FROM WORD SCORES TO RASTI AND BACK (An Experimental Study of the Relationship between RASTI and Word Scores)

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1. BACKGROUND INFORMATION

From our work on the Jubilee Line Extension and other intelligibility measurement projects we have amassed a well documented data mountain of Word Score and RASTI measurements. The Jubilee line project measurements involved a high degree of rigor and traceability. In this way for each position both Word Scores and RASTI are known together with the relevant acoustical parameters.

It became apparent at a fairly early stage in the project that there may not be a unique relationship between Word Scores and RASTI as suggested by the Common Intelligibility Scale (ref. 1) see fig. 1.

In addition, as part of a Smart research project (ref. 2) we noticed that for two spaces which had similar reverberation times whilst the RASTI results were comparable, the Word Scores were quite different (ref. 3).

The two spaces in question were a small Church Hall and the Royal Festival Hall (RFH). The acoustical data is given in the table below:

Parameter	Space	
	Church Hall	Royal Festival Hall
Volume	717m^3	21950m^3
RT_c1kHz	1.5 sec.	1.5 sec.*
mfp	6.2m	18m
*Assisted Resonance System off		

It can be seen that the spaces have similar RT's but quite different geometry.

The results of the Word Scores and RASTI measurements at acoustically comparable positions are given in figs. 2 and 3.

We also noticed that there was an inconsistency in regard of the way in which each of the descriptors (Word Score and RASTI) was affected by the deleterious effects of reverberation products and noise.

We therefore decided to construct an experiment to carry out a preliminary investigation into these apparent anomalies.

2. THE EXPERIMENT

In essence the experiment comprised measuring Word Scores and RASTI (STI) at identical positions and for identical conditions in a space.

The space we chose was the Great Hall at Pickets Lock Leisure Centre, Enfield. Our choice was determined by a number of factors including proximity to the office, previous knowledge of the space, the size and acoustics of the space and the relatively low noise floor in the space.

The tables below gives the approximate dimensions of the space together with the measured reverberation time.

Dimension	Quality	Unit
Length	35	m
Width	12	m
Height	8	m
Total Volume	3360	m^3
Floor Area	420	m^2
Walls Area	752	m^2
Roof Area	420	m^2
Total Area	1592	m^2
Mean Free Path 4V/S	8.4	m

	Octave Band (Hz)					
	125	250	500	1k	2k	4k
RT (secs.)	2.9	3.1	2.9	3.1	2.8	2.0

We selected 5 No. positions at increasing distance from the omni-directional source (2m, 4m, 8m, 16m and 32m). At each position the following measurements were made:

1. Octave band noise bursts (analysed to RT)
2. Band-limited pink noise (analysed to level)
3. 1kHz tone (analysed to distortion)
4. STI/RASTI
5. PB Word Scores x 2
6. CVC Word Scores x2.

All of the input data was contained on compact disk with known differences in level.

During the entire measurement exercise, which took one long day, controls were maintained to ensure that the replay levels were consistent and that an adequate signal-to-noise level was maintained at all times.

All measurements were binaurally recorded by Bruel & Kjaer Head and Torso simulator and professional DAT recorder. The recordings were calibrated.

The idea of the experiment can be seen from a consideration of fig. 4. Each of the Word Score and RASTI measurements made at positions 1, 2, 3, 4 and 5 were made under noiseless conditions.

If the noise is added to the Word Scores such that the noiseless results at Position 1 are degraded to the noiseless results and Positions 2, 3, 4 and 5, then if there is a unique relationship between Word Scores and RASTI, then the application of the same noise to the RASTI results of Position 1 will result in a correspondence at positions 2, 3, 4 and 5. If this correspondence is not observed then this brings into doubt the apparent unique relationship as suggested by CIS.

3. PROCEDURE

For each Word Score (PB and CVC) and RASTI, results were plotted against signal-to-noise ratio for each position. From these results, best-fit third order polynomial equations were deduced.

The equations took the form:

$$\%\text{Words} = A_n x^3 + B_n x^2 + C_n x + D_n$$
(or RASTI)

The polynomials were checked for correspondence with the actual measured results. The results are presented in figs. 5, 6 and 7 together with the raw data.

Next the direct-to-reverberant ratio was deduced for each measurement position as follows: Pos. 1 (+7dB), Pos. 2 (+1dB), Post 3 (-5dB), Pos. 4 (-11dB), Pos. 5 (-17dB).

