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THE EFFECT OF PULPITS IN THE RASTI VALUES WITHIN CHURCHES

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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 (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 were taken at multiple locations in each church (RT, EDT, C_{80}, D_{50}, TS, L, BR_RT, BR_L and RASTI). [1, 2, 3, 4, 5]
- *Subjective studies* - This has included both evaluating live musical performances and speech intelligibility testing by the use of a sample of listeners and using several locations in each church. [2, 5, 6, 7]

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 the RASTI values differences among churches, using the altar area or the elevated pulpit as the sound source emission area, could be measured.

The study consisted of two parts both regarding RASTI analyses in non occupied churches. The first part was to gather objective evaluations of the acoustical qualities of the churches from the use of the RASTI, using only its own sound source at the altar area (parameter named RASTI_altar). The second part was to use the same type of evaluations on the same sample of churches but with the use of the elevated pulpits for the sound source location (parameter named RASTI_pulpit). No sound reinforcement systems were used in these tests.

The limitations using this type of methodology for evaluations were fully realized. The acoustical response of the church changes when it is fully occupied. Nevertheless this methodology gives a normalized sound environment that could be easily compared among churches.

For the RASTI measurement in each church the transmitter location was in front of the main altar or at a pulpit (that occupied a central lateral position in the churches' nave and at an average height of 2.3 m) at about 1.65 m above the floor to represent a standardized speech situation during services. The level of the source was +10 dB compared with the RASTI standard level due to the large dimensions of some of the churches. Four positions in each church were used for the receiver location (*A*, *B*, *C* and *D* as seen in Figure 1). In each receiver position three RASTI measurements were taken and then averaged to give the RASTI value at that location. All the statistical analyses were done using the *SYSTAT®* software.

Sample of churches used. The investigation 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 in the world.

This study reports on acoustical field measurements done in 19 Roman Catholic churches that are a sample of nine centuries of church building in Portugal (Table 1). The oldest church tested was no. 13 (built in the 12th century) and the most recent was church no. 4 (completed in the 1950s).

The churches were selected to represent the main architectural styles and to represent the evolution of church construction in Portugal. For more uniformity of the sample, only churches with a room volume of less than 17500 m^3 were selected for the study. Their main architectural features are displayed in Table 2.

The pulpit (an elevated and enclosed platform from which the sermons were delivered during services) is a typical feature in Western church architecture since the 12th century (similar to the minbar in the Islam). The pulpit had a vital importance in the 16th-17th centuries. Therefore the evaluations were held in churches grouped by large periods of history and architecture representative of the use of pulpits in the history of Catholic Church: 1 *Romanesque* church (12th century), 3 *Gothic* churches (13th-15th centuries), 8 *Baroque* churches, 6 *Renaissance*/*Neoclassic* churches and 1 *Contemporary* church (20th century).

Table 1 - List of the churches tested.

No.	Name (town)	Vol. (m^3)	No.	Name (town)	Vol. (m^3)	No.	Name (town)	Vol. (m^3)
1	Lapa (Porto)	11423	8	Nevogilde (Porto)	1137	14	Pombeiro (Felgueiras)	11380
2	Clérigos (Porto)	5130	9	Sta Clara (Porto)	2491	15	Bustelo (Penafiel)	6476
3	S. Ildefonso (Porto)	3813	10	S. Pilar (Gaia)	11566	16	S. J. Baptista (Porto)	6048
4	S. Sacramento (Porto)	6816	11	Most. Grijó (Gaia)	7212	17	Sta Maria (Azurara)	7212
5	S. Francisco (Porto)	12045	12	Tibães (Braga)	8408	18	Matriz (V. Conde)	8408
6	Grilos (Porto)	14497	13	Sé (Braga)	5394	19	Sta Clara (V. Conde)	5394
7	S. B. Vitória (Porto)	17460						

Table 2 - Simple architectural statistics for the churches tested.

