THE SIGNIFICANCE OF THE CHURCH OCCUPANCY IN THE *RASTI* VALUES IN A CATHOLIC CHURCH

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ABSTRACT

This study reports on Rapid Speech Transmission Index (*RASTI*) field measurements made in a 17th century Portuguese Roman Catholic church. One source location (main altar area) was used in an empty and occupied same church, with and without the use of its own sound reinforcement system. This paper concentrates on the relationships of the *RASTI* values with the effect of the presence of a full occupancy in the church. The mean *RASTI* values in the church varied from 0.31 to 0.64 (non-occupied church) and from 0.32 to 0.56 (occupied church). The results show that the presence of persons, considering all receiver positions within the church, increases on average, 0.02 in the absolute *RASTI* values (or 7 per cent in the relative *RASTI* values) with the PA system off and about 0.05 (or 10 per cent) with the PA system on.

INTRODUCTION

This study is part of a research program initiated in 1991 at the U. of Porto (Portugal) and U. of Florida (USA) to explore methods to evaluate and predict the acoustical qualities of churches (http://www.fe.up.pt/~carvalho/igrejas.htm). It involves field measurements in a large number of Catholic churches and has included two major components to date:

- *Objective studies* - Measurements of objective acoustical parameters taken at multiple locations in each church (*RT*, C_{80}, D_{50}, *RASTI*, etc.). [1-5]
- *Subjective studies* - Evaluations of live musical performances and live speech intelligibility testing by the use of a sample of listeners and using several locations in each church. [2, 5-7]

The research program is focused on the Roman Catholic churches of Portugal. Portugal is one of the oldest European countries and played a prominent role in some of the most significant events in world history. It presents an almost perfect location to trace the history of Catholic Church buildings in the world. Portuguese churches can be considered a representative example of Catholic churches.

This paper presents a report regarding the first item and concerning the *RASTI* (Rapid Speech Transmission Index) measurements.

METHODOLOGY

Method summary. The main research hypothesis is that *RASTI* value differences within churches could be measured by greatly changing the number of persons present. The study tested the significance of the church full occupancy in the *RASTI* values. It was composed of two parts both regarding *RASTI* analyses.

The first part was to gather objective evaluations of the acoustical qualities of the churches from the use of the *RASTI* in a non-occupied church (parameter named *RASTI_empty*). The second part was to use the same type of evaluations in the same church but with the presence of persons (parameter named *RASTI_occupied*). In each situation the measurements were done using the *RASTI* sound source at the altar area but in two conditions:

- with the church's PA (Public Address) system turned off (parameter named *RASTI_Altar*);
- with the church's PA system turned on (parameter named *RASTI_PA*).

The parameter RASTI. The *RASTI* method involved measurement (with a B&K type 3361 set) of the reduction of a transmitted test signal that has certain characteristics representative of the human voice. This method, a simplified version of the Speech Transmission Index (*STI*), was developed in 1984 and has been related to subjective intelligibility [8] (see Table 1).

The advantage of *RASTI* regarding other methods is that it can be quickly evaluated without speakers or listeners. A transmitter generates pink noise for the 0.5 and 2 kHz octave bands, respectively, to mimic the long-term speech spectrum and with similar directional proprieties that would be measured from a human speaker. The low frequency modulations that exist in speech are simulated by 9 discrete modulation frequencies. A microphone receives the signal that is analyzed by the receiver unit to calculate the *RASTI*, a value between 0 and 1 derived from the measured reduction in signal modulation between the transmitter and receiver positions. It automatically includes the effect of reverberation and background noise because it is derived from the measured signal degradation.

Table 1 - RASTI transfer function. [8]

RASTI values	Subjective Intelligibility Scale
0.00 - 0.30	*Bad*
0.30 - 0.45	*Poor*
0.45 - 0.60	*Fair*
0.60 - 0.75	*Good*
0.75 - 1.00	*Excellent*

Fig. 1 - Picture of the St. John Church (front view).