From the best-fit S/N polynomial a new series of curves were deduced for each descriptor at 5dB S/N intervals plotted against direct-to-reverberant ratio. A sample of the curves is given in fig. 8, for clarity some lines have been omitted. The best-fit polynomial took the form of quadratic.

In this way a new set of equations were deduced, one for each descriptor which took the form of:

$$\%\text{Words} = aw^2 + bw + c$$
(or RASTI)

where: w = direct-to-reverberant ratio and the coefficients a, b and c are a function of S/N.

By plotting the coefficients a, b and c for each S/N against S/N and obtaining a best-fit polynomial, we were able to deduce an equation for each descriptor which took into account position and S/N.

The deduced salient equations were as follows:

$$\%PB = (0.0002x^2 - 0.007x + 0.03)\, w^2 + (0.002x^2 - 0.13x + 2.7)\, w + (-0.1x^2 + 4.5x + 49.6)$$

$$\%CVC = (0.003x + 0.06)\, w^2 + (0.003x^2 - 0.13x + 2.2)\, w + (-0.12x^2 + 5.0\,x + 38.7)$$

$$100\ RASTI = (-0.0001x^2 + 0.005x + 0.01)\, w^2 + (-0.002x^2 + 0.11x + 1.2)\, w + (-0.05x^2 + 1.9x + 37.6)$$

where: x = S/N in dB
w = D/R in dB.

In this way it is possible to select any position in the space, apply noise and deduce the value of any of the three descriptors.

The results calculated were compared with actual results and good correspondence was obtained (see figs. 9, 10 and 11).

Two important points to make are that the equations only hold true for the space under test and that the data should not be extrapolated beyond the experimental limits.

4. PRESENTATION OF RESULTS

The salient equations may then be used in several ways. firstly it is possible to choose a position close to the source and set the RASTI performance to a specific value by adjusting the S/N.

The same position and noise data may be input to the Word Score salient equations to deduce both PB and CVC scores.

Next a new position further from the source may be selected but compensating the S/N (improving) to maintain a constant RASTI. Against the new position and noise data may be input to the Word Score salient equation and a new value of Word Score results calculated.

If there is a unique relationship between RASTI and Word Scores, then for constant RASTI we would expect constant Word Scores.

The results for PB words and CVC words for various constant RASTI are presented in figs. 12 and 13.

It can be seen that for constant RASTI results constant Word Scores are not obtained thereby indicating that there may not be a unique relationship between these two parameters.

5. CONCLUSIONS

We believe that the foregoing suggests that there is sufficient doubt that there may not be a unique relationship between RASTI and Word Scores. We further believe that these differences result from the deleterious effects of reverberation products and noise affecting the subjective and objective measures differently.

Finally, we believe that caution should be exercised in using RASTI especially when the results are not in accord with subjective impression.

References:

1. Common Intelligibility Scale/P.W. Barnett, R.D. Knight/Proceedings IOA Vol. 17:Part 7:1995
2. Smart Research Project/AMS Acoustics/ Document No. IR/3/FS: 1999
3. Overview of Speech Intelligibility/P.W. Barnett/Proceedings IOA Vol. 21: Part 5: 1999

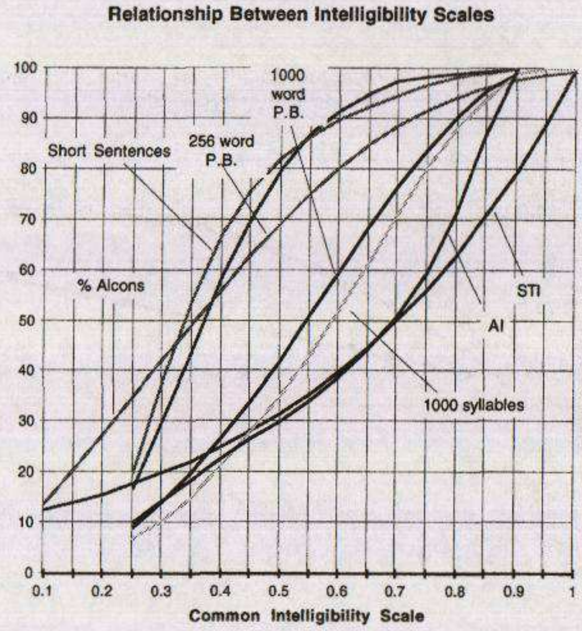
Relationship Between Intelligibility Scales
1000 word P.B.
256 word P.B.
Short Sentences
% Alcons
STI
AI
1000 syllables
Common Intelligibility Scale

