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RELATIONSHIP BETWEEN STI AND PB WORD SCORE INTELLIGIBILITY MEASUREMENTS IN LONDON UNDERGROUND STATIONS

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INTRODUCTION

Our investigations at London Underground Stations included Word Score, STI and RASTI measurements. This paper will discuss the relationship between the different forms of measurement and the reliability of that relationship under differing conditions.

Measurements were made at the Aldywch, Oxford Circus and Covent Garden Underground stations, both ON and OFF-axis from the loudspeakers.

The Aldwych platform was without tiles at one end, which rendered the acoustics at that end significantly deader than the other. Measurements were made at both ends.

STI and RASTI Measurements

Fig. 1 shows a typical STI table generated using the MLS method.

Each 'm' value in the table is generated [1] as follows:

$$m(F) = \frac{1}{\sqrt{1+\left(2\pi F \frac{T}{13.8}\right)^2}} \cdot \frac{1}{1+10^{(-S/N/10)}}$$

where: m(F) = the reduction in modulation at the modulation frequency f
F = the modulation frequency
T = the early part of the reverberation decay
S/N = the signal-to-noise ratio in dB.

Each 'm' value is then converted to an apparent S/N ratio:

$$S/N = 10Lg\ (m/(1-m))\ dB$$

These figures are then truncated to be within the range +/-15dB.

RELATIONSHIP BETWEEN STI AND PB WORD SCORES

For STI the 'Octave TI' is calculated in octave bands from 125Hz to 8kHz as follows:

$$TI = \frac{S/N_{ave} + 15}{30}$$

The weightings given to each band are as follows:

Frequency (Hz)	125	250	500	1k	2k	4k	8k
Weightings	0.13	0.14	0.11	0.12	0.19	0.17	0.14

Each TI figure is then multiplied by its weighting and a sum of these renders the final STI.

For RASTI, 9 modulation factors are taken, 4 in the 500Hz band and 5 in the 2kHz band. The apparent S/N ratios are averaged without weighting and the final RASTI value is as follows:

$$STI\ (RASTI) = \frac{S/N_{ave} + 15}{30}$$

STI MEASUREMENTS AND PB WORD SCORES

STI Measurement Technique

Measurements were made using the MLSSA analysis package. The MLSSA signal was applied to the Public Address System microphone via a B & K Mouth Simulator Type 4227. The signal was then received at the station platform with a B & K sound Level Meter Type 2230 and recorded on RDAT medium, to be returned to MLSSA at a later date.

This technique avoided the need for excessively long cable runs and allowed the controlled mixing of shaped pink noise. Fig. 2 shows the basic equipment arrangements.

Each STI/RASTI recording was adulterated with shaped pink noise with the following signal-to-noise ratios +18dB, +12dB, +6dB and 0dB.

RELATIONSHIP BETWEEN STI AND PB WORD SCORES

PB Word Scores

Word Scores were conducted for both ON and OFF-axis at each station position corresponding to the STI measurement positions. In common with the STI/RASTI measurements, each Word Score was adulterated with noise and was the subject of a jury audit. For further information see Ref. [2].

STI has been shown to correlate with speech intelligibility through PB Word Scores [1].

Relationship between STI and PB Word Scores at the Aldwych

Fig. 3 shows PB Word Scores plotted against STI for results obtained at the Aldwych. The results include noise influenced measurements.

Although there is a certain amount of scatter, the general agreement is good.

Fig. 4, shows the corresponding RASTI measurements plotted against the same best-fit line which, it can be seen, exhibit considerable spread.

Where results have fallen to the right of the best-fit line, the STI/RASTI indicates an **optimistic** result compared to the PB Word Score. Values to the left of the best-fit line indicate **pessimistic** STI/RASTI results. Fig. 5 illustrates this.

The major deviations which are seen in the Aldwych RASTI results tended to be optimistic.

Relationship between STI and PB Word Scores at Oxford Circus and Covent Garden

Figs. 6 and 7 show results of Word Scores and STI/RASTI measurements at Oxford Circus and Covent Garden plotted on the same best-fit line. These results are all in the absence of noise.

The STI measurements are again in agreement but the RASTI results show a very clear tendency to be pessimistic.