Architectural Feature	Minimum	Median	Mean	Maximum
Volume (m^3)	1137	8408	7630	17460
Area (m^2)	176	595	626	1300
Maximum Height (m)	8.6	16.7	17.2	35.1
Maximum Length (m)	26.0	44.0	42.6	63.0
Width Nave (m)	7.4	10.7	13.0	22.8
Pulpit Height (m)	1.05	2.2	2.28	3.55

The parameter RASTI. The RASTI method involved measurement (with a Brüel & Kjaer type 3361 set) of the reduction of a transmitted test signal that has certain characteristics (such as intensity, modulations or directional proprieties) 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, 9] (see Table 3).

The advantage of RASTI regarding other methods is that it can be quickly evaluated without speakers or listeners. A transmitter generates pink noise at levels of 59 and 50 dB, or +10 dB (situation used in this survey), for the 500 Hz and 2 kHz 1/1 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.

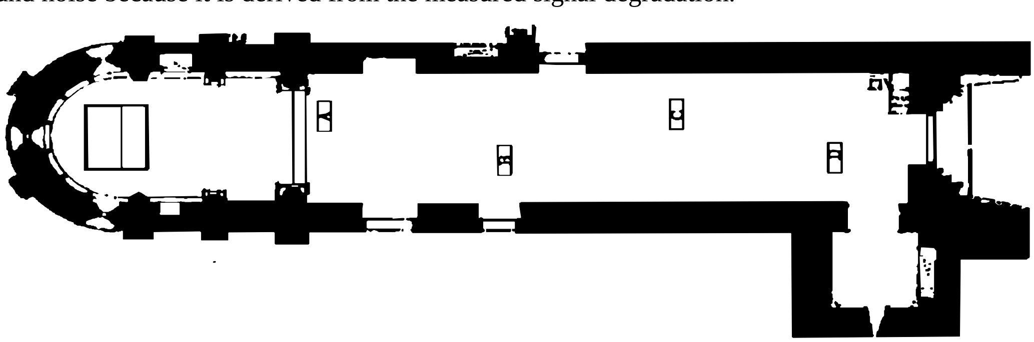

Fig. 1 - The 4 standard receiver positions from left (altar) to right: A, B, C and D.

Table 3 - Definition of the RASTI transfer function. [9]

RASTI	0 - 0.30	0.30 - 0.45	0.45 - 0.60	0.60 - 0.75	0.75 - 1
Subjective Intelligibility Scale	Bad	Poor	Fair	Good	Excellent

RESULTS

Overall results. Table 4 presents a simple general statistical analysis concerning all data collected. Figures 3 and 4 present general analyses of the RASTI data collected. They show, for each church, a boxplot. Each bar represents the within church variation where the center horizontal line marks the median of the sample. The length of each box shows the range within which the central 50% of the values fall, with the box edges (called *hinges*) at the 1st and 3rd quartiles. The *whiskers* show the range of observed values that fall within 1.5*Interquartile Range (the difference between the values of the 2 hinges). Values outside the *whiskers* (the outliers) are plotted with asterisks.

The mean church values range from 0.26 to 0.56. About 50 per cent of the churches tested have RASTI values below 0.45 giving a poor rating in the quality of speech intelligibility. Only 3 churches (16 per cent) achieved the minimum performance of 0.50 required in many spaces, for instance when using voice systems [10]. The largest mean RASTI value (0.56) was found in church no. 9 that has a very small reverberation time of 1.2 s (at 500 Hz) due to extensive woodcarving.

Figures 5 and 6 display the RASTI behavior controlling for the receiver location (*A*, *B*, *C* and *D*). These Figures 3 to 6 show that the emission from the Pulpit contributes for a sound field homogenization within the churches. However, it slightly decreases the number of positions where values above 0.50 were measured.

Figures 7 and 8 plot the variation of the RASTI values with the distance to the sound source. Figure 8 shows negative and positive distances (*x*-axis) that indicate, respectively, receiver positions closer to the altar or closer to the opposite end of the nave. There is a steep decrease in the positions closer to the sound source (direct field) and a reduced slope at larger distances where receiver positions are located in the reverberant field. In Figure 7 the best-fit equation is:

$$\text{RASTI\_Altar} = 0.90 - 0.40 \lg (\text{Distance\_to\_altar}) \qquad \text{, with a } R^2 = 0.66.$$

Table 4 - Simple general statistics regarding all RASTI data collected (76 cases).