Church used. This study reports on field measurements done in one typical Roman Catholic church that is a good example of church building in Portugal (Fig. 1 and 2). Its main architectural features are displayed in Table 2.

The church used was the *S. João Baptista* (Saint John Baptist Church) located in the Largo Igreja da Foz in Porto, Portugal. It was built in the 17th century in the neoclassic style and it was officially declared by the state as a Building of Public Interest by the Law 129/77 of 29.9. This church was selected because:

- it is a median size church;
- it is a sample of a median range style (very "distant" from the Romanesque style and from the Contemporary churches);
- it is similar to a very large number of other Catholic churches;
- it was possible to have it completely occupied;
- it was possible to have a total cooperation from the priest and congregation.

Methodology. The measurements were done during a Sunday mass when the church had almost 200 persons (full occupancy). The service was paused during the homily for a short period (about 10-15 minutes) in which the measurements were done. The measurements in the non-occupied church had been done previously.

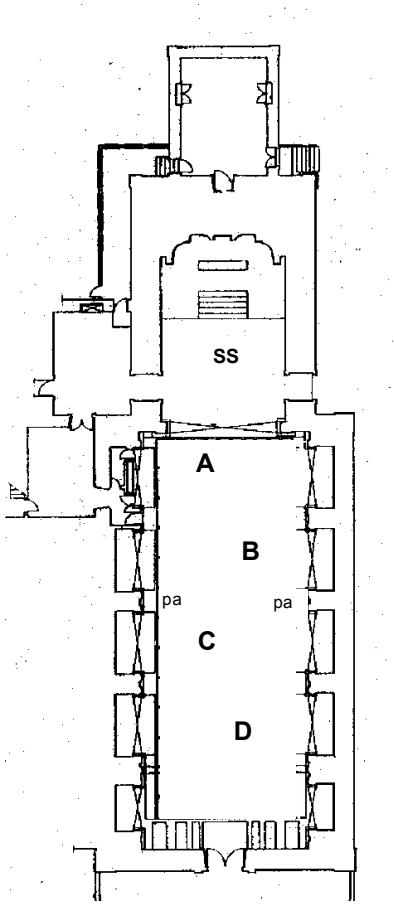

Fig. 2 - Plan of the St. John Baptist church (SS: sound source position, A-D: Receiver positions, pa- PA system position).

Table 2 - Architectural features for the church tested.

Architectural Feature	Value
Total Volume (m^3)	6048
Nave Volume (m^3)	3390
Total Area (m^2)	412
Nave Area (m^2)	219
Maximum Height (m)	17
Nave Height (m)	17
Average Height (m)	15
Maximum Length (m)	36
Nave Length (m)	24
Nave Width (m)	9
Average Width (m)	9
Total Absorption (m^2)	230
Average Absorption Coefficient	0.1

For the *RASTI* measurement in the church the transmitter location was in front of the main altar at about 1.65 m above the floor to represent a standardized speech situation during services. The sound level of the source was +10 dB compared with the *RASTI* standard level due to the large dimensions of some of the churches used in this research program. The microphone used in the situation with the PA system on, was held at about 0.15 m from the *RASTI* transmitter. Four positions within the church were

used for the receiver location (*A*, *B*, *C* and *D* as stated in Table 3) - see Fig. 2. In each receiver position three *RASTI* measurements were taken and then averaged to give the *RASTI* value at that location.

Table 3 - Measurement positions within the church.

Position	Distance to the Altar (m)
A	7.3
B	16.3
C	23.4
D	29.8

RESULTS

Tables 4 and 5 present a general analysis concerning all data collected. The mean *RASTI* values range from 0.31 to 0.64. About 44 per cent of the situations measured have *RASTI* values below 0.45 giving a poor rating in the quality of speech intelligibility. Only seven situations (44 per cent) achieved the minimum performance of 0.50 required in many public spaces, for instance when using voice systems [9]. The largest mean *RASTI* value (0.64) was found in position *B* (PA system on, occupied church).