DISCUSSION

Our explanations for the differences between the STI and RASTI results are firmly rooted in the limitations of the RASTI method, in particular the fact that RASTI only tests in the 500Hz and 2kHz octave bands. The RASTI method therefore only covers the frequency range 350Hz - 3kHz.

Effects which occur outside this range are therefore not detected by a RASTI measurement [3].

In the presence of noise, the RASTI figure is not cognisant of the reduced frequency response which the PA system exhibited. This resulted in very poor S/N ratios at low and high frequencies which the RASTI test did not detect. It is for this reason that many of the noise-influenced measurements at the Aldwych produced optimistic RASTI results.

The reverberation times measured at Oxford Circus and Covent Garden are shown in fig. 8. It can be seen that the reverberation times begin to fall smartly above 2kHz. Again, this falls outside the frequency range of a RASTI measurement. The reduction in high frequency reverberation has a beneficial effect on intelligibility but the RASTI measurement does not account for this and produces a pessimistic result.

Figs. 9 and 10 show examples of RASTI and STI measurements made at the Aldwych with a S/N ratio of +6dB. It can be seen that the figures are lowest in the 125Hz and 8kHz bands, a trend which cannot be detected by the RASTI measurement.

Figs. 11 and 12 show examples of RASTI and STI measurements made at Covent Garden in the absence of noise. The figures in the STI table are highest in the 4kHz and 8kHz bands, beyond the range of the RASTI measurement.

The results, whilst providing a good correlation between PB Word Scores and full STI measurements do indicate that some misleading results can be obtained using the RASTI method unless the S/N ratio and reverberation time are constant across the frequency range.

If these parameters are unclear, we believe that it is advisable to use a full STI assessment as dictated by BS 6840: Part 16: A Guide to the RASTI Method for the Objective Rating of Speech Intelligibility in Auditoria.

Note: An IOA Working Party is currently assessing the range of validity for the RASTI method.

CONCLUSION

We are of the opinion that the results of our experimentation indicate that, unless the conditions laid down in BS 6840: Part 16 [4] are clearly met, then the following is expected.

(i) If the results are influenced by noise then the returned RASTI value is likely to be optimistic compared with a full STI and hence speech intelligibility.

(ii) If the results are influenced by reverberation then the result and RASTI value is likely to be pessimistic compared with a full STI and hence speech intelligibility.

(iii) Notwithstanding the above, caution is advised.

Further Work

Clearly our experimentation was for a specific type of acoustics and for a limited range of reverberation and noise. Combination of reverberation and noise may yield slightly different results.

As a result of the IOA Working Party, limits on the extent of reverberation and noise have been proposed.

References:

[1] A Review of the MTF Concept in Room Acoustics and its use for Estimating Speech Intelligibility in Auditoria - T. Houtgast & H.J.M. Steeneken.

[2] The use of Binaural Recording Techniques in the Assessment of Speech Intelligibility using Word Scores on London Underground - P.W. Barnett.

[3] Some Practical Limitations of STI Method - P.W. Barnett & R.D. Knight.

[4] BS 6840: Part 16: 1989: Guide to RASTI Method for the Objective Rating of Speech Intelligibility in Auditoria.

RELATIONSHIP BETWEEN STI AND PB WORD SCORE

Frequency-Hz	125	250	500	1000	2000	4000	8000
level dB	-53.5	-32.8	-33.7	-26.3	-24.5	-23.4	-37.6
m-correction	1.000	1.000	1.000	1.000	1.000	1.000	0.992
0.63	0.443	0.605	0.575	0.753	0.802	0.840	0.728
0.80	0.443	0.605	0.575	0.753	0.802	0.840	0.728
1.00	0.443	0.605	0.575	0.753	0.802	0.840	0.728
1.25	0.443	0.605	0.575	0.753	0.802	0.840	0.728
1.60	0.421	0.325	0.465	0.636	0.657	0.694	0.627
2.00	0.421	0.325	0.465	0.636	0.657	0.694	0.627
2.50	0.340	0.275	0.380	0.565	0.565	0.570	0.564
3.15	0.340	0.275	0.380	0.565	0.565	0.570	0.564
4.00	0.364	0.235	0.335	0.504	0.490	0.465	0.486
5.00	0.290	0.133	0.360	0.439	0.423	0.390	0.456
6.30	0.243	0.117	0.227	0.354	0.342	0.272	0.389
8.00	0.272	0.033	0.164	0.248	0.257	0.175	0.312
10.00	0.310	0.077	0.106	0.216	0.198	0.136	0.272
12.50	0.242	0.166	0.100	0.134	0.131	0.094	0.210
octave TI	0.413	0.353	0.412	0.510	0.521	0.517	0.518

