THE EFFECTS OF NOISE ON SPEECH INTELLIGIBILITY IN TELEPHONE COMMUNICATION

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SUMMARY

This paper presents the subjective ratings of speech intelligibility in broadband ambient noise as a function of signal level for telephone communication. The appraisals were evaluated for English messages in an acoustic studio by Asian subjects conversant in the language. To present the necessary signal levels for satisfactory intelligibility under different levels of steady and fluctuating noise fields, two speech interference criteria expressed separately in terms of the preferred speech interference level (PSIL) and L_{50} were proposed.

SOMMAIRE

Cet article présente L'évaluation subjective de l'intelligibilité du langage parlé en présence d'un bruit d'ambiance de fréquences étendues à la fonction du niveau du signal pour la communication téléphonique. L'évaluation a été faite par des sujets asiatiques, sur la netteté de la perception des messages anglais, dans un studio acoustique. A fin de présenter les niveaux nécessaires du signal avec une intelligibilité sastifaisante sous des bruits de masque continus et variables, on a proposé deux critères d'interference qui s'experiment séparément en taut que niveau de perception de la parole (PSIL) et L_{50}.

INTRODUCTION

Speech intelligibility is an important factor to be considered in the design of working environments which involve verbal communication. This is specially so in work places such as air traffic control towers, police radio vehicles, classrooms and lecture theatres where good communication is essential. In general there are two main methods of verbal communication, namely by face-to-face conversation and by telephone. In assessing speech intelligibility in noise for these two methods, one has to make the following distinction: whereas sound perception in the former situation is biaural where both ears of the listeners are subjected simultaneously to the signal and ambient noise, in the latter situation, the ambient noise is received largely by one ear with the other ear of the listener being screened to a large extent by the telephone receiver and listening is monaural.

The interference effect of noise on speech intelligibility in the usually encountered face-to-face situation has been extensively studied.[1-5] Based on the preferred speech interference level (PSIL), Webster[4] has proposed a speech interference criterion which has become the most widely used rating for speech interference assessment. More recently ISO[6] has redefined the PSIL and put forward a revised assessment for satisfactory intelligibility.

In this paper, we report the results of speech intelligibility appraisals in telephone communication masked by broadband noise. The ratings evaluated in an acoustic studio by a sample of Asian subjects for various levels of signals and broadband noise were obtained and plotted separately in terms of PSIL and L_{50}. To present the necessary signal levels for satisfactory intelligibility under different levels of steady and fluctuating noise fields, two speech interference criteria were proposed and their significance discussed.

EXPERIMENTAL PROCEDURE

The schematic diagram of the experimental arrangement is shown in Fig. 1.

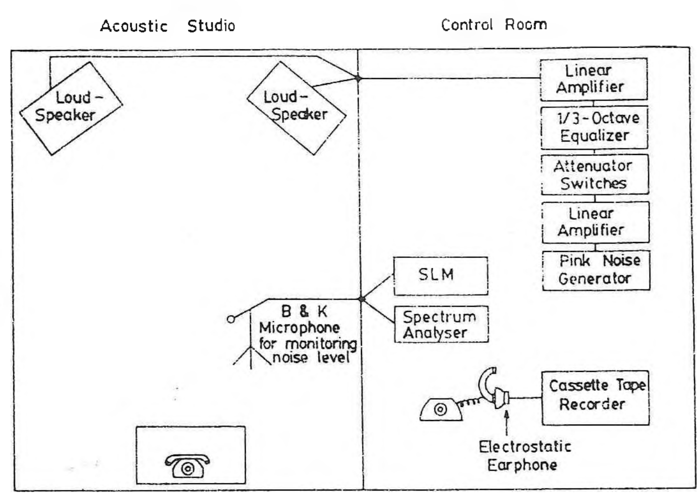

Fig. 1 Experimental Arrangement for Speech Interference Test

For the subjective study, four short telephone messages and a typical broadband noise were generated. The messages, each lasting about 30 sec, were in English and specially composed to contain meaningful sentences with words of vowels and consonants selected from a pool of words compiled by ISO. Each message was first prerecorded at four different levels. During the test, it was played back through the mouth piece of a handset and sent via the telephone exchange to be received by another telephone installed inside the acoustic studio. The four signal levels for each message at the receiving end were measured by an impedance matching IEC artificial ear coupler to be 60 dBA, 70 dBA, 80 dBA and 88 dBA.

