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ABSTRACT

This paper is from the proceedings of a second international conference on noise as a public health hazard. Funded by the Office of Noise Abatement and Control of the Environmental Protection Agency, these conference proceedings serve as a source material summarizing all known criteria that could be used in establishing national standards for noise control. The conference limited content to the effects of noise on health, thus eliminating discussions of a technical engineering or legal nature. Numerous topics discussed at the conference include: noise-induced hearing loss; community response; and sleep disturbance due to noise. The paper presented here concerns noise and its effect on the hearing of speech. In this research, the author reports that the speech interference level depends upon a number of varying factors. Among these are the octaves chosen for speech communication, the types of speech discrimination tests used, and the wearing of ear plugs or muffs by normal and hearing loss subjects. (MA)

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PROCEEDINGS of the INTERNATIONAL CONGRESS on NOISE as a PUBLIC HEALTH PROBLEM

DUBROVNIK, YUGOSLAVIA
May 13–18, 1973

U.S. ENVIRONMENTAL PROTECTION AGENCY
Washington, D.C. 20460

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Prepared by
THE U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Noise Abatement and Control

W. Dixon Ward, Editor

Foreword

In 1968, a Conference on Noise as a Public Health Hazard was organized by the American Speech and Hearing Association. At this conference, an attempt was made to bring together a group of speakers who could present summaries of the current state of knowledge on all aspects of the "noise problem", ranging all the way from fairly technical treatises to completely non-technical statements of personal opinion. Such a wide-ranging representation was judged to be necessary for the purpose of that conference, which was to present a broad overview of what "noise pollution" was all about, to government personnel and other intelligent laymen who saw that it was probably going to become a hot issue, and give at least a few examples of the scientific evidence underlying arguments about just what effects noise does have.

At that time it was realized that as the environmentalist movement gathered momentum, a rapid development of public concern could be expected, and so a permanent Committee of ASHA was established, one of whose charges was to plan another conference when it was judged appropriate.

The burgeoning of interest in noise in the intervening 5 years has clearly met, if not surpassed, our expectations at that time. In the developed areas of the world, millions of dollars or their equivalent are being spent on surveys of noise levels and exposures, and increasingly stringent noise regulations are being imposed by all levels of government. And, although the measurement of the effects of noise is nowhere near as simple as the measurement of the noises themselves, many laboratories, mostly with federal support, are engaged in full-time research on the hearing losses, sleep disturbance, speech interference, alteration of physiological state, and annoyance caused by noise.

Accordingly, in 1971 we began looking for a sponsor for a second conference—one who would agree, we hoped, to fund attendance by a substantial number of researchers from abroad, so that certain areas of knowledge less intensively studied in the USA could be included in the subject matter. Fortunately, the head of the newly-created Office of Noise Abatement and Control (ONAC) of the Environmental Protection Agency, Dr. Alvin F. Meyer, had need of just such a conference, as a source material for a document summarizing all known criteria that might be used to establish national standards for noise control—that is, provided that the Congress passed the bill, then being duly debated and amended, that would make such a document necessary. Furthermore, certain PL 480 funds (money that must be spent in other countries) were available, which meant that the degree of participation by foreign scientists might be even greater than we had hoped. Not only that, but the particular PL 480 funds in this case were in Jugoslavia, the country that includes one of the garden spots of the world, Dubrovnik.

On the assumption that our Congress would pass some form of the bill in question (which it did on October 27, 1972), we forged ahead with plans for our meeting, now upgraded to an International Congress. With the help of Dr. Grujica Žarković, the energetic President of the Jugoslavian Medical Association, and Dr. Mario Levi of the University of Sarajevo, a planning meeting was held to which we invited a representative from most of the countries in which noise research was being done (I say "most" because we could not quite afford to pay for attendees from Japan, Australia, and South Africa because of the distance involved, even though considerable research is being done there). At this meeting the formal agenda was decided on, and the list of invited participants prepared. It was agreed that we would try to limit the Congress content strictly to the effects of noise on health, thereby excluding discussions of engineering aspects of noise reduction and control, descriptions of methods for legal control, and presentation of viewpoints of special-interest groups. There was some debate about how much time to allot to public opinion surveys of annoyance, some of us contending that annoyance, as measured in that manner, is not a health hazard at all in the ordinary sense of the term. However, proponents of the WHO definition of "health", in which any deviation from "optimum well-being" is regarded as undesirable, carried the field, and the final day of the Congress was therefore given over to the sociologists.

Despite a series of crises precipitated by governmental red tape originating both in Washington and Belgrade, the Congress was held on May 13-18, 1973 at the Libertas Hotel in Dubrovnik. We had two major disappointments; one was the failure of our Russian invitees to appear due to the fact that our official invitations had not been sent early enough. The other was that the Xerox machine at the Libertas was out of commission. However, the general success of the Congress can be gauged by the fact that the audience was as large on the final afternoon as at any other time.

A side benefit of the Congress (or so we hope) was the formation of an international organization consisting of 5 "teams" who will try to accumulate and coordinate knowledge about the effects of noise on (1) temporary and permanent hearing loss; (2) extra-auditory function; (3) speech; (4) sleep; and (5) community reaction. The parent group, or "basic" team, will attempt to consolidate this knowledge for use by governmental agencies, and will make plans for the next Congress. Although the organization is now alive, its name is still in question. At the moment it is still the "International Scientific Noise Teams", but the resulting acronym has a negative connotation that pleases few of us. Other names are being considered.

I regret that the length of the invited papers made it impracticable to publish at this time any of the short contributed papers that were presented at the Congress, many of which were excellent, or the often-lively discussions that followed each session. It is hoped that these can be included if another printing of the Proceedings is to be made.

An enterprise of this scope cannot be a success without hard work on the part of many people. Without doubt the most effort of all was put forth by Dr. Levi, who managed all the mechanical details of the Congress, with the help of his and Dr. Žarković's staff, particularly, Felih Vesna. Of Dr. Meyer's staff, David Bach deserves special thanks for handling the oft-complicated travel arrangements of the participants.

Official thanks are extended to our sponsoring organizations: The Jugoslavian Medical Association, The American Speech and Hearing Association, the World Health Organization, and of course most of all the Office of Noise Abatement and Control.

Finally, I would like to thank my fellow participants (with two exceptions) for getting their manuscripts to me rapidly so that, with the help of Miles Kahn and Jean Pellegrini of ONAC and quick work by the Government Printing Office, the Proceedings of this Congress are appearing before they are out of date.