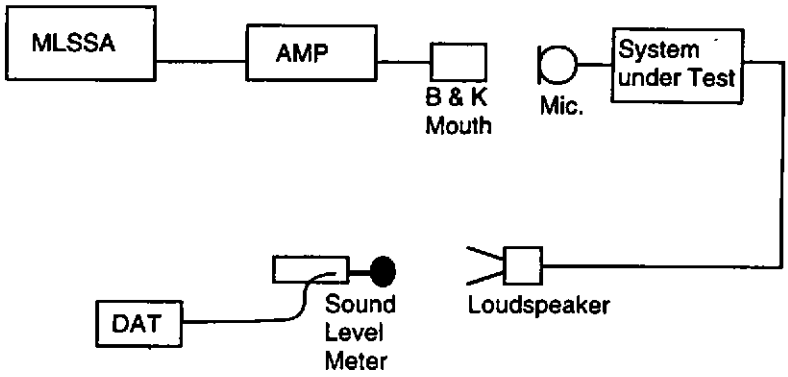
STI value= 0.469 (0.489 modified) ALcons= 13.4% Rating= FAIR

Typical STI Calculation Table MLSSA: STI

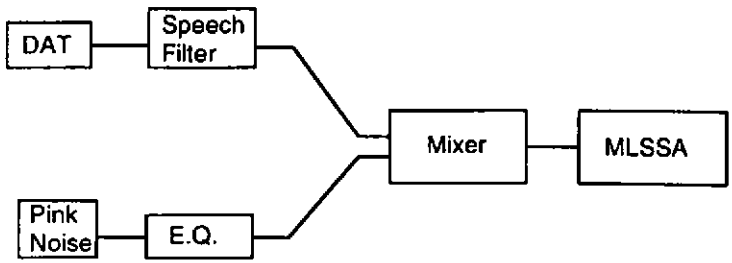
Fig. 1

Figure 2 - Equipment Used for STI/RASTI Measurements

Measuring Equipment



Analysis Equipment



RELATIONSHIP BETWEEN STI AND PB WORD SCORE