The ambient broadband noise was based on a time-averaged noise spectrum (Fig. 2) recorded at the junction of two major roads in the heart of the city.[7]

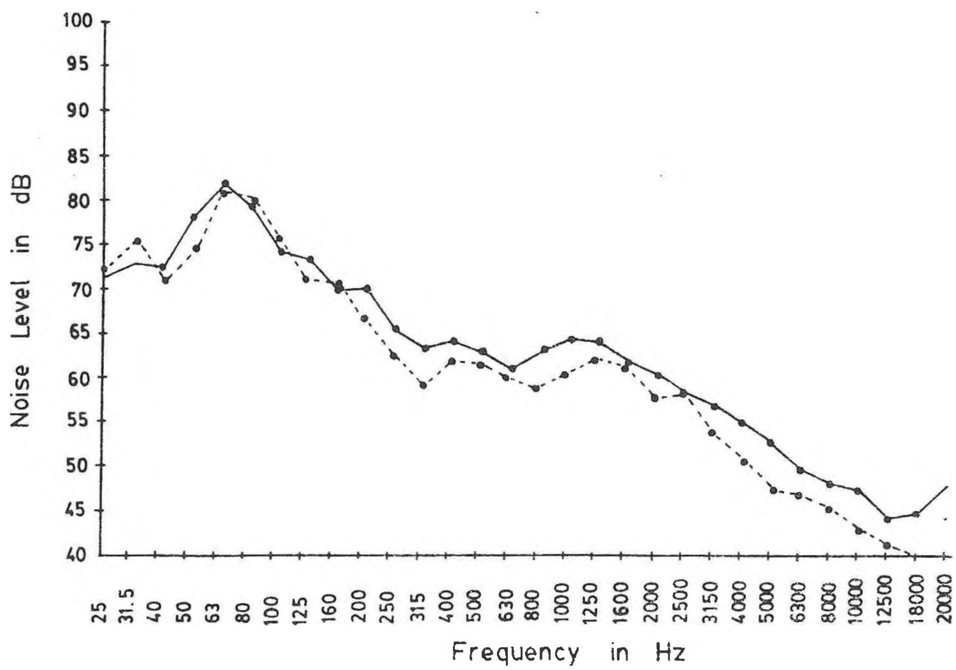

Fig. 2 The solid line is the frequency spectrum of traffic noise and the dotted line is the noise spectrum simulated in the acoustic studio.

As the noise level distribution was found to be normal, the spectrum gave the L_{50} values for the various frequencies. To reproduce the noise, the spectrum was simulated by a pink noise generator in conjunction with a $\frac{1}{3}$-octave equalizer and an amplifier system. It was then played through a pair of high-quality speakers at one of the four chosen (L_{50}) levels of 65 dBA, 70 dBA, 75 dBA and 80 dBA.

The simulated broadband noise was steady without fluctuations or transients, and contained no significant tones. Its spectrum at 75 dBA as measured at ear level about 30 cm from the telephone is also shown in Fig. 2. Comparing with the noise criteria (NC) curves[8], it can be observed that except for frequencies below 100 Hz, the spectrum follows very closely that of NC60 curve. The background noise employed in this investigation can therefore be taken to represent noise from more general noise situations rather than confined solely to noise from steady traffic flow. The set of background noise measured at 65dBA, 70 dBA, 75 dBA and 80 dBA corresponds to the set of noise criteria curves numbering NC50, NC55, NC60 and NC65 respectively, thus it follows that the corresponding PSIL for the chosen background noise levels may be taken respectively as 50 dB, 55 dB, 60 dB and 65 dB.