Parameter	Minimum	Mean	Median	Maximum	Range	Standard deviation
RASTI altar	0.20	0.43	0.41	0.75	0.55	0.13
RASTI pulpit	0.23	0.44	0.45	0.67	0.44	0.11

Comparison between RASTI from the Pulpit and the Altar. The Figure 9 presents the RASTI values (all 4 receiver positions) measured for both situations: Pulpit and Altar with a best-fit curve:

$$\text{RASTI\_Pulpit} = -0.124 + 2.24\,(\text{RASTI\_Altar}) - 2.00\,(\text{RASTI\_Altar})^2 \qquad \text{, with a } R^2 = 0.34.$$

To measure the effect of the Pulpit emission a new parameter was defined, the RASTI_Gain, which represents the difference between the RASTI measured from the Pulpit and Altar: RASTI_Gain = RASTI_Pulpit - RASTI_Altar. If RASTI_Gain is positive it represents that the emission from the Pulpit increases the RASTI values.

Figure 10 presents the RASTI_Gain data controlling for each receiver position. It shows that for Position A (the closest to the altar) the use of the Pulpit generally decreases the RASTI values. Almost the opposite happens with receiver positions *B* and *C* where the Pulpit usually increases the RASTI values (up to 0.25). No significant trend was found for positions *D*.

The Figure 11 displays the RASTI_Gain with the Distance to the sound source (Altar). For distances up to about 10 m it is shown that the RASTI_Pulpit is usually smaller than the RASTI_Altar. Its best-fit equation is:

$$\text{RASTI\_Gain} = -0.257 + 0.029 * (\text{Distance\_to\_altar}) - 0.0006 * (\text{Distance\_to\_altar})^2 \qquad \text{, with a } R^2 = 0.34.$$

To better understand the effect of the Pulpit on the RASTI values within the churches an Improvement Factor ($IF_{p/a}$) was defined as follows:

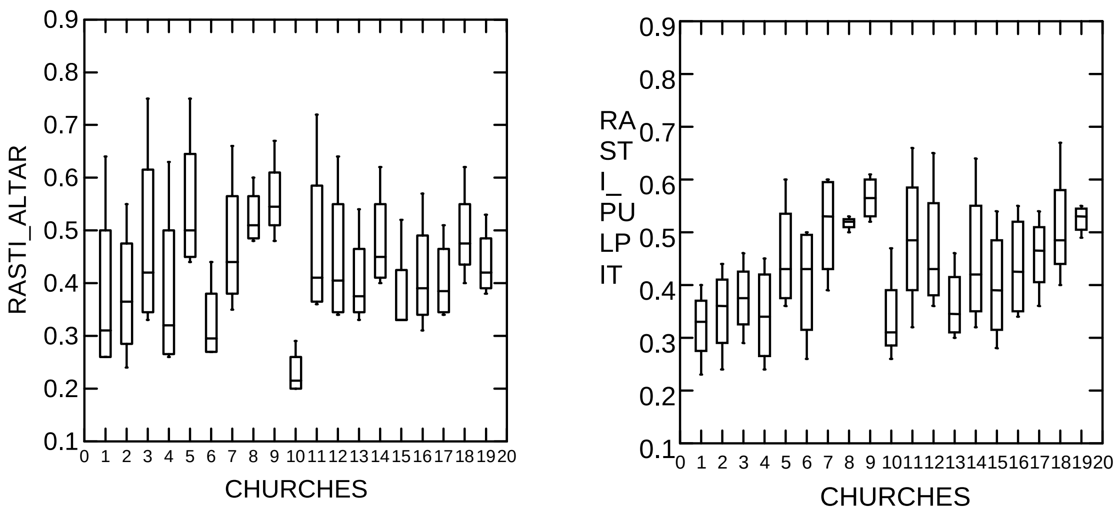

Fig. 3 and 4 - Within church variation of the RASTI values (Altar and Pulpit) (the x-axis shows the 19 churches).

