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THE EFFECT OF NOISE ON SPEECH INTELLIGIBILITY

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OBJECT

The object of this Paper is to present the findings of a limited investigation into the effects on speech intelligibility under differing noise conditions.

INTRODUCTION

With the advent of a number of British Standards and a general desire to improve the performance of public address, the prediction of speech intelligibility is assuming greater importance.

Speech intelligibility is affected by two primary components, the acoustics of the space and the presence of noise.

The investigation is directed towards the determination of speech intelligibility degradation caused by the presence of noise.

METHOD

It was decided to use PB word scores (modified rhyme test) as the method of rating intelligibility. A spoken word list comprising 50 words was mixed with varying amounts of noise and committed to RDAT format. Listeners were then invited to carry out word scores listening to the tape recordings over high quality headphones.

SOURCE

The PB word list comprised six sets taken at random from a master list. The six lists were committed to RDAT tape under anechoic conditions without the presence of noise by a trained speaker. Each word was preceded by 'Now Mark' i.e. 'Now Mark Shed'.

NOISE

Two types of noise were used in the experiments.

1. Pink noise (full bandwidth)

2. Football crowd noise.

Pink Noise:
The pink noise was mixed with the PB word score with the following signal-to-noise ratios:

15 dB, 10 dB, 6 dB, 3 dB, 0 dB, -3 dB

Fig. 1 shows sample traces of the noise with speech superimposed.

Crowd Noise:
The crowd noise was taken from a section of a football match recorded earlier in the year. The section chosen was contrived to have the same $L_{A10,T}$ as the half from which it was taken. Fig. 2 shows temporal response of the noise sample.

Figs. 3 and 4 show the statistical distribution of the noise. The table below gives salient data:

Sound Pressure Level dBA (dB)				
L_{90}	L_{50}	L_{eq}	L_{10}	SD σ
73	80	87	90	6.6

The crowd noise was mixed with the PB word list and committed to RDAT tape in a similar way to the pink noise providing the following signal-to-L_{10} noise ratios.

15 dB, 10 dB, 6 dB, 3 dB, 0 dB, -3 dB

RESULTS

The table below shows the results obtained:

Pink Noise

Signal-to-noise-ratio	+20	15	11	6	2	-1	-4	-7
PB Word Score (MRT method)	99	93	89	76	66	54	33	20
Standard Deviation σ	1.6	1.5	2.7	2.8	4.5	5.3	6.1	5.8

Crowd Noise

Signal-to-Noise-Ratio	+20	15	11	6	2	-1	-4	-7
PB Word Score (MRT method)	98	94	92	82	74	63	42	34
Standard Deviation σ	2.6	2.9	3.4	4.6	4.6	6.2	6.6	7.4

A control using the same signal without noise was scored and this gave:

Signal-to-Noise Ratio	>40dB
PB Word Score	98.6
Standard Deviation σ	1.1

We would therefore expect an error of up to 2 x σ (94% confidence limits) of 2.2%.

Hence the best result expected would be as follows:

Pink Noise

Signal-to-noise-ratio	+20	15	11	6	2	-1	-4	-7
Corrected PB Word Score	100	95	91	78	68	56	35	22

Crowd Noise

Signal-to-Noise-Ratio	+20	15	11	6	2	-1	-4	-7
Corrected PB Word Score	100	96	94	84	78	65	44	36

DISCUSSION OF RESULTS

Subsequent analysis of the source indicated that our supposed signal-to-noise ratio may have been in error since there was a marked difference in level between 'Now Mark' and the word. See fig. 5. From analysis of the source we determined the following speech levels (normalised to 'Now Mark').

Speech	Average Level	SD σ
Now Mark	0	1.3
Word	-4	3.5

We therefore decided to reduce the signal-to-noise ratios accordingly.

Hence the revised situation is as follows:

Original	15	10	6	3	0	-3
Revised	11	6	2	-1	-4	-7

This unfortunately restricted the data points and high signal-to-noised ratios and therefore some limited tests were conducted at +15dB and +20dB.

Fig. 6 shows the results of the experiments after adjustment for the signal-to-noise ratio anomaly. It can be seen that the intelligibility degrades consistently with decreasing signal-to-noise ratio. Not surprisingly the pink noise offers rather more masking than the fluctuating crowd noise.

The standard deviations obtained indicate that the results were consistent and that any error would be relatively small.