Intelligibility appraisals were carried out by 86 untrained Asian subjects. All subjects had normal hearing and equal acuity in both ears. They were drawn entirely from the University community and consisted of academic and technical staff, students, secretaries and clerks. The breakdown of their race, sex and age is summarised in Table 1.

Table 1

Age Group \ Race	Chinese		Malay		Indian		Other		Total
	M	F	M	F	M	F	M	F	
18 - 30	11	8	6	4	3	3	1	1	37
31 - 40	12	5	4	1	2		2		26
41 - 50	7	1	1	2	1			1	13
51 - 60	6	1	1		1		1		10
							Grand Total		86

During the appraisals, a subject stood at about 30 cm in front of the telephone box with his/her back facing the noise source. With the background noise on, the subject listened to the telephone messages and assessed the influence of noise on intelligibility using the following multiple Criteria:

Criterion	Rating
Background noise has negligible interference on intelligibility	1 2
Background noise has slight interference on intelligibility	3 4
Background noise has large interference on intelligibility	5 6
Background noise has severe interference on intelligibility	7 8

For improved resolution, two ratings were assigned to each criterion. For the case of normal telephone communication, ratings 1 and 2 correspond to the ideal situation where hearing is clear and precise. Ratings 3 and 4 correspond to acceptable situations where little effort is required for satisfactory intelligibility. Ratings 5 and 6 correspond to the grey region which may be acceptable if conversation is short and the audibility requirement is not stringent. Ratings 7 and 8 correspond to situations in which speech perception is very low and is therefore not acceptable under any circumstances. In a separate experiment, attempts had been made to quantified some of the ratings. This was carried out according to the method described by Beranek[9]. 30 selected sentences[9] were recorded and played back successively through the telephone system in the manner as described earlier. A subject after listening to each sentence was required to write it down and the articulation score was then computed from the number of key words correctly recorded. In this test, rating 4 was found to correspond to a score of approximately 78%. This is a sufficiently high articulation level which, despite the loss of a small part of the message, enables meaning and important points to be extracted from context. This rating, which was accepted by 85% of the subjects as the threshold of satisfactory listening condition, was therefore taken as the basis for the speech interference criteria in telephone communication.

RESULTS AND DISCUSSION

For the various combinations of signal and noise levels, a total of 1376 appraisals were recorded. The data obtained were then processed to yield the average ratings for all the possible predetermined signal/noise situations. To present the results of interest, Fig. 3 was plotted showing four rating curves for varied signal level as a function of PSIL (lower scale) and L_{50} (upper scale).

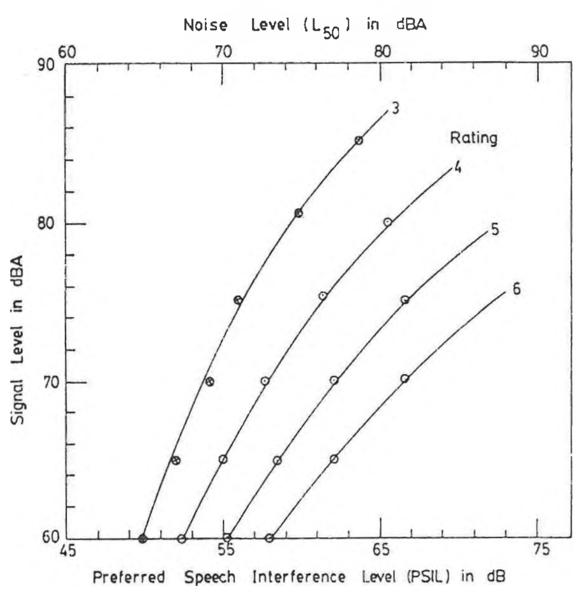

Fig. 3 Variation of signal level with PSIL (lower scale) and L_{50} (upper scale) for ratings 3, 4, 5, 6. This figure is plotted for steady noise fields for which $\Delta L_T = 0$.

