; ICVS 2000, Garmisch.
Pompoli R, Prodi N Marisilio M: On the prediction of reverberation time and sound levels in mosques, 17th ICA, Rome 2001
Vallet M, Vincent B, Karabiber Z Celik E, Erdogan S : Psychoacoustic evaluation of the sounds in old Turkish mosques; 17th ICA Rome 2001
Weitze C, Rindel J, Christensen C, Gade A: Computer simulation of the acoustics of mosques and Byzantine churches; 17th ICA, Rome 2001
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