CONVERSION OF PB WORD SCORE TO STI

From measurements made on public address systems over the last two years using both PB word scores and STI we are able to conjecture a relationship between the two methods. Fig. 7 shows a graph of the smoothed results. The public address systems measured were for a wide variety of acoustic situations but at all times the signal-to-noise ratio was greater than 25dB. Fig. 8 shows the PB word list results converted to STI.

COMPARISON WITH THEORY

Using the results obtained together with our conversion between PB word score and STI it is possible to compare the results of our research with theory. This comparison is shown in fig. 9. The theoretical values were derived from the following method.

Consider the STI expression:

$$m(f) = \frac{1}{\sqrt{1+[2\pi F \frac{T}{13.8}]^2}} \frac{1}{1+10^{(-S/N)/10}}$$

The first part of the product $\frac{1}{\sqrt{1+[2\pi F \frac{T}{13.8}]^2}}$ includes the modulation frequency and the reverberation time.

The second part $\frac{1}{1+10^{(-S/N)/10}}$ is only dependent upon the signal-to-noise ratio.

If we assume the best case when the transfer is perfect then the first term tends to unity and hence the modulation reduction factor m(f) is a function of signal-to-noise ratio only.

To determine the dependence of STI upon signal-to-noise ratio under perfect transfer conditions the following steps are necessary:

Determine apparent signal-to-noise ratio ($S/N_{(a)}$) where

($S/N_{(a)}$) = 10Log_{10} [m(f)/(1-m(f)] and then limit $S/N_{(a)}$ to the range +/-15dB.

Finally, the STI is calculated from

$$STI = [S/N_{(a)} + 15]/30$$

CONCLUSIONS

There appears to be a considerable divergence between theory and our results. At the time of writing the Paper we are unable to offer any substantiated reason for this difference. The PB word results were consistent with small reasonable deviations between samples. The conversion of PB word score to STI was from a statistically-large data base. The short time span between completing the research and the preparation of this Paper has precluded an in-depth investigation.

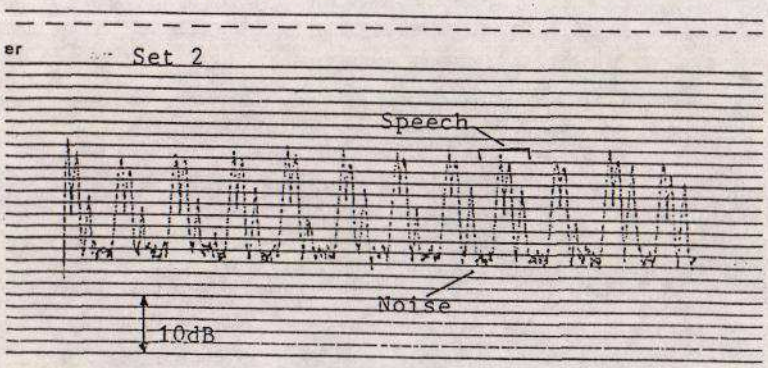
Cursory comparisons with works by others indicate that our PB word score results are rather more sensitive to noise. Our STI conversion however is consistent with earlier work.

We believe that our results indicate a need for further investigation.

References:

Sound System Engineering 2nd Edition - Don Davis & Carolyn Davis
STI Measurements on Simulated Acoustic Environments - P.W.Barnett & P.H.Scarbrough - Proceedings Institute of Acoustics Vol.11: Pt. 7: (l989)
Practical Assessment of Speech Intelligibility - P.W. Barnett - Proceedings of the Institute of Acoustics, Vol. 12: Part 8: (l990)
B & K Technical Review - RASTI
A Review of the MTF Concept in Room Acoustics and its use for Estimating Speech Intelligibility in Auditoria - T. Houtgast & H.J.M. Steeneken
BS 6840: Part 16: 1989 - Guide to RASTI Method for the Objective Rating of Speech Intelligibility in Auditoria
BS 7443: 1991 - Sound Systems for Emergency Purposes