It is interesting to note that the variations and inter-spacings of the curves are highly regular. This regularity permits additional information such as that pertaining to intermediate ratings to be obtained if so desired by extrapolation. For the present experiment, this necessity did not arise since rating 4 had been established as the listening condition for satisfactory intelligibility. Based on this rating, two speech interference criteria were proposed for (i) steady background noise and (ii) fluctuating background noise.

Steady background noise. In this case, the noise level is expressed in PSIL. The relation between the signal level and PSIL corresponding to rating 4 may be approximated by the expression:

$$SL_A \geqq 130 \log \left[\frac{1}{10} (\mathrm{PSIL} - 23)\right] \qquad (1)$$

where SL_A is the A-weighted signal level of the telephone receiver for satisfactory intelligibility. Its value is to be measured by an IEC artifical ear coupler. In practice, however, SL_A may be approximately correlated to the voice level of the talker which depends to a large extent on the telephone system in use as well as the manner the handset is held by the talker. For example, using the Singapore telephone system, it had been found that to produce a telephone signal level of about 74 dBA as stipulated by Eq. (1) for satisfactory intelligibility against a background noise level of 75 dBA (PSIL = 60 dB), a slightly raised voice level (measured 65 dBA at a distance of one meter) would suffice when the talker speaks into the mouth piece of the handset held in the normal manner.

Fluctuating background noise. A different class of situations exists where the background noise has short-term fluctuations in time. Such fluctuations and, in particular, rapid transients could adversely increase the annoyance perceived and hence increase the interference with speech intelligibility.

To test this effect due to the fluctuating noise, 15 subjects drawn from the original 86 subjects were asked to repeat the appraisals with background noise generated by the original tape recording of the traffic noise. The fluctuation, as given by $\Delta L_T = L_{10} - L_{90}$, was measured by a Bruel and Kjaer statistical noise analyser and found to be approximately 7-8 dBA for the four levels as mentioned earlier. The results of the test showed that noise fluctuations may be interpreted as equivalent to enhancing the steady background level by a margin ΔL_T.

Thus including the enhanced annoyance due to noise fluctuation ΔL_T, the relation between the signal level and L_{50} corresponding to rating 4 takes the following form:

$$SL_A \geqq 130 \log \left[\frac{1}{10} (L_{50} + \Delta L_T - 38)\right] \qquad (2)$$

Since ΔL_T is a variable quantity which may be different for different noise fields, the rating curves in fig. 3 are therefore presented in terms of L_{50} for steady ambient noise for which $\Delta L_T = 0$ (upper scale). For fluctuating noise with $\Delta L_T \neq 0$, the curves are equally valid except in such situation one has to do the necessary adjustment, i.e. to obtain the same level of audibility for a particular rating, the signal has to increase by an amount corresponding to the additional value of ΔL_T for the fluctuating noise level measured in L_{50}.

In this connection, it is interesting to note that the psycho-acoustic effect of a fluctuating noise appears to be closely linked to the accepted noise pollution level (L_{NP}) which is defined[10] as

$$L_{NP} = L_{EQ} + \Delta L_T$$

because of the normal distribution of noise levels as mentioned earlier.

Eq. (2) had been subjected to further confirmation by a number of on-site evaluation using telephones installed in exposed telephone booths located at street corners. The appraisals obtained for a variety of fluctuating noise fields showed the same consistent results closely in agreement with Eq. (2).

CONCLUSIONS

This work presents the results of speech intelligibility in telephone communication as appraised by a random selection of Asian subjects. All the subjects are conversant in English and can be taken to represent a cross section of the English speaking population in some Asian cities. Because of the small subject sample, no attempt was made to analyse the effect of age on the appraisal results. Two speech interference criteria for steady and fluctuating noise fields were proposed. They were derived mainly from the experimental data obtained in an acoustic studio and confirmed by on-site evaluations. It is hoped that these criteria can be used as guidelines for the improvement of speech perception in the design and installation of telephone booths in those Asian cities where English is one of the main languages used for telephone communication.