W. Dixon Ward
Editor
27 August 1973

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TABLE OF CONTENTS

Session 1

Introduction and Masking Effects of Noise
Chairman: Henning von Gierke (USA)

Page

Session 2

Noise-Induced Hearing Loss (NIHL)—Empirical Data
Chairman: D. Robinson (UK)

Session 3

Noise-Induced Hearing Loss—Mechanism

Chairmen: H.G. Dieroff (DDR), R. Hinchcliffe (UK)

Session 4A

Interaction of Noise with Other Noxious Agents in Production of Hearing Loss

Chairman: E. Lehnhardt (BRD)

Session 4 B

Performance and Behavior

Chairman: D. E. Broadbent (UK)

Session 5

Non-Auditory Physiological and Pathological Reactions
Chairmen: E. Grandjean (Switzerland), S. Kubik (Czechoslovakia)

Session 6

Sleep and Its Disturbance by Noise
Chairmen: B. Metz (France), M. Levi (Yugoslavia)

Session 7

Community Response I
Chairmen: G. Thiessen (Canada), P.N. Borsky (USA)

Page

Session 8

Community Response II
Chairman: R. Rylander (Sweden)

Session 9

Summary and Integration
Chairmen: G. Žarković (Yugoslavia), W.D. Ward (USA)

THE EFFECTS OF NOISE ON THE HEARING OF SPEECH

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To cover this subject matter, I will talk about the Articulation Index or AI, and the Speech Interference Level, or SIL, and in particular the relation between them. I will show that the best octaves to choose in calculating the SIL depend on what Articulation Index (AI) you want to work at or design for. And to make this meaningful, I will have to show you what scores you can expect to get on syllable, word, or sentence tests at various Articulation Indices. Beyond this, I will discuss what sort of tests can be used to test systems or listeners operating at high AIs, that is, in relatively quiet environments. If this seems off the subject, I will relate these types of tests to methods of evaluating hearing aids and/or different kinds of hearing losses including noise-induced hearing losses.

To talk of these things intelligently, I will have to spend a little bit of time discussing the pros and cons of efficient intelligibility tests. At the first of these conferences (Webster, 1969) I traced the early history of intelligibility testing. I will not repeat it here, but I would like to stress a single distinction made by the early Bell Telephone Laboratory investigators, namely, articulation testing as opposed to intelligibility testing. Articulation testing involves the use of nonsense syllables to determine what single speech sounds, phonemes, distinctive features, or consonants are misheard. Once any aspect of redundancy or language enters the testing it is no longer articulation but intelligibility that is being tested. Articulation testing centers on speech sounds per se. Intelligibility testing involves both the ear and the brain or involves both speech sounds and language.

To summarize very briefly the problems associated with speech testing, I must mention that the construction of speech intelligibility tests varies along two dimensions—the redundancy and/or vocabulary size of the input stimulus (language) and the constraints or number of possible choices in the output or response. Within vocabularies of the same size the relative familiarity of the word and the number of syllables in a word and the context within which it is imbedded influence its intelligibility. The constraints on the response, open vs. closed sets, also affect intelligibility scores. Closed set or Modified Rhyme Tests (MRT) (House et al., 1965; Clarke, 1965; Kreul et al., 1968) and pseudo-closed set rhyme word tests (Fairbanks, 1958) are largely replacing the open-set Phonetically Balanced (PB) (Egan 1948) and Spondee tests and other multiple choice tests at the present time. The major reason is the time and effort required to train both talkers and particularly listeners in the open-set PB-type word test.

This is not the document to trace out in any more detail the history, the rationale, the strengths and weaknesses, nor the actual listings of syllables, words, phrases, or sentences used this century to evaluate the effects of noise on speakers, listeners, communication components and systems, etc. Recently, however, Webster (1972) has compiled 24 lists of word, phrase, and sentence tests in English. A very good reference for more details on intelligibility tests is Clarke, Nixon, and Stuntz (1965) because it has abstracts of over 160 earlier references.

23

Table 1 shows the relationship between intelligibility scores and Articulation Index (a special form of speech-to-noise ratio) of many standard speech tests. The generalizations to be made from Table 1 are that the smaller the stimulus vocabulary and/or the size of the response set, or the more redundant in terms of context, the higher the score for a given AI or speech-to-noise ratio.

Table 1

Expected Word or Sentence Scores for Various Articulation Indices (AI)

AI	PB*	MRT**	SENT*
0.2	22	54	77
0.3	41	72	92
0.35	50	78	95
0.40	62	86	96
0.50	77	91	98
0.60	85	94	98
0.80	92	98	99

*From Kryter and Whitman (1963)

**From Webster and Allen (1972)

So far I have mentioned only the printed stimulus and response variables that affect intelligibility testing. The talkers, listeners, and the noise environment around them have very large effects on test validity and reliability. For example, Dreher and O'Neill (1957) had 15 naive speakers read in 5 different noise levels. When the words and sentences were played to listeners at a constant speech-to-noise differential the speech originally recorded in noise was the more intelligible. Pickett (1956) shows, however, that if vocal effort measured one meter in front of the lips exceeds 78 dB, intelligibility drops.

It should be apparent by now that intelligibility test results require some interpretation. It is neither simple nor straightforward to assess the affects of noise on speech using word testing methods. It would be advantageous to specify the effects of noise on speech in terms of the spectra and level of the noise and of the speech. Two such physical schemes exist—the Articulation Index, AI, and the Speech Interference Level, SIL. The Articulation Index or AI assumes that there are 20 bands in the speech spectra between 200 and 6100 Hz that differ in bandwidth such that each band contributes 1/20 of the total articulation. Each band contributes linearly to the extent that the speech peak level exceeds the RMS noise level by from 0 to 30 dB. The AI is a specialized method of specifying the speech-to-noise ratio. It is a non-dimensional numeric that varies from zero to one, but it can be considered to be a decibel scale ranging from zero to 30 such that for example an AI of 0.5 corresponds to a complex signal-to-noise ratio of 15 dB, 0.8 to 24 dB, etc.

The AI was introduced by French and Steinberg (1947), generalized and simplified by Beranek (1947a), and refined and validated by Kryter (1962a, 1962b). The AI was discussed at the first Congress of Noise as a Public Health Hazard by Webster (1969) and by Flanagan and Levitt (1969) in sufficient detail that it will not be belabored further here.