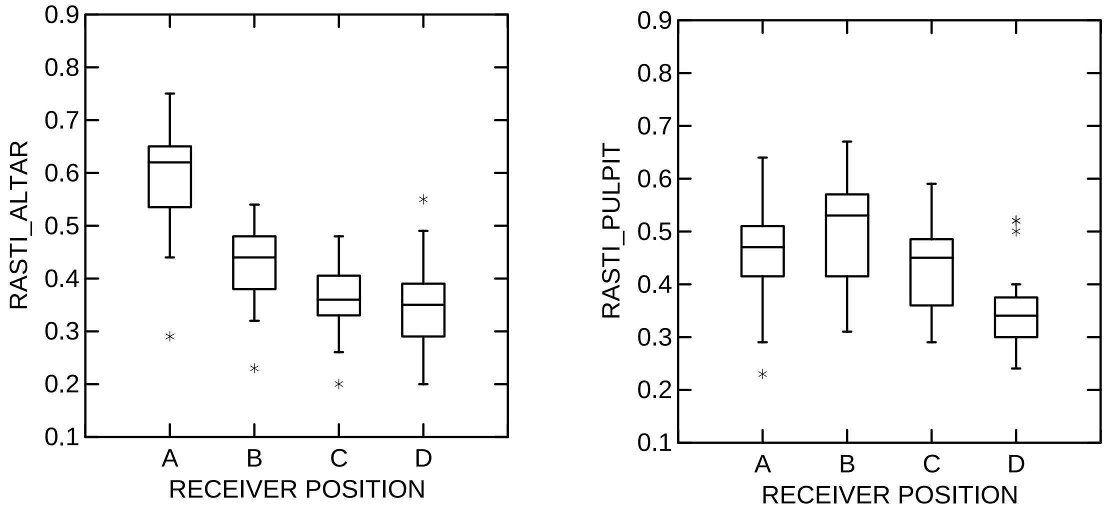

Fig. 5 and 6 - RASTI values (Altar and Pulpit) controlling for the receiver position (A: the closest to the altar).

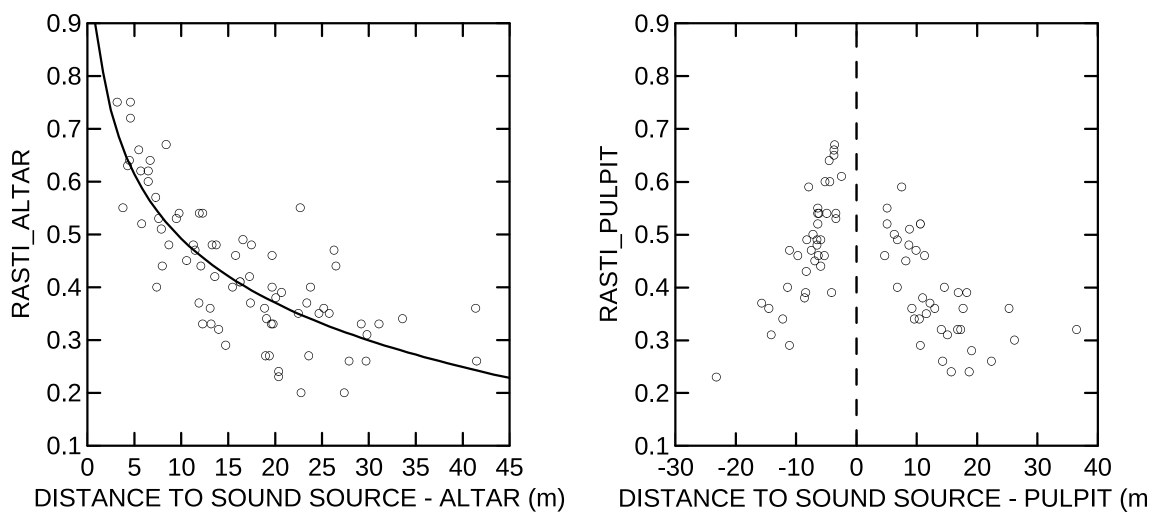

Fig. 7 and 8 - RASTI values (Altar and Pulpit) with the distance to the sound source (Altar or Pulpit).