Figure 3 displays all data collected and shows the effect of the presence of persons in the *RASTI* values with the PA system off (parameter named *RASTI*_Altar) and with the PA system on.

To measure the significance of the presence of persons a new parameter was defined, the *RASTI*_Gain, which represents the absolute difference between the *RASTI*, measured in the occupied and non-occupied church:

RASTI_Gain = RASTI_occupied - RASTI_empty.

If the *RASTI_Gain* is positive it represents that the presence of persons increases the *RASTI* values.

The same was done regarding the relative difference between the *RASTI* values measured. Another parameter was defined, the *%RASTI_Gain*, which represents the relative difference between the *RASTI*, measured in the occupied and non-occupied church:

%RASTI_Gain = (RASTI_occupied - RASTI_empty) / RASTI_empty.

Figure 4 and 5 display the variation in the absolute *RASTI* values (*RASTI_Gain*) and in the relative *RASTI* values (*%RASTI_Gain*) with the full occupancy of the church.

In all the situations (except one) the presence of persons increases the *RASTI* values (up to 0.09). Only for position *A* (the closest to the altar) with the PA system off, the *RASTI* decreases its value in 0.04.

The Figure 5 displays the *%RASTI_Gain* with the distance to the sound source. In all the situations the presence of persons increases the *RASTI* values (up to 21%).

Table 4 - Results with the PA system off (parameter named RASTI_Altar).

Posit.	*RASTI Altar occupied*	*RASTI Altar empty*	*RASTI Gain*	*%RASTI Gain*
A	0.53	0.57	-0.04	-7.0
B	0.44	0.41	0.03	7.3
C	0.39	0.37	0.02	5.4
D	0.38	0.31	0.07	22.6
avg.	0.44	0.42	0.02	7.1

Table 5 - Results with the PA system on (parameter named RASTI_PA).

Posit.	*RASTI PA occupied*	*RASTI PA empty*	*RASTI Gain*	*%RASTI Gain*
A	0.52	0.43	0.09	20.9
B	0.64	0.60	0.04	6.7
C	0.57	0.54	0.03	5.6
D	0.49	0.46	0.03	6.5
avg.	0.56	0.51	0.05	9.9

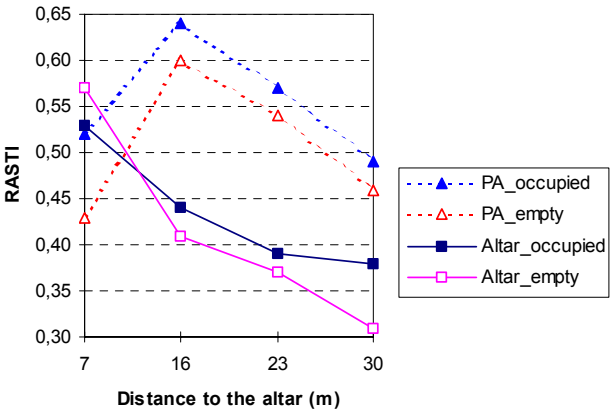

Fig. 3 - All RASTI results in the church. Effect of the presence of persons in the RASTI from the Altar (PA system off) and with the PA system on.

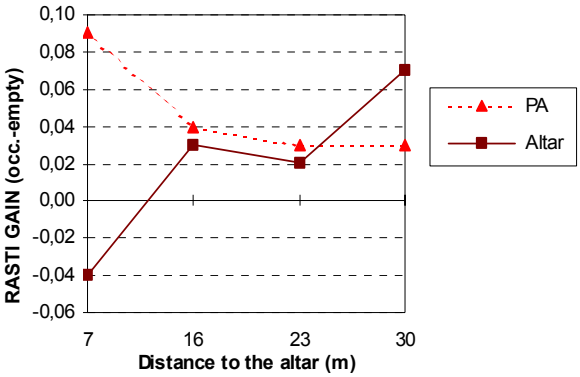

Fig. 4 - Variation in the absolute RASTI values with the presence of persons in the church.