SPEECH SUPERIMPOSED ON NOISE



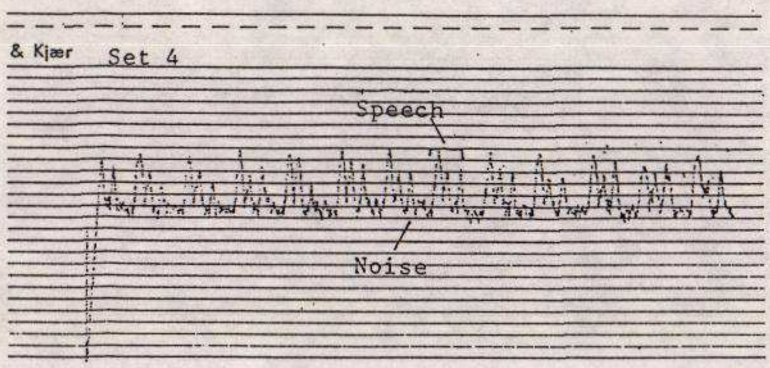


Fig. 1

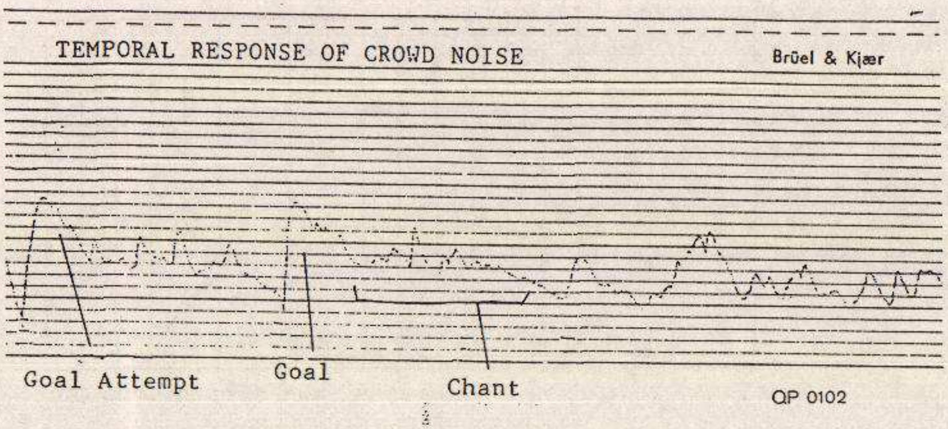

TEMPORAL RESPONSE OF CROWD NOISE
Brüel & Kjær
Goal Attempt
Goal
Chant
QP 0102

Fig. 2

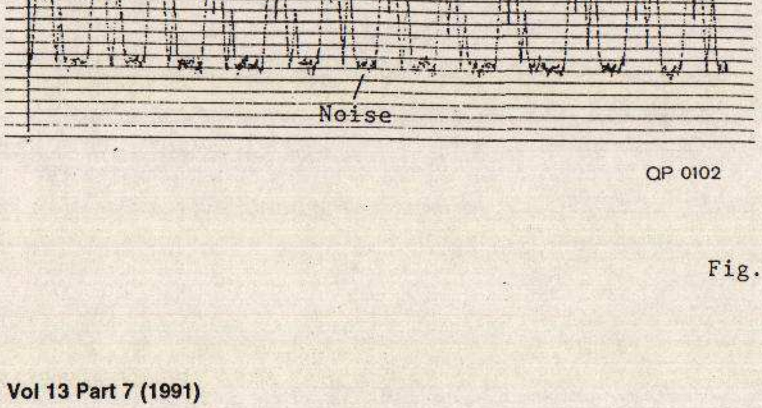

DIFFERENCE IN SPEECH LEVEL
Brüel & Kjæ
'Now Mark'
Word
Noise
QP 0102

Fig. 5