Almost simultaneously with the introduction of the AI, Beranek (1947b) proposed a simplified substitute for it, the Speech Interference Level (SIL) of noise. The definition of SIL is the arithmetic average of the decibel levels in three or four selected octaves. The choice of octaves will be discussed later. The SIL is only a measure of noise, and to interpret it in terms of permissible distances between talker(s) and listener(s), reference must be made to a table (Beranek (1947b)) or a graph (Botsford (1969), Webster (1969)). An updating, Mark II, of the Webster (1969) graph is shown as Figure 1. It differs from Mark I unveiled at the first of these conferences by (1) adding two new physical measures, the four octave PSIL (.5/1/2/4) and the proposed SI-60 weighting which will be discussed in more detail later; (2) appending an AI scale to help orient people in the real meaning of the figure; and (3) a droopoff in the communicating voice level curve to reflect the fact that at voice levels above 78 dB intelligibility does not increase as fast with vocal effort as at lesser levels. The gist of the figure is that for an AI of 0.5 using "normal" vocal effort (65 dB at 1 meter) conversation at 16 feet or 5 meters can take place in noises as high as 50 dB as measured on the A-weighting network of a sound level meter.

The one aspect of AI that has been alluded to by many (see Webster (1965)) but not fully appreciated is that as the AI and its correlate, word intelligibility, increase, the most important speech frequencies and/or the frequency range of noise that masks the speech most effectively increases from between 800 and 1000 Hz to between 1700 and 1900 Hz. This of course should be reflected in the octaves chosen to calculate the SIL, and this relationship will be developed in the next four figures.

Figure 2 shows a method of calculating the AI by counting the proportion of dots between the noise spectra and the upper limit of the conversational level speech spectrum. The example shows how it can be used to specify the AI for a -6 dB per octave (-3 when measured in octaves) noise.

This figure was developed from the Cavanaugh et al., (1962) procedure of deriving AI's from dot patterns spaced in a 30-dB range in the shape of the normal male speech spectrum. The concentration of dots reflects the relative importance of different frequency bands to the intelligibility of speech heard in noise. Figures 3, 4, and 5 show the results of calculating AI's at 0.2, 0.5, and 0.8 for 5 theoretical noises, and show why and how the octaves chosen for SILs should vary accordingly.

Note from Figure 3 that the spectra lines cross each other (with about a 2 dB spread) at 1000 Hz. Since these are all well-behaved, theoretical noises with constant slopes, the

23 FEB 1973

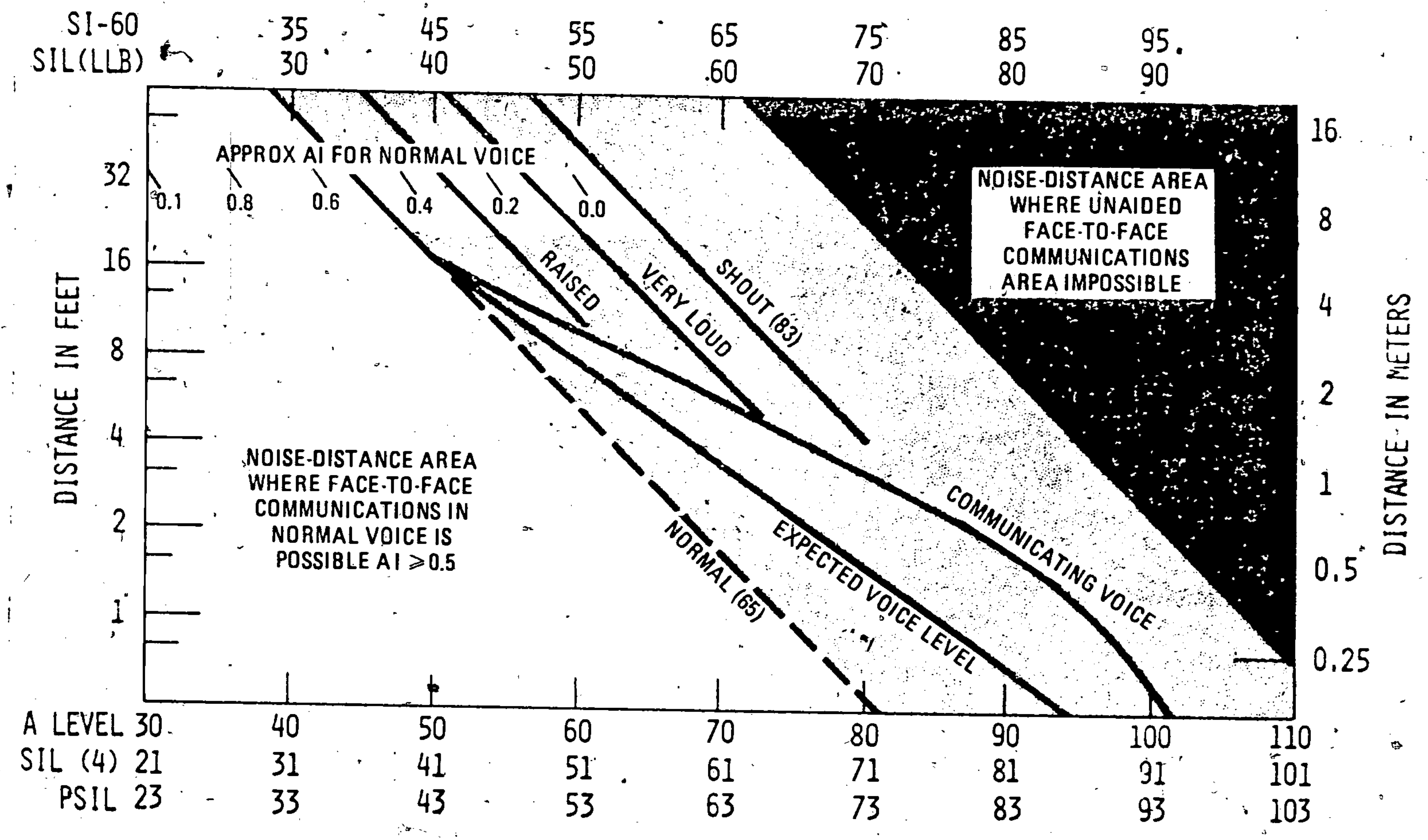

Figure 1. Necessary voice levels as limited by ambient noise for selected distances between talker and listener for satisfactory face-to-face communication. Along the abscissa are various measures of noise, along the ordinate distance, and the parameters are voice level. At levels above 50 dB(A) people raise their voice level as shown by the "expected" line if communications are not vital or by the "communicating" line if communications are vital. Below and to the left of the "normal" voice line communications are at an AI level of 0.5, 98% sentence intelligibility. At a shout, communications are possible except above and to the right of the "impossible" area line.