Fig. 1

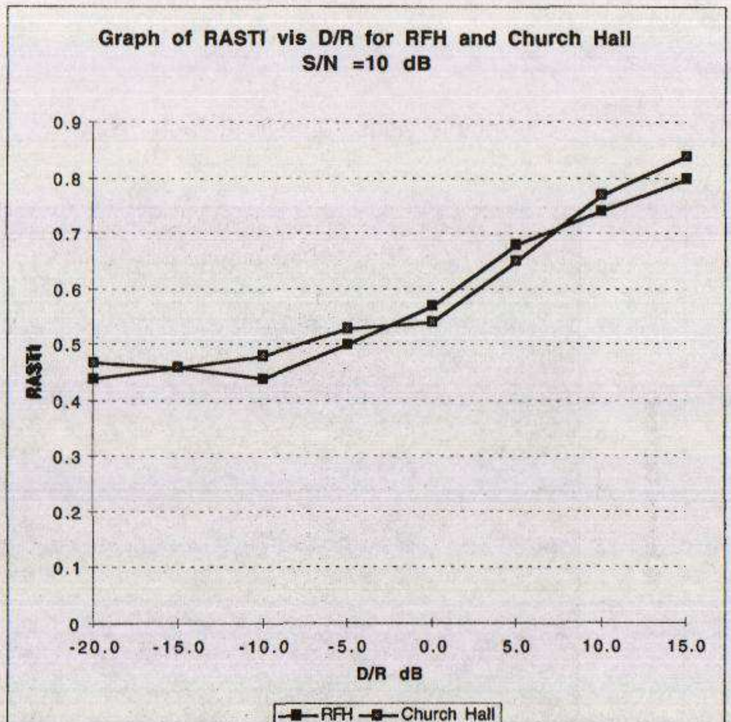
Graph of RASTI vis D/R for RFH and Church Hall
S/N =10 dB
RASTI
D/R dB
RFH
Church Hall