Graph of STI and PB Wordscore obtained at the Aldwych showing STI Data Points

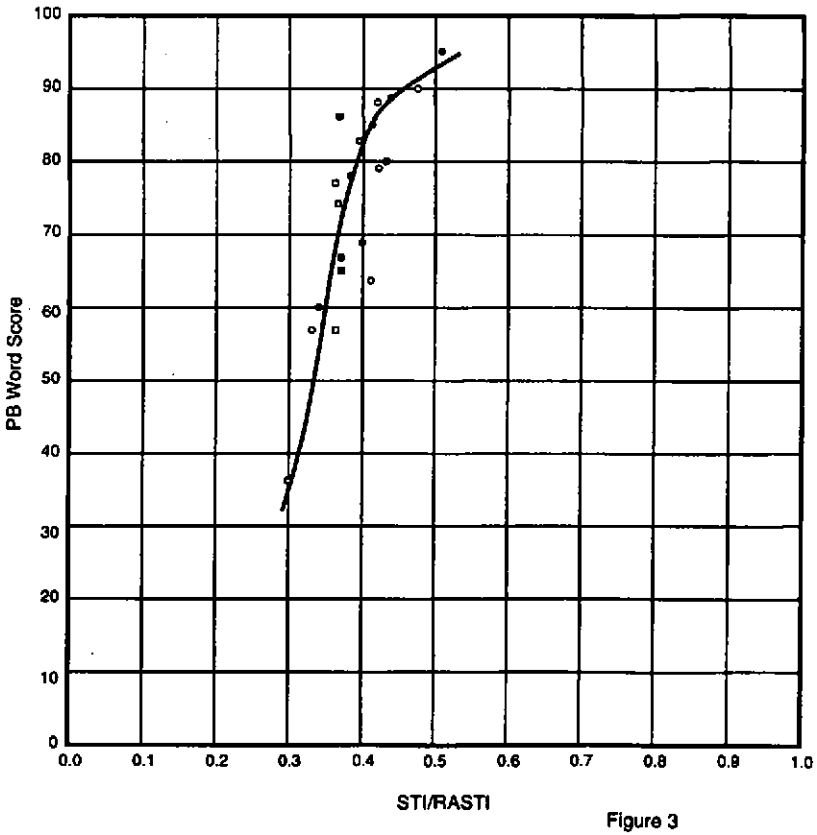


Figure 3

RELATIONSHIP BETWEEN STI AND PB WORD SCORE

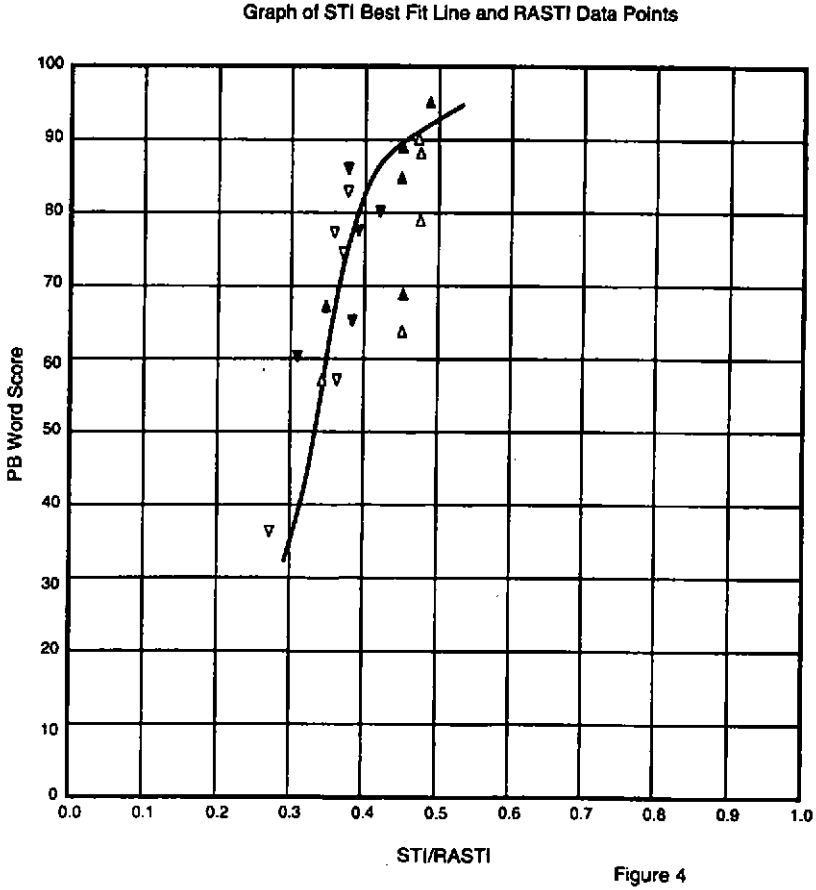


Figure 4

RELATIONSHIP BETWEEN STI AND PB WORD SCORE

Graph of STI and PB Wordscore showing areas of uncertainty