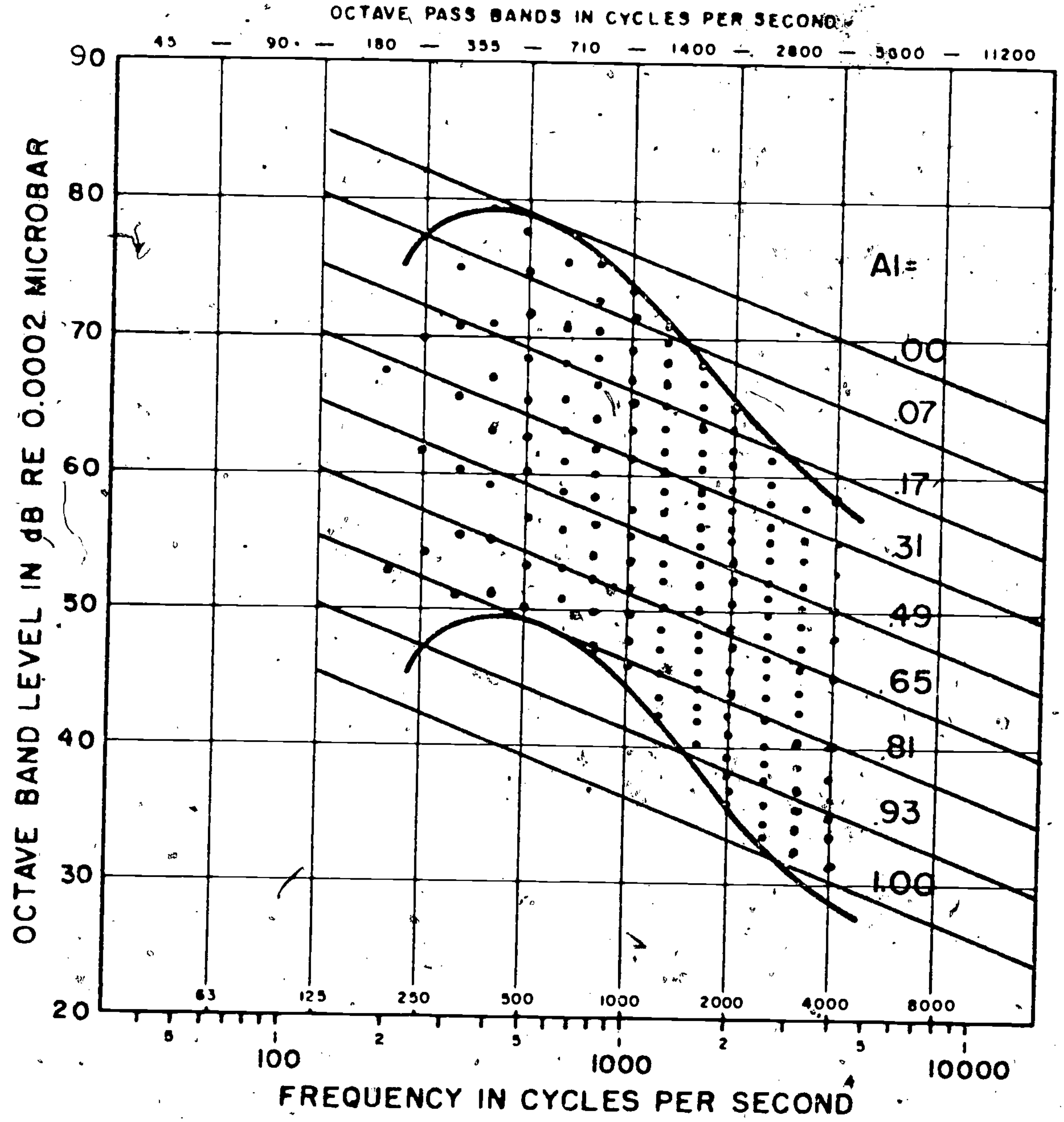

Figure 2. AI speech region for "conversational level" speech. The number of dots in each band signifies the relative contribution of speech in that band to the AI. A series of idealized thermal noises with -6 dB/oct spectra are drawn in 5 dB steps. The number of dots above each noise contour is proportional to the AI of conversational level speech in that level of noise. (After Cavanaugh et al., 1962.