Fig. 2

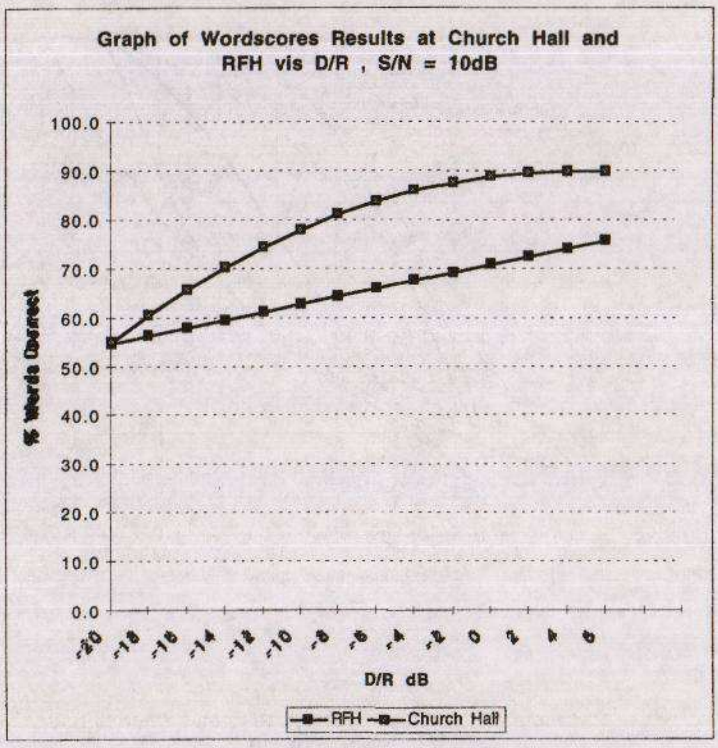

Fig. 3

Sample Measurements at each Position

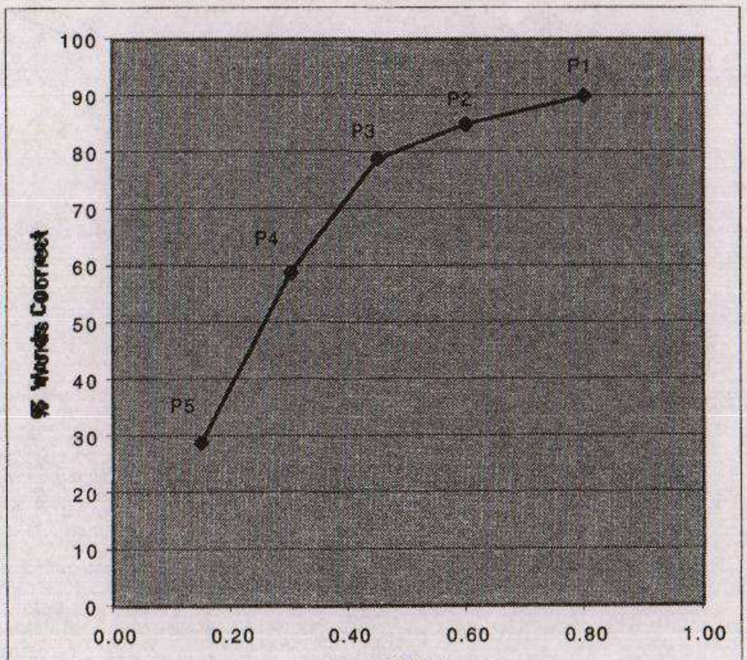

Fig. 4

PB Best-fit Polynomial with actual data

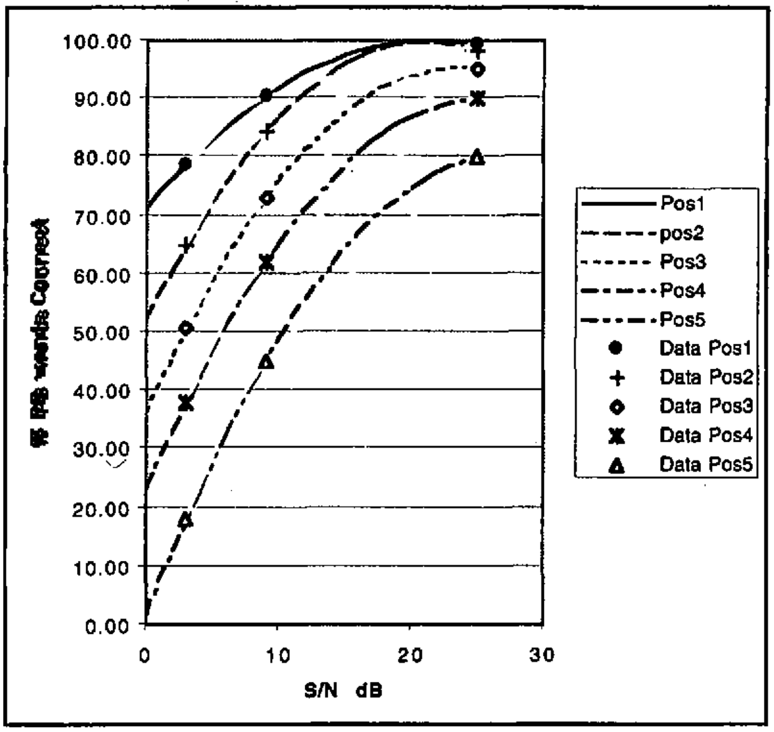

Fig.5

CVC Best-fit Polynomial with actual data