THE EFFECT OF NOISE ON SPEECH INTELLIGIBILITY

STATISTICAL DISTRIBUTION OF CROWD NOISE

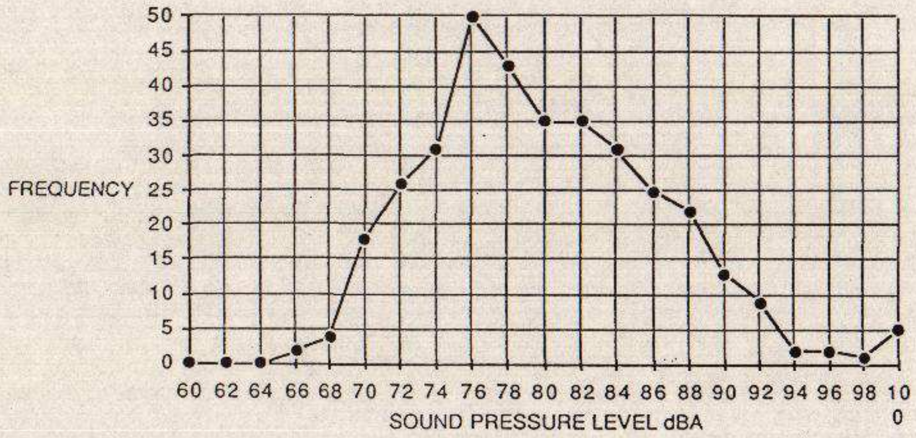


Fig. 3

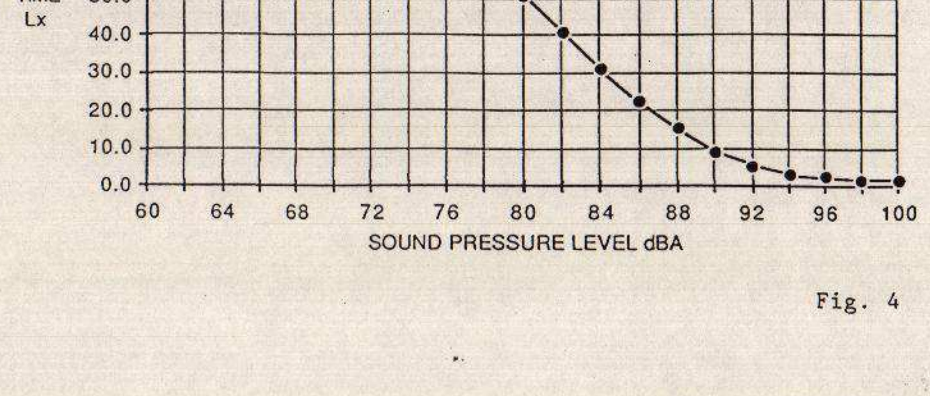


Fig. 4

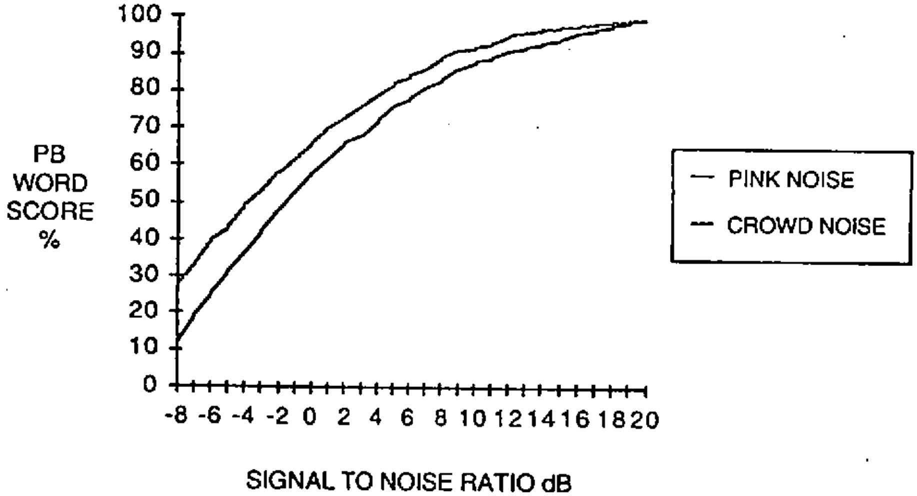

100
90
80
70
60
50
40
30
20
10
0
PB
WORD
SCORE
%
PINK NOISE
CROWD NOISE
-8 -6 -4 -2 0 2 4 6 8 10 12 14 16 18 20
SIGNAL TO NOISE RATIO dB