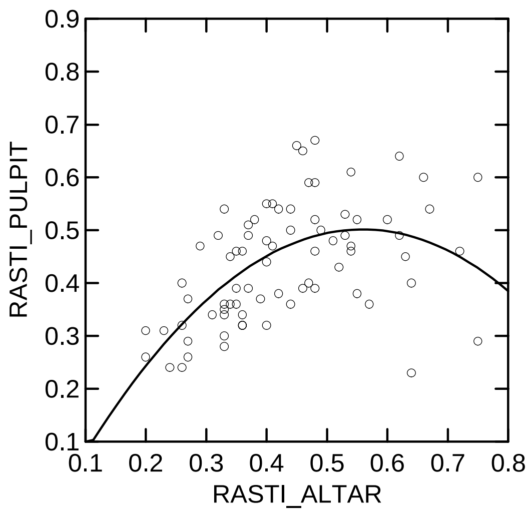

Fig. 9 - Comparison among RASTI values (from Altar and Pulpit) with a best-fit smooth.

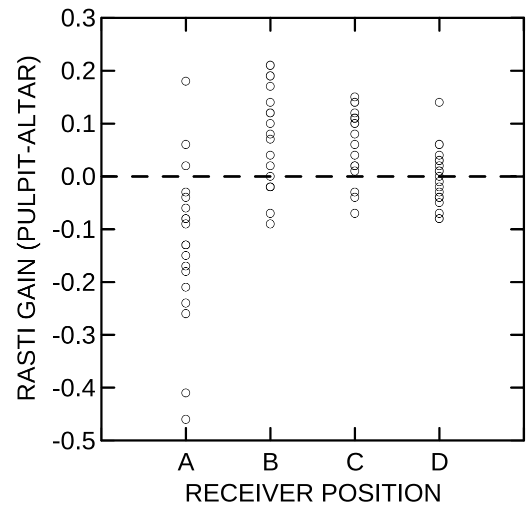

Fig. 10 - Gain in the RASTI values controlling for the Receiver positions (A: the closest to the altar).

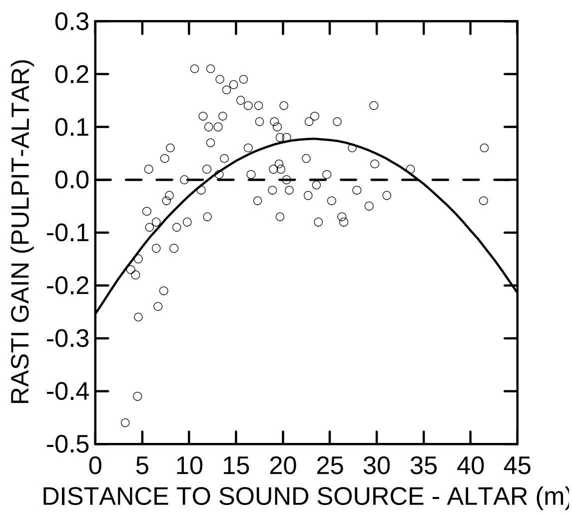

Fig. 11 - Gain in the RASTI values with the Distance to Sound Source (Altar).