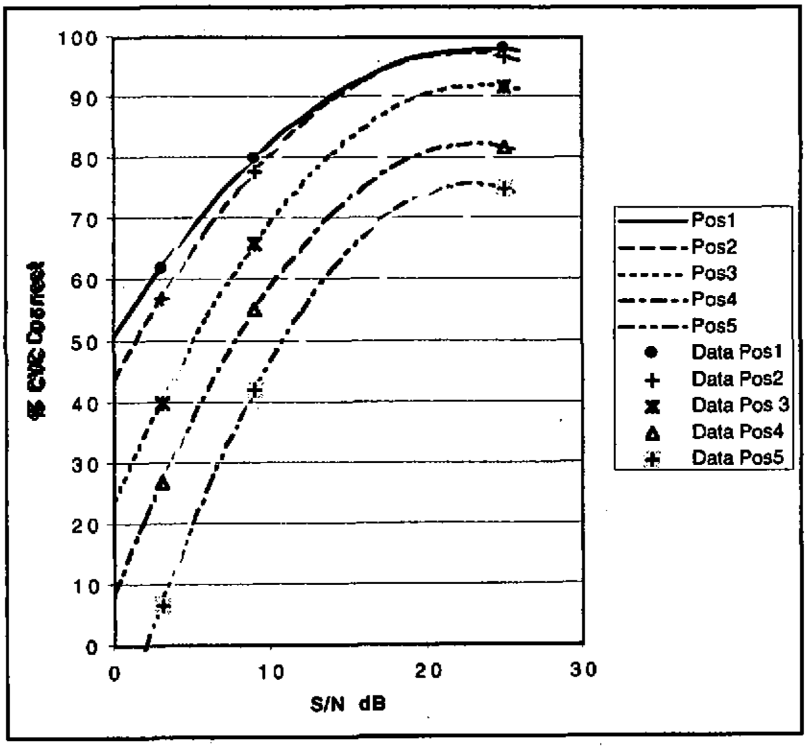

Fig. 6

RASTI Best-fit Polynomial with actual data

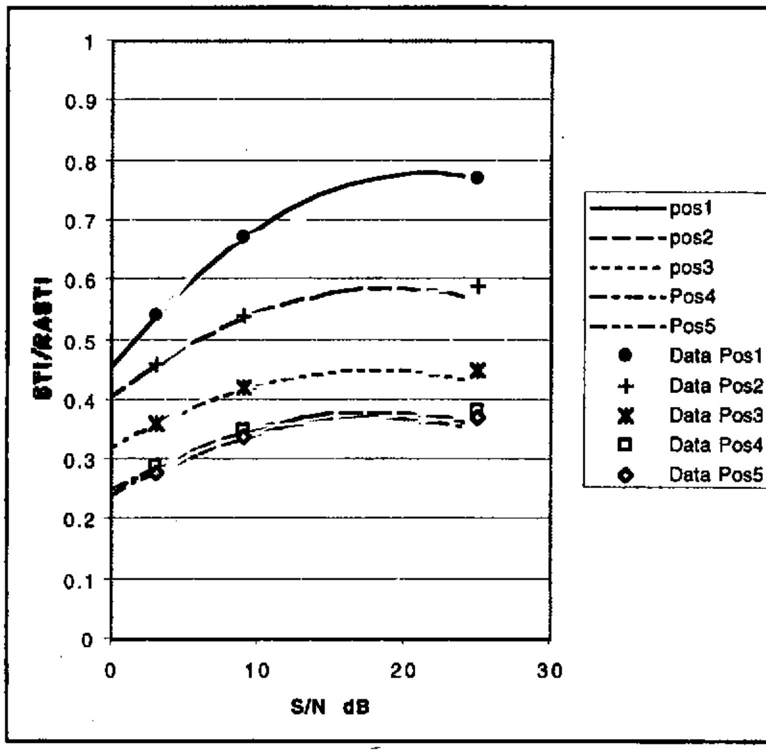

Fig. 7

PB Best-fit Positional Polynomials

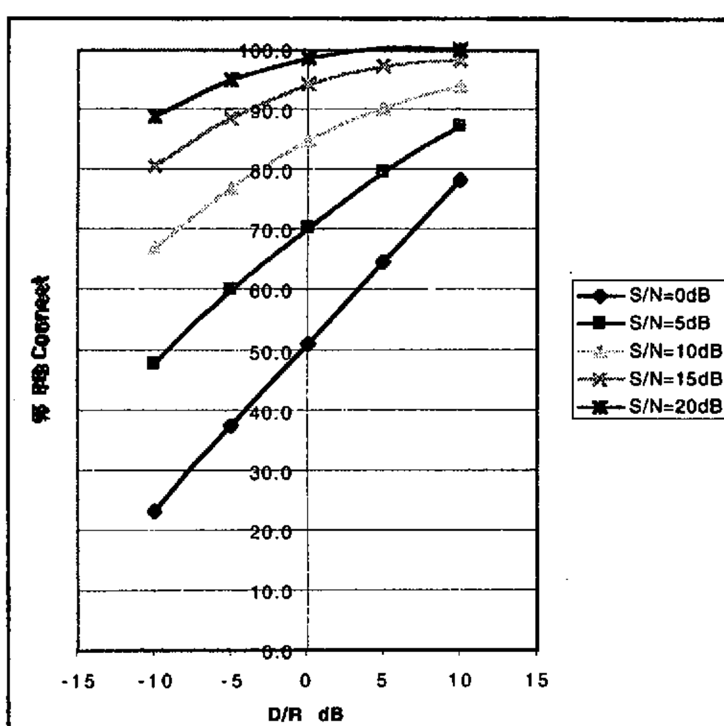

Fig. 8