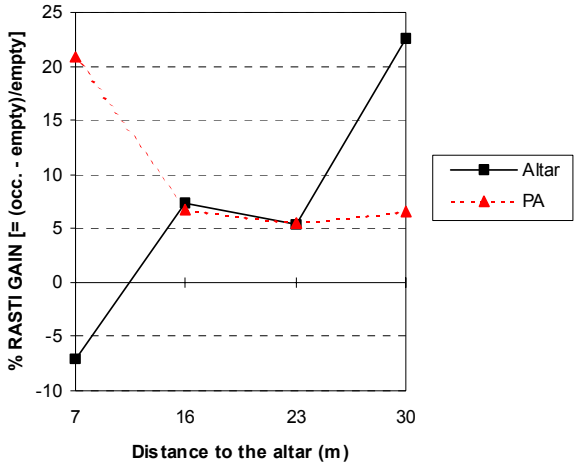

Fig. 5 - Variation in the relative RASTI values with the presence of persons in the church.

In each situation a best-fit equation (*RASTI* vs. *Distance*) can be written with a good correlation (R^2 from 0.86 to 0.98):

- Regarding Figure 4:

RASTI_Gain_Altar = 0.0703 ln(*Distance_to_altar*) - 0.0359*(*Distance_to_altar*) (R^2 = 0.86).

RASTI_Gain_PA = 0.0125*(*Distance_to_altar*)^2 - 0.0815*(*Distance_to_altar*) + 0.1575 (R^2 = 0.98).

- Regarding Figure 5:

%RASTI_Gain_Altar = 0.7102*(*Distance_to_altar*)^2 - 5.1375*(*Distance_to_altar*) - 11.099 (R^2 = 0.86).

%RASTI_Gain_PA = 3.8074*(*Distance_to_altar*)^2 - 23.471*(*Distance_to_altar*) + 40.04 (R^2 = 0.96).

CONCLUSIONS

This paper concentrates on the *RASTI* values within a church. One source location was used in an empty and occupied church, with and without the use of a sound reinforcement system.

The mean *RASTI* values in the church varied from 0.31 to 0.64 (non-occupied church) and from 0.32 to 0.56 (occupied church). The variation in each individual *RASTI* value regarding the presence of persons changed from -0.04 to +0.09 depending strongly on the receiver position.

The presence of persons, considering all receiver positions within the church, increases on average, 0.02 in the absolute RASTI values (or 7 per cent the relative *RASTI* values) with the PA system off) and about 0.05 (or 10 per cent) in the *RASTI* values with the PA system on.

Excluding the closest position to the sound source (Position *A*), the full occupancy of the church increases 0.03 (or 6%) the *RASTI* values with the PA system on. With the PA system off the significance of the church occupancy is not homogeneous. The *RASTI* value decreases in the closest position to the sound source and increases of about 22% in the furthest position.

The *RASTI_Gain* increases with the distance to the altar when no PA system is used but the opposite happens when the PA system is *ON*. This can be explained by two reasons. One is that the sound absorption given by the presence of the congregation in the church plays a more important role in the sound field created from the altar sound source (because it acts essentially in the reverberant field of the room) than when using the PA system. In this situation the congregation is more condensed in the direct field of the PA's sources and less in the reverberant field of each sound source.

Other reason is that the *RASTI* values decrease steeper with distance in the empty church than in the occupied when not using the PA system (see Fig. 3). This difference in slopes is important because with the PA system *ON* a similar slope exists for both situations (occupied and empty).

With this study a *transfer function* (from an unoccupied to an occupied church) was determined that can be used (even if with caution) to all the data collected in this research program. More data must be collected to validate the transfer function. However, this task is not easy due to the need of interrupting the religious services during the *RASTI* measurements.

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