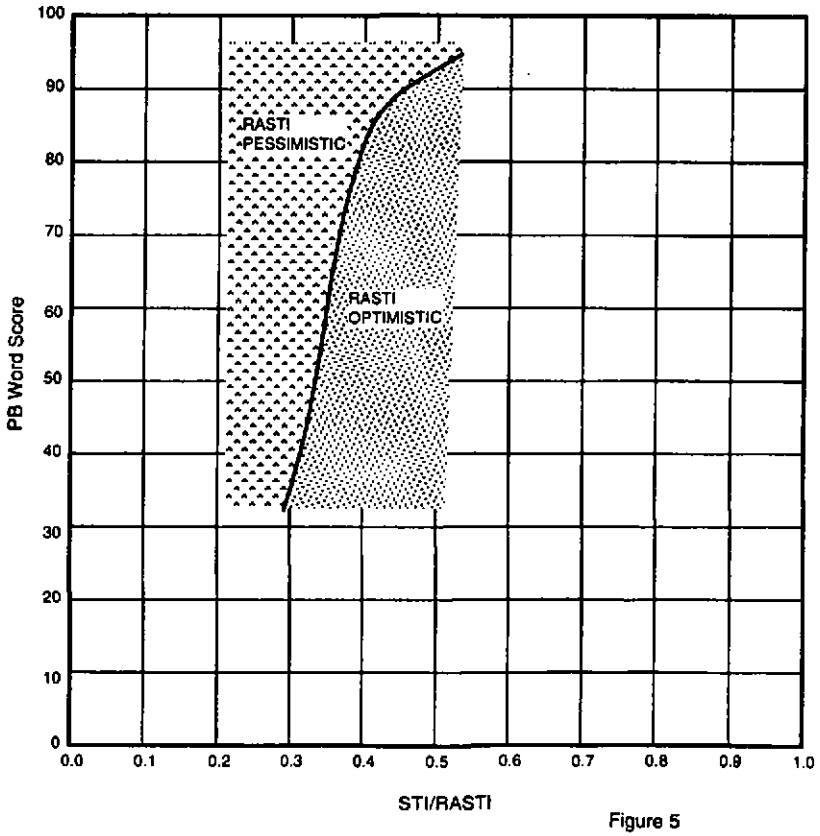


Figure 5

RELATIONSHIP BETWEEN STI AND PB WORD SCORE

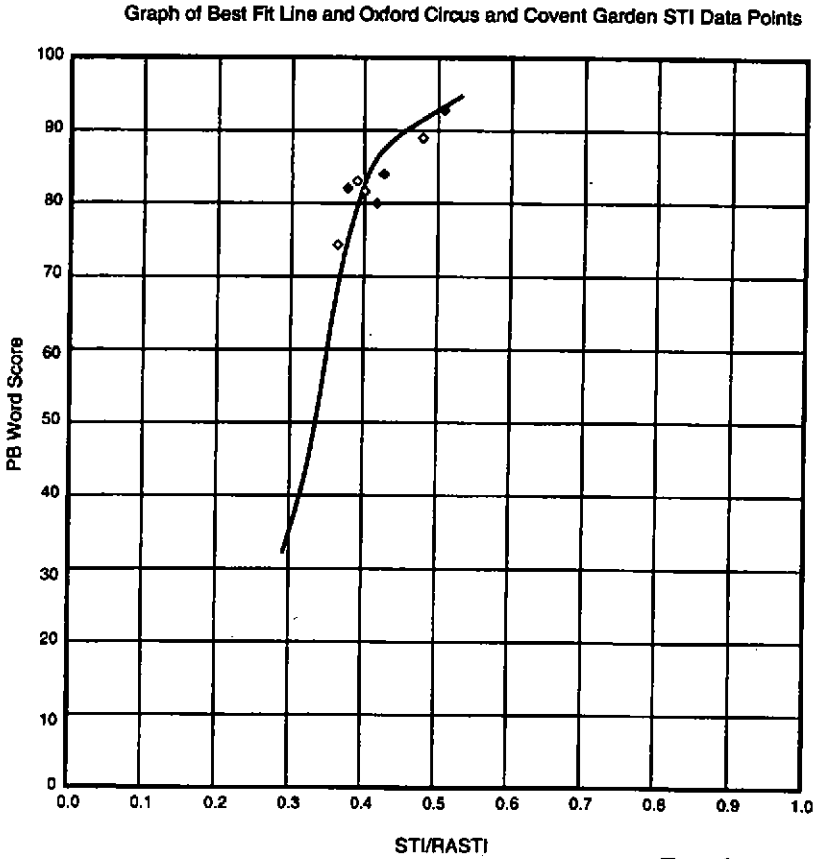


Figure 6

RELATIONSHIP BETWEEN STI AND PB WORD SCORE

Graph of Best Fit Line and Oxford Circus and Covent Garden RASTI Data Points

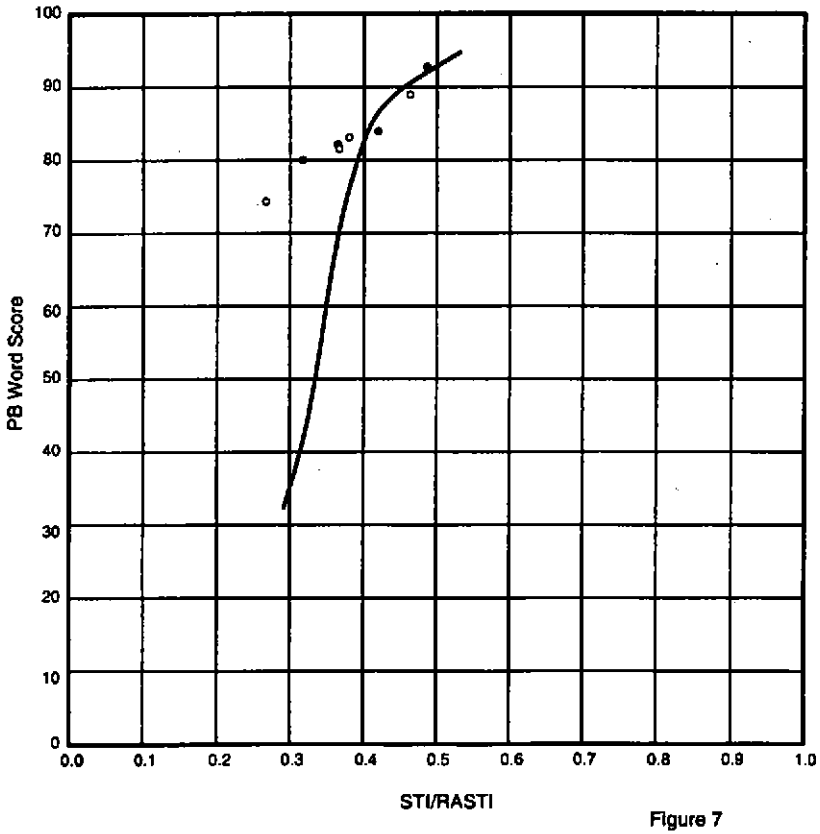


Figure 7

RELATIONSHIP BETWEEN STI AND PB WORD SCORE