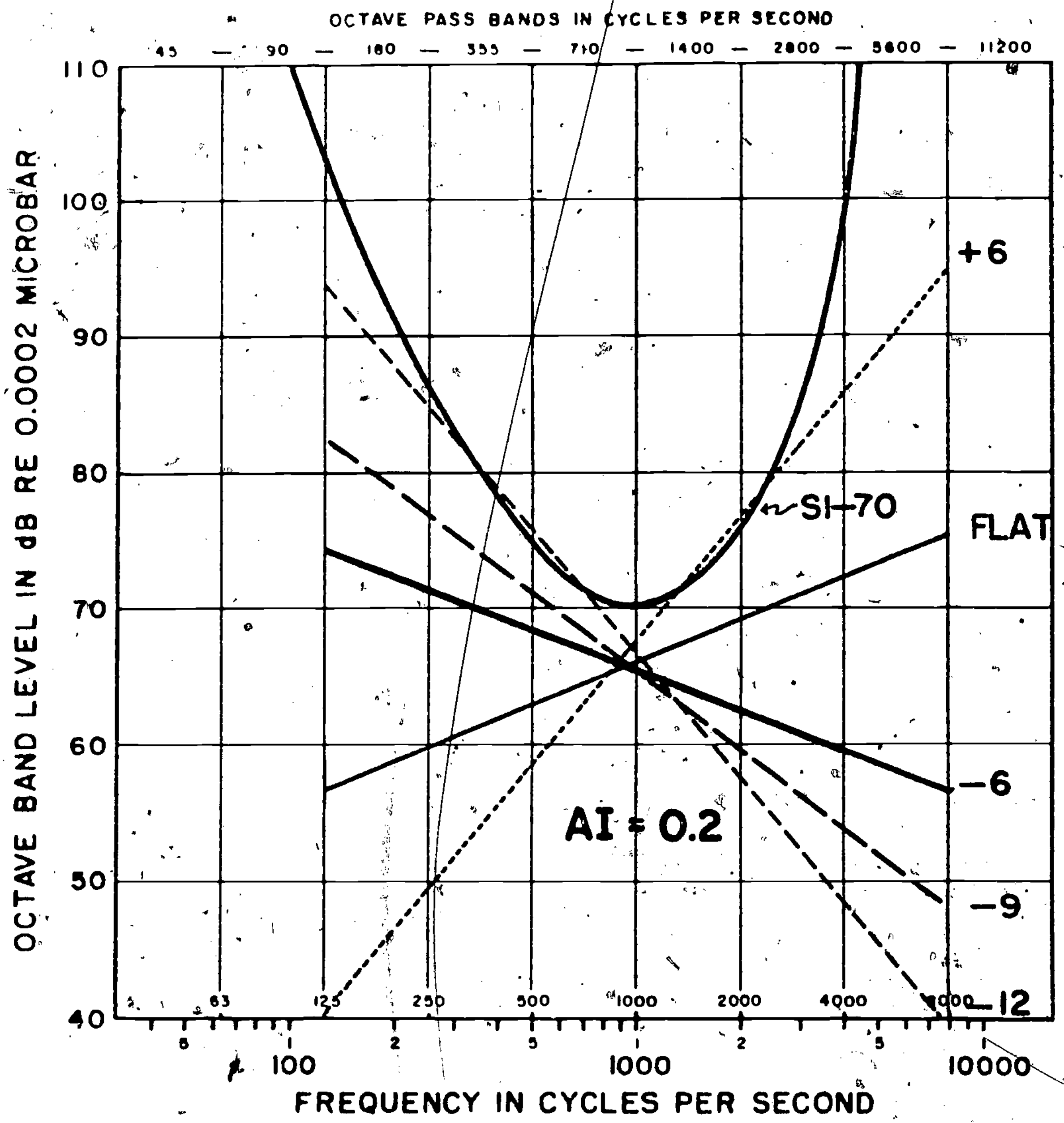

Figure 3. Allowable octave band sound pressure levels of steady state noises with spectrum slopes of -12, -9, -6, flat, and +6 dB per octave for an AI of 0.2 and conversational level speech. The superimposed SI-70 contour is a proposed frequency weighting network for evaluating the speech interfering aspects of noise at AI = 0.2.

crossing point at 1000 Hz is also the SIL for the octaves centered at 500, 1000, and 2000 Hz (.5/1/2 SIL). Note also that the spectra cross a hypothetical line at 1414 Hz (.5/1/2/4 SIL) with a spread of about 9 dB and that the spread at 2000 Hz (1/2/4 SIL) is about 18 dB. Obviously, the .5/1/2 SIL is the measure with the least variability for specifying the level of diverse-spectrum noises at an AI of 0.2, which corresponds roughly to Fairbanks (1958) Rhyme Test (FRT) and Modified Rhyme Test (MRT) score of just over 50%, a 1000 word phonetically Balanced (PB) word score of just under 25%, and a sentence score of just over 75%.

Interpreting Figure 4 in the same way, it is evident that (1) at 1000 Hz (.5/1/2 SIL) the spread is about 10 dB; (2) at 1414 Hz (.5/1/2/4 SIL) the spread is minimal, about 2 dB; and (3) at 2000 Hz (1/2/4 SIL) the spread is about 8 dB. It is equally apparent therefore that the .5/1/2/4 SIL shows the least variability in specifying an AI of 0.5 which corresponds to a PB score just over 75%, an MRT (and FRT) score of about 90%, and a near perfect sentence score.

Figure 5 shows the 1/2/4 SIL to be the least variable in specifying an AI of 0.8 which results in near-perfect socres on all word and sentence testing materials.

It should now be apparent that the choice of octaves in calculating SIL is directly related to the intelligibility required of the system to be evaluated or to the AI expected of the system. But just to summarize it once more let us look at Figure 6.

Note for example that the slope of AI versus SIL decreases with decreasing SIL levels as the spectral slope changes from -12 to -6, to 0, to +6 dB per octave. It therefore follows and it is evident from Figure 6 that when these 4 theoretical noises are equated in level to give an approximately equal AI of 0.2, as measured by the .5/1/2 SIL, they are not equal at AIs of 0.5 or 0.8. When equated by the .5/1/2/4 SIL, the noises are generally equivalent in level at an AI of 0.5 but not at 0.2 nor 0.8. Finally, if equated by the 1/2/4 SIL they are generally equivalent at an AI of 0.8 and not at 0.5 nor 0.2.

Interpolation shows that a 50% PB score (AI = 0.35) could be about equally well specified, over a large diverse sample of noises by an .5/1/2 or a .5/1/2/4 SIL. An AI of 0.35, MRT (FRT) score of 80 and sentence score of 95% has been recommended as the minimum acceptable specification for certain military communication equipments (see Webster and Allen, 1972) operating in highly adverse environments. Even lower levels for acceptance have been suggested for use in the past (see Webster, 1965) and thus lend credence to using the .5/1/2 SIL for measuring the effects of Navy noises. Architects and others working in quieter environments and requiring higher levels of communication efficiency naturally prefer AIs of 0.5 for which the .5/1/2/4 SIL is the least variable measure. Only the perfectionist would need to design or operate at AI levels of 0.8 and so there is probably no serious reason for considering the 1/2/4 SIL for practical engineers.

Probably the best validating data concerning the change of SIL frequency with AI are those of Cluff (1969). Cluff equated the spectra and levels of 112 industrial noises to give one-third octave AIs of 0.1, 0.2---0.9, and then determined the bandwidth that gave the best prediction (least standard diviation) over all noises for (1) an average level in one third octave bands—similar to an SIL—(2) an overall or band level—similar to a C-weighted (but band-limited) sound level meter reading—as well as broadband measures of (3) the A-weighting, and (4) the proposed SI-70 weighting. He found as the AI increased from 0.1 to 0.9 the center frequency of the optimum bandwidths increased from 848 to 2264

