inter•noise 94
YOKOHAMA-JAPAN, AUGUST 29-31

RELATIONS BETWEEN RASTI AND OTHER ACOUSTICAL MEASURES IN PORTUGUESE CHURCHES

António Pedro O. Carvalho

Acoustical Laboratory - Faculty of Engineering - University of Porto
P-4099 PORTO CODEX, PORTUGAL

INCE Subj. Classif.: 72.9

INTRODUCTION

Activities mainly related to speech are an important part of services in Catholic churches. Nevertheless, acoustical problems related to poor speech intelligibility are the general rule in this type of building. The use of the RASTI (Rapid Speech Transmission Index) as an index to predict the intelligibility of speech in churches does not have a large bibliographic data base. Only a few studies have been published. However, there is a larger availability regarding other objective acoustical measures. The study of the relationships between RASTI and other acoustical measures appears as an interesting necessity. Therefore, several monaural acoustical measures pertinent to churches were evaluated and their relationships with the RASTI calculated in a major survey of Portuguese churches built in the last 14 centuries.

PROCEDURE

Description of Churches This paper reports on acoustical field measurements in a major survey of 41 Roman Catholic churches in Portugal that were built from the sixth century until 1993. The churches were chosen to represent the evolution of the architectural styles in church construction in Portugal. The main architectural features of these churches are displayed in the following table:

ARCH. FEATURE	Min.	Max.	Mean	Median
VOLUME (m^3)	299	18674	5772	3918
AREA (m^2)	56	1031	450	427
MAX. HEIGHT (m)	7	39	15	13
MAX. LENGTH (m)	12	62	33	31

Measurement Method Eight acoustics parameters were calculated from impulse responses:
RT - Reverberation Time (calculated from -5 to -35 dB);
EDT - Early Decay Time (calculated from 0 to -10 dB);
C80 - Early/Late Sound Index or Clarity with a time window of 80 ms. $C80 = 10 \log E(0,80)/E(80,\infty)$;
D - Early/Total Energy Ratio, Early En. Fract. or Definition with a time window of 50 ms. $D=E(0,50)/E(0,\infty)$;
TS - Center Time (point in time where: energy received before it = energy received after it);
L - Loudness or Total Sound Level;
BR_RT-Bass Ratio based on Reverberation Time. $BR\_RT = [RT(125) + RT(250)] / [RT(500) + RT(1k)]$;
BR_L - Bass Ratio based on Loudness. $BR\_L = [L(125) + L(250) - L(500) - L(1k)] / 2$.

Speech intelligibility was estimated by the calculation of the RASTI which has been related to subjective intelligibility[12] (see Table 1). The RASTI method involved measurement (with B&K-3361) of the reduction of a transmitted test signal that has certain characteristics representative of the human voice. Table 2 presents a general statistical summary of all data. The method used for the calculation of the eight room acoustic parameters is based on the integrated impulse-response method. A limited-bandwidth noise-burst is generated and transmitted into the church by a loudspeaker via an amplifier. The room's response to the noise-burst is then sampled from the RMS detector output of the sound level meter. A loudspeaker (B&K-4224) emitting short noise pulse bursts in 3/2 octave frequency bands was used as sound source. The receiving section consisted of one 1/2" diameter microphone (B&K) and a sound level meter (B&K-2231) with a 1/1 octave filter set (B&K-1625). All of the procedures were controlled by a software (*Room Acoustics* B&K-BZ7109 and VP7155) from a notebook computer (*Compaq* LTE). In each church the loudspeaker was placed at two sound source locations: in front of the altar and in the center of the main floor (just at the altar for the RASTI). The sound source was positioned at 0.8 m above the floor and at a 45° angle with the horizontal plane (at 1.65 m for the RASTI and without using the churches' PA system). Each measurement was calculated by average from an ensemble of three or four consecutive responses in each position. Five (or eight for the RASTI) receiver positions were used on average in each church. The microphone was placed at 1.30 m above the floor at each location. In total, nearly 8000 values were determined (all combinations of the six octave-frequency bands, 125 to 4000 Hz, and source-receiver locations) - other 1200 data-points for the RASTI.

TABLE 1. Relation between RASTI and acoustical quality.

RASTI (%)	SUBJECTIVE ACOUST. QUALITY
0 - 30	BAD
30 - 45	POOR
45 - 60	FAIR
60 - 75	GOOD
75 - 100	EXCELLENT

TABLE 2. RASTI simple statistics.