CVC Best-fit Positional Polynomials

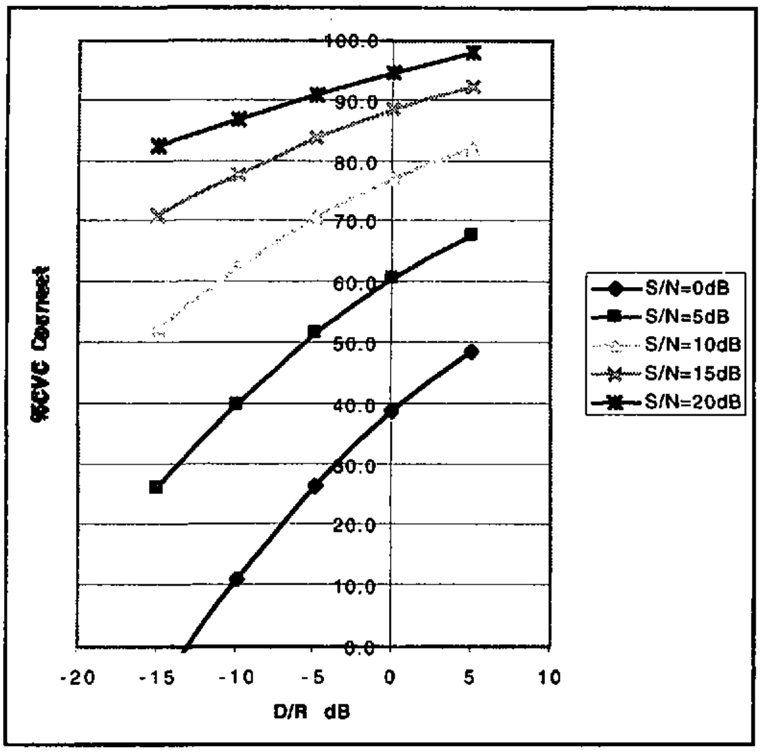

Fig. 9

RASTI Best-fit Positional Polynomials

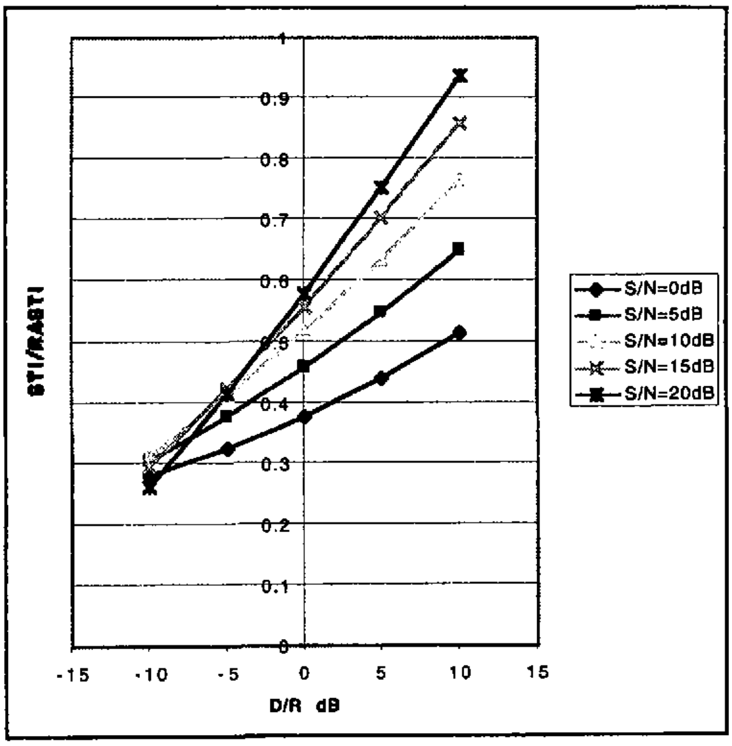

Fig. 10

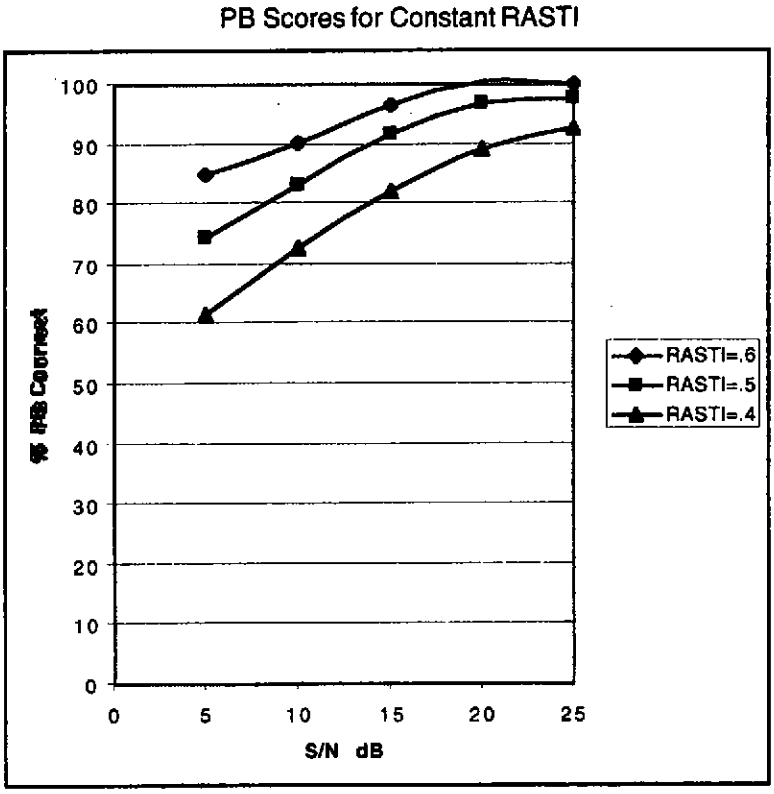
PB Scores for Constant RASTI
% PB Correct
100
90
80
70
60
50