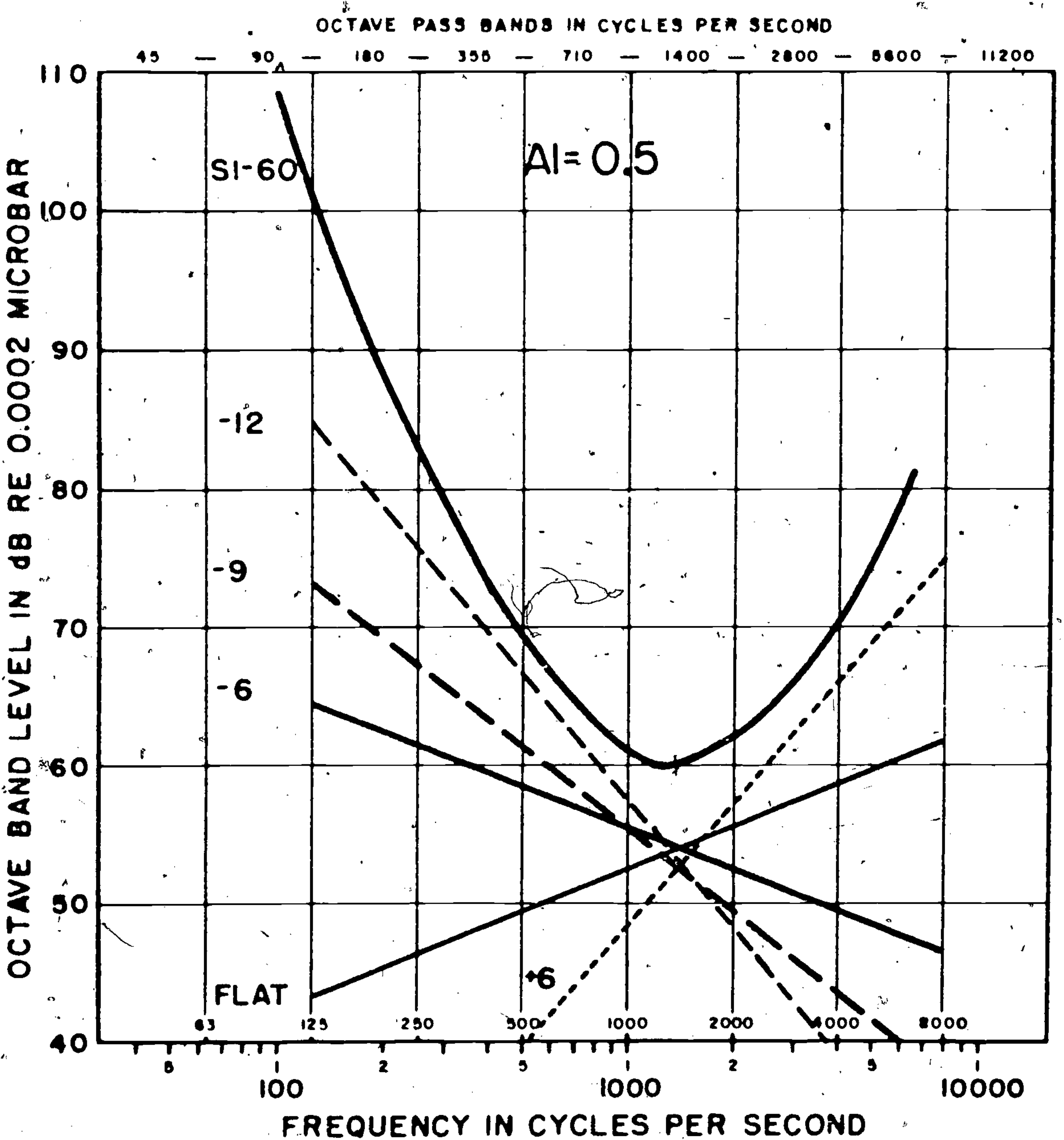

Figure 4. Allowable octave band sound pressure levels of steady state noises with spectrum slopes of -12, -9, -6, flat, and +6 dB per octave for an AI of 0.5 and conversational level speech. The superimposed SI-60 contour is a proposed frequency weighting network for evaluating the speech interfering apsects of noise at AI = 0.5.

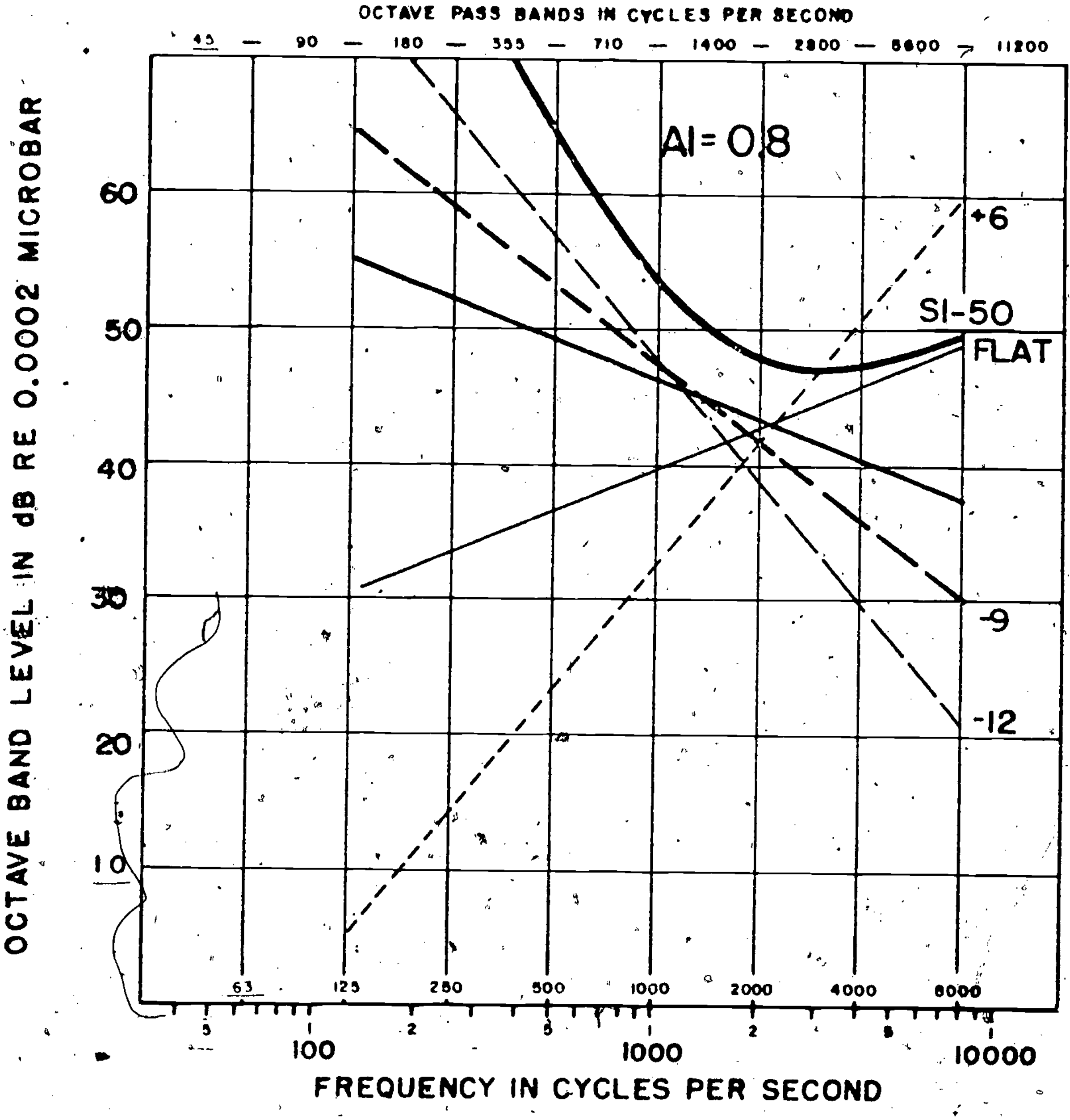

Figure 5. Allowable octave band sound pressure levels of steady state noises with spectrum slopes of -12, -9, -6, flat, and +6 dB per octave for an AI of 0.8 and conversational level speech. The superimposed SI-50 contour is a proposed frequency weighting network for evaluating the speech interfering aspects of noise at AI = 0.8.