STATISTICS	RASTI (%)
Minimum	21
Median	40
Mean	43
Maximum	79
St. deviation	12

RELATIONSHIPS BETWEEN RASTI AND OTHER ACOUSTICAL MEASURES

Procedure Statistical analysis was used to determine the relationships between those eight room acoustic measures and the RASTI. Data were used only from those positions in which all the acoustical measures were determined (nearly 150 points). Models were calculated using several types of smoothing to determine the best regression line for the correspondence between RASTI and each of the other acoustical measures The models tested were the linear ($y=a+b.x$), logarithmic ($y=a+b.log_e x$), power ($y=a.x^b$) and exponential ($y=a.e^{b.x}$). Two approaches were followed: i) Using ALL DATA (including points in the transmitter's direct field); ii) Using DATA WITHOUT THE DIRECT FIELD (values at a distance < 5 m or not in the main volume of the church).

Statistical Models For each of the eight acoustical measures and for each octave frequency band - 38 cases in total - linear and non linear models were tested. Table 3 summarizes the results found displaying the type of smoothing used, the R^2 for each model and the corresponding equations for the best model for each acoustical measure. Figures 1 to 6 show the plots for the best models.

General Linear Model A general linear model was calculated using the Forward Stepwise Modeling method (with an α-to-enter/remove=0.05), to predict RASTI (with R^2 = 0.835) in any position within a church (not in the sound source's direct field) using the other objective acoustical measures:

RASTI = - 6.139 EDT(4k) + 1.479 C80(2k) + 12.417 D(125) + 0.046 TS(4k) + 0.692 BR_L

TABLE 3. Statistical analyses for the relations between the 38 acoustic measures and RASTI.

Ac. Measure	Direct Field Data	Smooth type	R^2	Equation: RASTI = ...	Fig.
RT(125)	No	Power	0.629		
RT(250)	No	Power	0.679		
RT(500)	No	Power	0.731		
RT(1k)	No	Power	0.743		
RT(2k)	No	Power	0.756	57.149 (RT2k) ^ (-0.406)	1
RT(4k)	No	Power	0.753		
EDT(125)	No	Power	0.627		
EDT(250)	No	Power	0.690		
EDT(500)	No	Power	0.782	58.335 (EDT500) ^ (-0.386)	2
EDT(1k)	No	Power	0.775		
EDT(2k)	No	Power	0.779		
EDT(4k)	No	Power	0.771		
C80(125)	Yes	Linear	0.516		
C80(250)	Yes	Exponential	0.534		
C80(500)	Yes	Exponential	0.667		
C80(1k)	Yes	Exponential	0.655		
C80(2k)	Yes	Exponential	0.735	49.19 EXP [0.06659 C80(2k)]	3
C80(4k)	Yes	Linear	0.677		
D(125)	Yes	Linear	0.497		
D(250)	Yes	Linear	0.509		
D(500)	Yes	Linear	0.700		
D(1k)	Yes	Linear	0.680		
D(2k)	Yes	Linear	0.705	26.91 + 62.92 D(2k)	4
D(4k)	Yes	Linear	0.621		
TS(125)	No	Power	0.645		
TS(250)	No	Power	0.675		
TS(500)	No	Power	0.784		
TS(1k)	No	Power	0.803	378.136 TS(1k) ^ (- 0.419)	5
TS(2k)	No	Power	0.787		
TS(4k)	No	Power	0.736		
L(125)	Yes	Linear	0.141		
L(250)	Yes	Linear	0.120		
L(500)	Yes	Linear	0.122		
L(1k)	Yes	Linear	0.108		
L(2k)	Yes	Exponential	0.128		
L(4k)	Yes	Exponential	0.167	30.45 EXP [0.02594 L(4k)]	6
BR_RT	No	Linear	0.033	46.28 - 8.274 BR_RT	
BR_L	Yes	Linear	0.020	39.28 + 1.382 BR_L	

CONCLUSIONS

RASTI values within churches (in positions not in the direct field of the sound source) can be reasonably predicted by the use of the TS(1 kHz) in the same position, with a R^2 =0.80. Regardless of the receiver position, RASTI can be predicted, with R^2= 0.74 by the use of the C80(2 kHz). Concerning the two approaches for this study (data *with* or *without* the direct field positions) it was found that the exclusion of the direct field data only strongly affected the prediction models for the RT and EDT (achieving a 55% higher R^2). Five of the 38 acoustical measures tested can be used together in a General Linear Model to explain 84% of the variance of the RASTI. L does not appear as an important characteristic regarding the RASTI (R^2_{max} = 0. 167).