40
30
20
10
0
0
5
10
15
20
25
S/N dB
RASTI=.6
RASTI=.5
RASTI=.4

Fig. 11

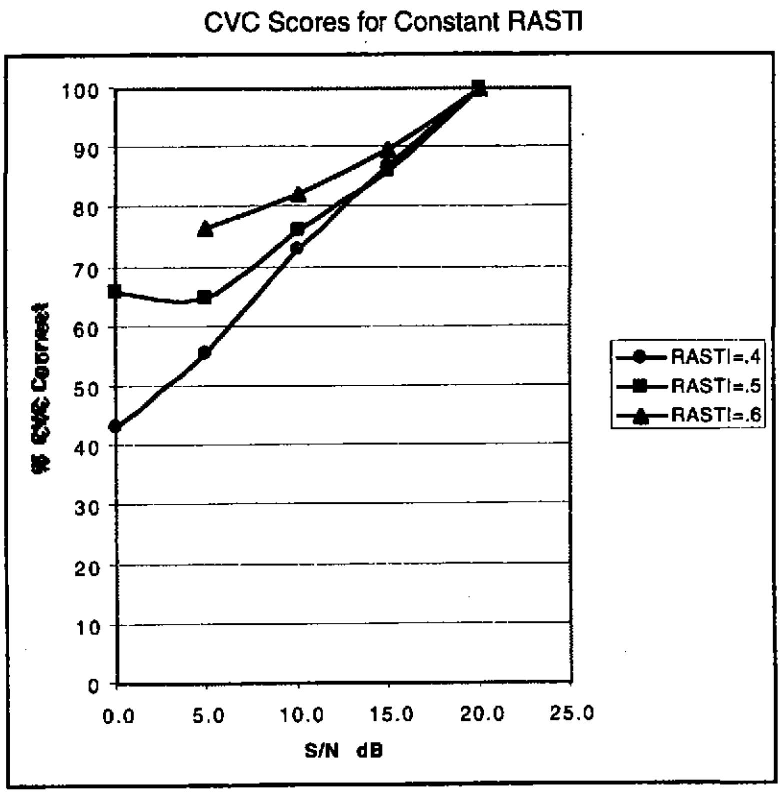
CVC Scores for Constant RASTI
% CVC Correct
100
90
80
70
60
50
40
30
20
10
0
0.0
5.0
10.0
15.0
20.0
25.0
S/N dB
RASTI=.4
RASTI=.5
RASTI=.6

Fig. 12