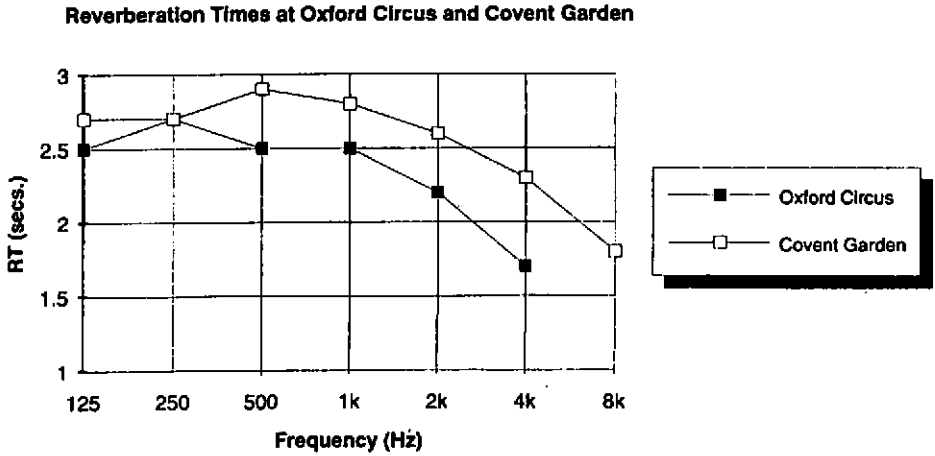


Fig. 8

RELATIONSHIP BETWEEN STI AND PB WORD SCORE

Frequency-Hz	125	250	500	1000	2000	4000	8000
level dB			-35.2		-40.3		
0.71					0.749		
1.00			0.555				
1.41					0.622		
2.00			0.350				
2.80					0.437		
4.00			0.148				
5.60					0.248		
8.00			0.157				
11.20					0.062		