REFERENCES

1. Brüel & Kjær, "Instruction Manual: Speech Transmission Meter Type 3361", (Denmark, 1986).
2. T. Houtgast and H.J.M. Steeneken, "A Multi-Language Evaluation of the RASTI method for estimating Speech Intelligibility in Auditoria", Acustica, 54, 185-199 (1984).

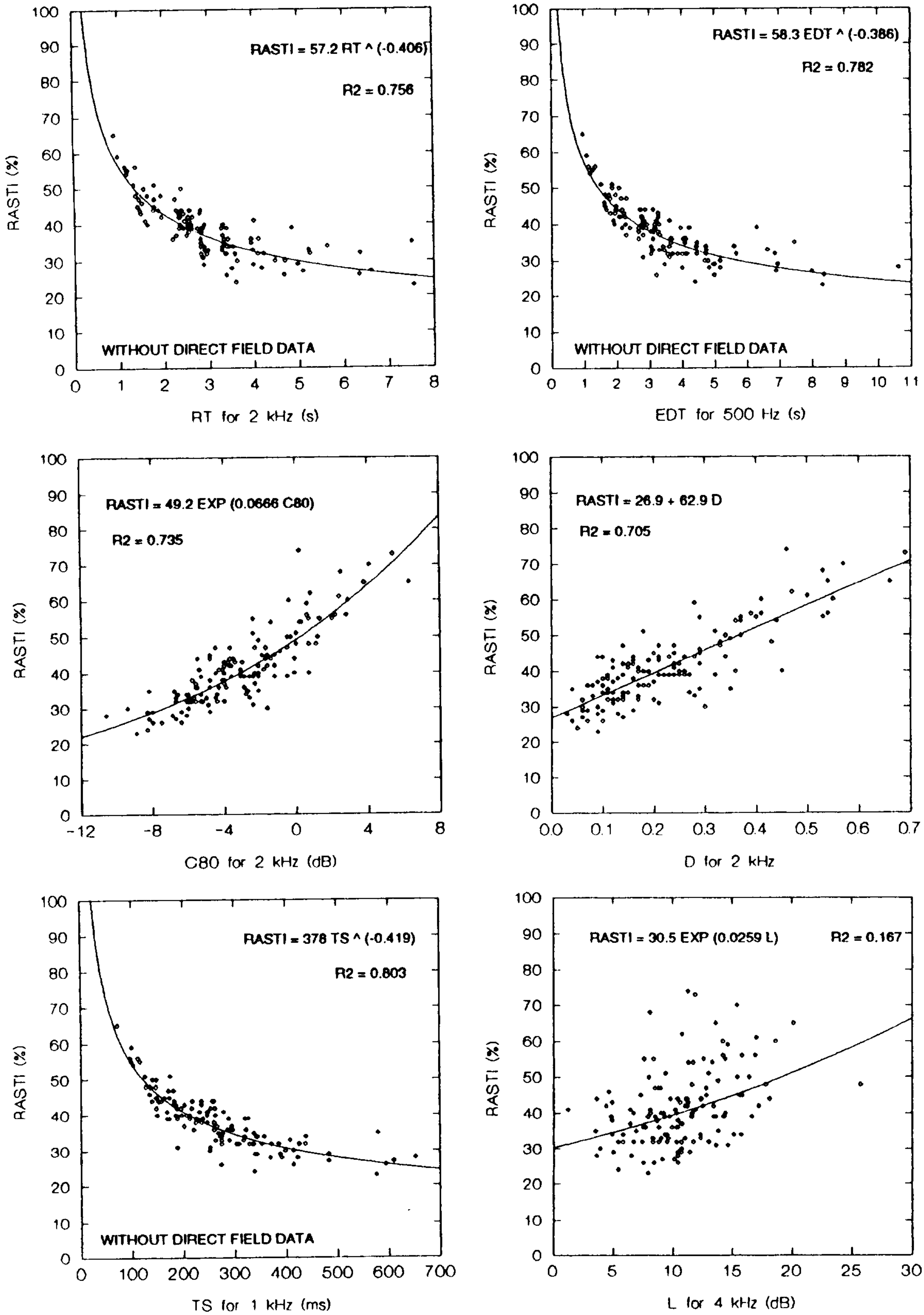

FIG. 1 to 6 - Plots of RASTI vs six acoustical measures for all churches with regression models.