Fig. 6

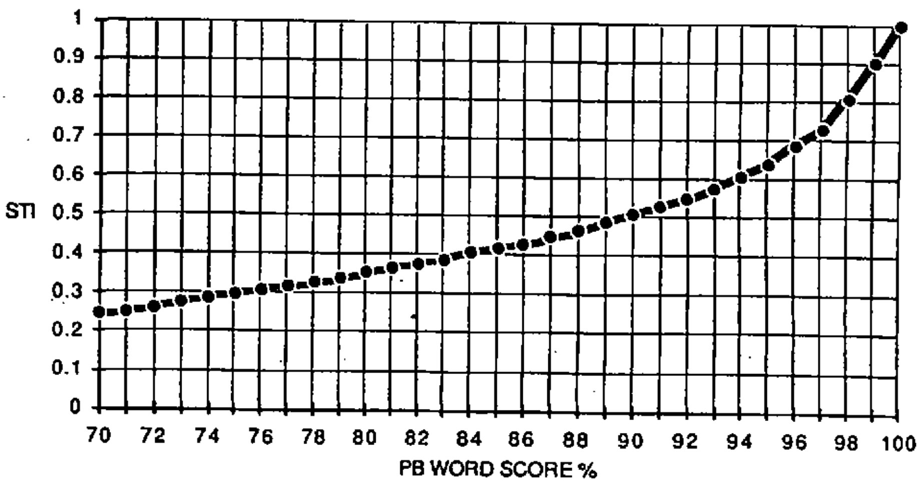

1
0.9
0.8
0.7
0.6
STI 0.5
0.4
0.3
0.2
0.1
0
70 72 74 76 78 80 82 84 86 88 90 92 94 96 98 100
PB WORD SCORE %

Fig. 7

THE EFFECT OF NOISE ON SPEECH INTELLIGIBILITY

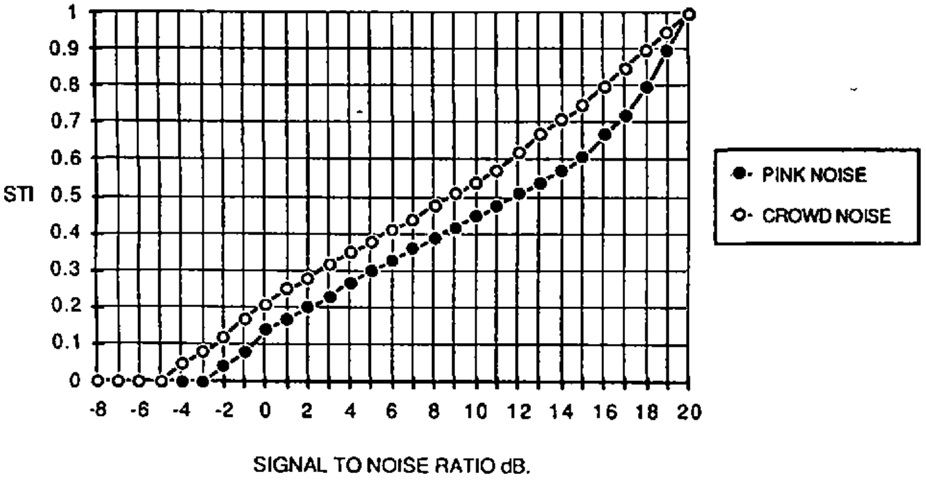


Fig. 8

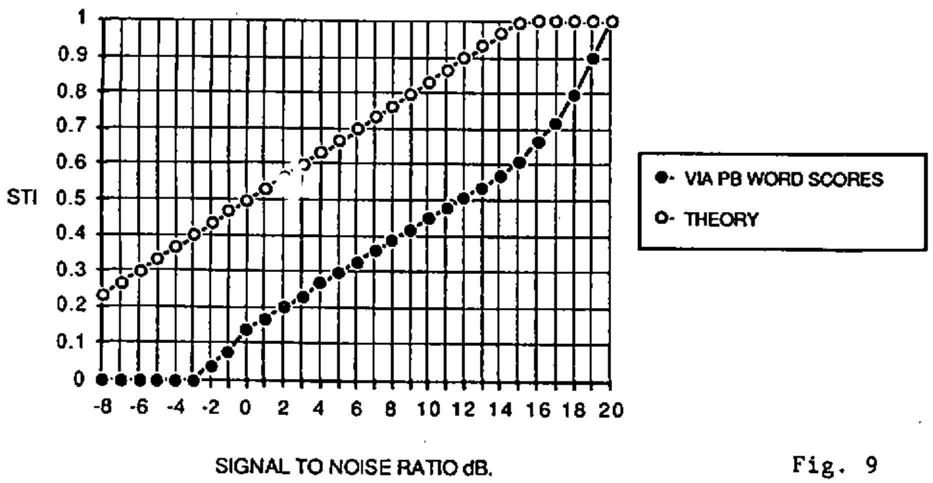


Fig. 9