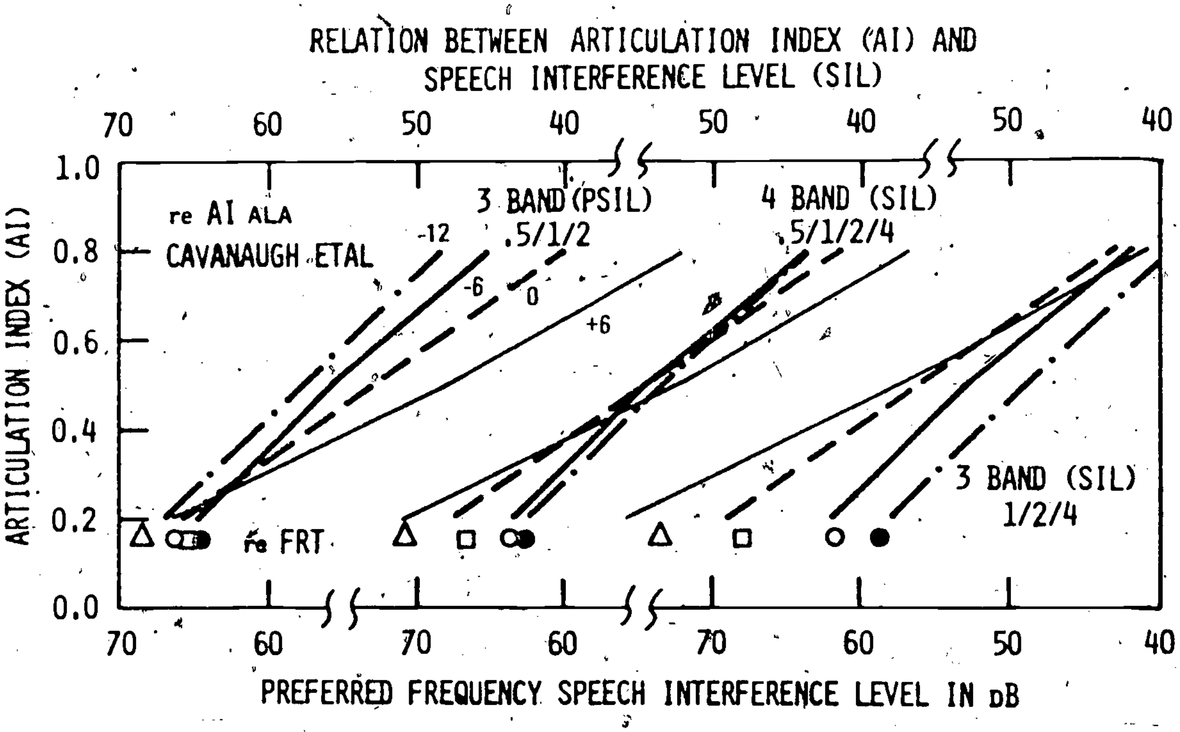

Figure 6. Relation between Articulation Index (AI) and Speech Interference Level (SIL) for 4 noises with spectrum level slopes of -12, -6, flat, and +6 dB/octave. Three different sets of octaves are shown for calculating SIL; from left to right: 500, 1000, and 2000 Hz (.5/1/2); 500, 1000, 2000, and 4000 Hz (.5/1/2/4); and 1000, 2000, and 4000 Hz (1/2/4). The overall level of each noise is adjusted to obtain AI levels of 0.2, 0.5, and 0.8, and then the SIL is calculated for each of 3 sets of octaves. The data points at an AI of 0.18 are actual experimental points (50% Fairbanks Rhyme Scores) from Klumpp and Webster (1963), i.e., these are the SILs for noises No. 1, 4, 10, and 15 in their study.

Hz—average—or 709 to 2530—overall. For the average measure (SIL-type) the center frequencies and bandwidths were 1135 Hz (3.33 octaves) for an AI of 0.2, 1421 Hz (433 octaves) at 0.5 AI, and 1797 Hz (3.33 octaves) for 0.8. These values compare very well indeed to those proposed in this paper of 1000, averaged over the three octaves 500, 1000, and 2000 Hz; 1428, averaged over the four octaves 500, 1000, 2000, and 40000 Hz; and 2000, averaged over the three octaves 1000, 2000, and 4000 Hz. Cluff also found the SIL-type measure gave standard diviations varying from 0.3 to 0.9 (ave.-0.54) while the standard deviation of the A-weighted levels varied from 1.6 to 3.8 with an average of 2.20.*

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*Cluff, G. L. (1969), "A comparison of selected methods of determining speech interference calculated by the Articulation Index," J. Auditory Res. 9, 81-88.

The previous analysis has shown that the octaves chosen to calculate an SIL vary according to what AI the SIL is trying to estimate. Webster (1964a, 1964b) constructed a set of contours (see Figure 7) for predicting AIs or SILs that also showed the increasing importance of the high speed frequencies for increasing levels of intelligibility (and AI). It is suggested that weighting networks for sound level meters could be built to predict AI levels of 0.2 (SI = 70 dB); 0.5 (SI = 60 dB); and 0.8 (SI = 50 dB). A good set of noises on which to test these hypotheses are the 16 noises of Klumpp and Webster (1963).

Calculations made on Klumpp and Webster's 16 noises equated in level at AIs of 0.2, 0.5, and 0.8, comparing 4 sound level weighting networks A, SI-70, SI-60, and SI-50, and 3 ways of calculating SIL, namely using the 3 octaves 500/1000/2000, the 4 octaves from 500 to 4000 and the 3 octaves from 1000 to 4000 are shown in Table 2. The results generally confirm everything that has just been stated, namely, that at a level of intelligibility corresponding to (1) 0.2, the SI-70 and the 500 to 2000 SIL are the best (lowest σ and R) (2) 0.5 and 0.8, the SI-60 and the 500 to 4000 SIL are the best, and (3) 0.8, the SI-50 and the 1000 to 4000 SIL are good. A-weighting appears slightly inferior to the proposed SI-60 and any SIL that included 500 Hz.

If the manufacturers of sound level meters are seriously considering weighting networks other than A, B, and C, an SI-60 should be considered. It is appreciably better than A for predicting speech intelligibility at all AI levels.

I have shown how the choice of frequencies for SILs or weighting networks is dependent on the level of intelligibility to be specified. Now we get back to intelligibility testing. What tests should be used for various levels of AI?