RASTI value= 0.398 ALcons= 19.7% Rating= POOR

Aldwych Station, 'dead end',off axis, s/n +6 dB MLSSA: RASTI

Fig. 9

Frequency-Hz	125	250	500	1000	2000	4000	8000
level dB	-41.8	-28.5	-35.7	-36.6	-41.0	-49.2	-45.7
m-correction	1.000	1.000	0.998	1.000	0.999	0.998	1.000
0.63	0.107	0.704	0.585	0.654	0.663	0.724	0.025
0.80	0.107	0.704	0.585	0.654	0.663	0.724	0.025
1.00	0.107	0.704	0.585	0.654	0.663	0.724	0.025
1.25	0.107	0.704	0.585	0.654	0.663	0.724	0.025
1.60	0.097	0.401	0.413	0.510	0.520	0.545	0.061
2.00	0.097	0.401	0.413	0.510	0.520	0.545	0.061
2.50	0.104	0.256	0.260	0.447	0.414	0.443	0.037
3.15	0.104	0.256	0.260	0.447	0.414	0.443	0.037
4.00	0.062	0.127	0.157	0.348	0.352	0.384	0.090
5.00	0.113	0.134	0.070	0.294	0.279	0.332	0.075
6.30	0.062	0.142	0.175	0.218	0.216	0.231	0.042
8.00	0.009	0.133	0.231	0.150	0.165	0.175	0.050
10.00	0.012	0.238	0.077	0.082	0.079	0.123	0.031
12.50	0.020	0.180	0.107	0.074	0.130	0.051	0.012
octave TI	0.137	0.401	0.365	0.425	0.431	0.448	0.050

STI value= 0.330 (0.422 modified) ALcons= 28.5% Rating= POOR

Aldwych Station, 'dead end',off axis, s/n +6 dB MLSSA: STI

Fig. 10

RELATIONSHIP BETWEEN STI AND PB WORD SCORE

Frequency-Hz	125	250	500	1000	2000	4000	8000
level dB			-28.4		-17.8		
0.71					0.762		
1.00			0.431				
1.41					0.512		
2.00			0.237				
2.80					0.258		
4.00			0.146				
5.60					0.186		
8.00			0.061				
11.20					0.167		

RASTI value= 0.357 ALcons= 24.6% Rating= POOR

Covent Garden, on axis

MLSSA: RASTI

Fig. 11

MTF Matrix (Uncalibrated)

Frequency-Hz	125	250	500	1000	2000	4000	8000
level dB	-45.1	-27.5	-28.9	-19.9	-18.2	-18.1	-33.1
m-correction	1.000	1.000	1.000	1.000	1.000	1.000	0.991
0.63	0.241	0.592	0.488	0.591	0.660	0.761	0.625
0.80	0.241	0.592	0.488	0.591	0.660	0.761	0.625
1.00	0.241	0.592	0.488	0.591	0.660	0.761	0.625
1.25	0.241	0.592	0.488	0.591	0.660	0.761	0.625
1.60	0.008	0.297	0.241	0.340	0.415	0.545	0.504
2.00	0.008	0.297	0.241	0.340	0.415	0.545	0.504
2.50	0.125	0.115	0.171	0.241	0.256	0.438	0.434
3.15	0.125	0.115	0.171	0.241	0.256	0.438	0.434
4.00	0.102	0.302	0.090	0.180	0.173	0.386	0.366
5.00	0.130	0.274	0.079	0.145	0.159	0.339	0.334
6.30	0.100	0.102	0.034	0.133	0.186	0.321	0.337
8.00	0.061	0.133	0.091	0.097	0.197	0.312	0.328
10.00	0.086	0.022	0.024	0.097	0.184	0.311	0.328
12.50	0.046	0.182	0.052	0.128	0.113	0.336	0.274
octave TI	0.192	0.344	0.268	0.358	0.398	0.504	0.471

STI value= 0.373 (0.392 modified) ALcons= 22.6% Rating= POOR

Covent Garden, on axis

MLSSA: STI

Fig. 12