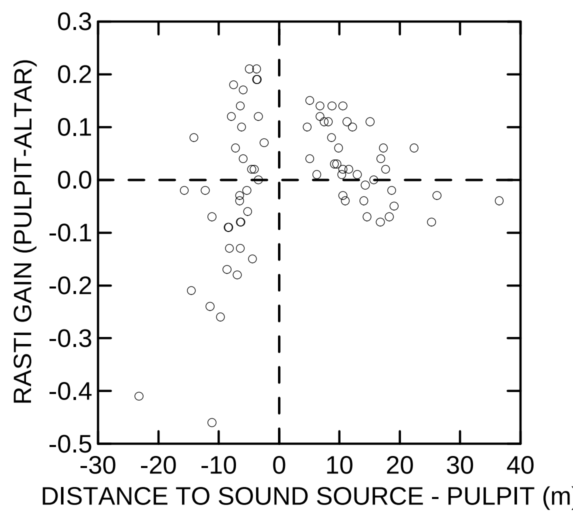

Fig. 12 -. Gain in the RASTI values with the Distance to the Sound Source (Pulpit).

$$IF_{p/a} = \frac{(RASTI\_Pulpit)_{church.average}}{(RASTI\_Altar)_{church.average}}$$

Table 5 shows the IF's calculated for all churches. The use of the Pulpit, considering all receiver positions within the churches increases, on average, 2 per cent the mean RASTI. However, only 21 per cent of the churches tested show a noticeable average improvement of more than 10 per cent on their RASTI values by the use of the Pulpit and 42 per cent even decrease their mean RASTI values. In fact, only in 5 churches (26 per cent) the mean RASTI values achieved the minimum performance of 0.50 required in many spaces. The highest IF values found are for churches no. 6 and 10 which are very large and reverberant spaces where the pulpits occupy a more central location. Table 5 also shows the IFs but calculated without the values measured on receiver positions *A* (Altar direct field). In this situation the mean RASTI values increase an average of 14 per cent when using the Pulpit.

Table 5 - Improvement Factors (IF) calculated for all churches.

Church No.	RASTI_Altar (church avg.)	RASTI_Pulpit (church avg.)	*IF p/a*	RASTI_Pulpit - RASTI_Altar	*IF ' p/a* (without position *A*)
1	0,38	0,32	0,85	-0,06	1,20
2	0,38	0,35	0,92	-0,03	1,05
3	0,48	0,38	0,78	-0,10	1,03
4	0,38	0,34	0,90	-0,04	1,02
5	0,55	0,46	0,83	-0,09	0,85
6	0,32	0,40	1,25	0,08	1,30
7	0,47	0,51	1,08	0,04	1,18
8	0,52	0,52	0,99	-0,01	1,03
9	0,56	0,56	1,01	0,00	1,10
10	0,23	0,34	1,47	0,11	1,40
11	0,48	0,49	1,03	0,01	1,26
12	0,45	0,47	1,04	0,02	1,28
13	0,40	0,36	0,90	-0,04	0,92
14	0,48	0,45	0,94	-0,03	0,89
15	0,38	0,40	1,06	0,02	1,18
16	0,42	0,44	1,05	0,02	1,27
17	0,40	0,46	1,13	0,05	1,22
18	0,49	0,51	1,04	0,02	1,15
19	0,44	0,52	1,20	0,09	1,32
avg	*0,43*	*0,44*	***1,02***	***0,00***	***1,14***

CONCLUSIONS

This paper concentrates on the Rapid Speech Transmission Index (RASTI) values within churches. Two source locations (main altar and an elevated pulpit) were used in each empty churches, without the use of sound reinforcement systems. The mean RASTI values in each church varied from 0.23 to 0.56 (from the altar) and from 0.32 to 0.56 (from the pulpit). The variation in each individual RASTI value regarding the use of the pulpit over the altar as the source location, changed from -0.46 to +0.21 depending strongly on the receiver relative position to the sound source. The use of pulpits increases an average of 2 per cent on mean RASTI values in churches. Only for the receiver positions in the central area of the church (positions *B* and *C*) does the pulpit position increase the RASTI (an average of 20 per cent or about 0.07 on their absolute values). The churches' front row positions (named *A*) have their RASTI decreased (an average of 18 per cent or about 0.13 on their absolute values) when the sound source is on the pulpit. On the last row positions (named *D*) RASTI does not change significantly (on average) with the location of sound source. The pulpit, being located in a more central location in the church than the church, increases the RASTI values in about half of the nave area and induces a more homogeneous sound field.

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