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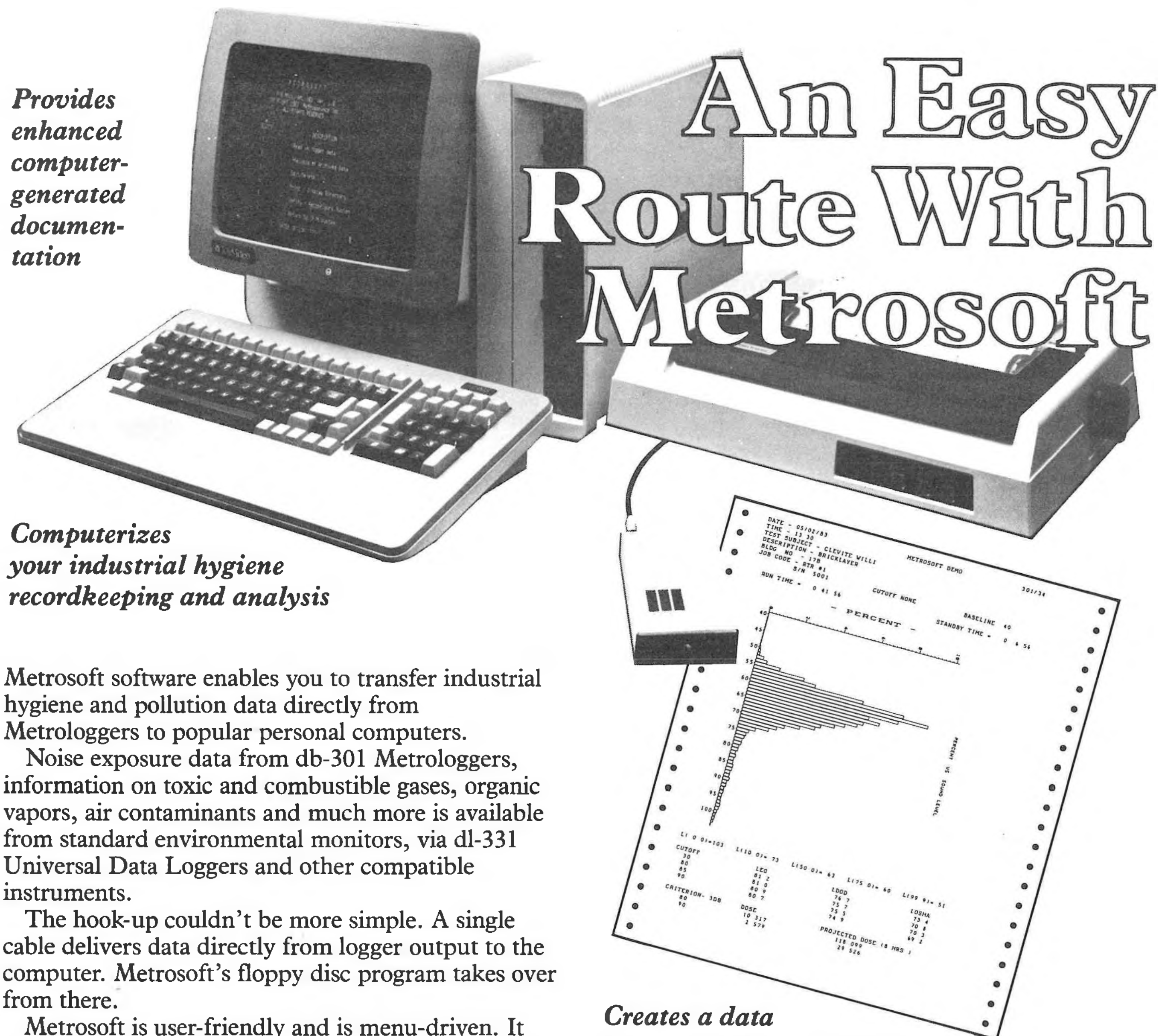

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