Efficiency factors in test design dictate that the functional relationship between the dependent and independent variable should be steep and linear in the critical testing region. Therefore, consideration should be given to using different language tests for different communication effectiveness areas. For example, for marginal conditions, AI = 0.2, closed set rhyme words (Fairbanks, 1958; House et al., 1965; Kreul et al., 1968; Griffiths, 1967; Clarke, 1965), which yield scores of about 50%, would make very efficient tests. If a listening situation—room or communications equipment—required adequate intelligibility, i.e., an AI of 0.35, then open-set, 1000-word PB tests would yield scores close to 50% and therefore be efficient in test design, although inefficient in terms of crew training, test scoring, etc. The use of closed response-set rhyme words would be on the border line of acceptability since the expected scores would be around 75%.

At AI levels around 0.8, no intelligibility test is inherently difficult enough to be an efficient test. Even 1,000 nonsense syllables have an intelligibility of greater than 90% at AI levels of 0.8. To discriminate between listening conditions—communication systems, components, etc.—at AI levels of 0.8 requires something more than a simple intelligibility test. Reaction times, quality judgments, scores on secondary tests, or interference tasks, such as competing messages, have been used or suggested. We will have time to discuss only one of these promising approaches, namely the competing message paradigm. Tillman, Carhart, and Olsen (1970) show the decrement in performance on a competing message task due merely to adding the equivalent of a hearing aid between the sound field and the listener's ears. The listener's task was to recognize in turn one of 50 phonetically balanced (PB) words from a loudspeaker in one corner of a room while competing sentences at levels 6 or 18 dB down were coming from a loudspeaker in the other corner ahead of the listener, i.e., the 2

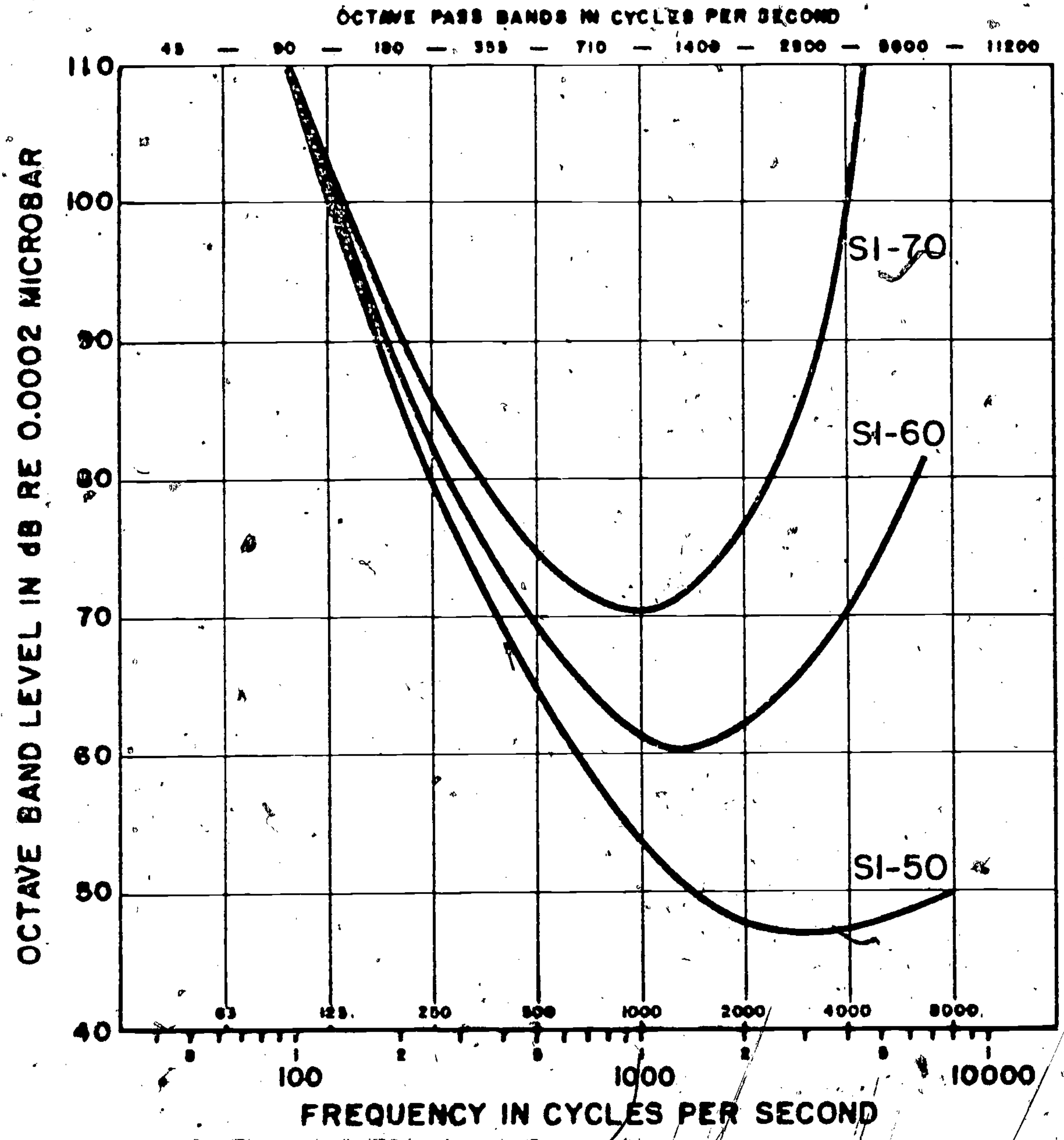

Figure 7. Noise rating contours for estimating SILs based on different averaging octaves. Use SI-70 for estimating the .5/1/2 SIL, = AI of 0.2; the SI-60 for the .5/1/2/4 SIL, = AI of 0.5; and the SI-50 for the 1/2/4 SIL, = AI of 0.8. The inverse of these contours could be used as frequency weighting networks in sound level meters to measure the speech interfering aspects of noises. The SI-60 is the best compromise contour.

Table 2

Cells on the diagonal show the Mean (M), Standard Deviation (σ), and Range (R) for the designated parameters for AI levels of (from left to right) 0.2, 0.5, and 0.8. Cells above the diagonal show the physical statistics for the 16 Klumpp and Webster (1963) noises (AI is not a factor). The numbers in the cells (above the diagonal) represent the M, σ, and R of the difference distribution between the parameters listed at the left and across the top.

		Weighting Networks				SILs			
		A-Wtng.	SI-70	SI-60	SI-50	3L .5/1/2	4 .5/1/2/4	3H 1/2/4	
Weighting	A-Wtng	83.1 72.3 62.6	5.6	6.6	3.2	9.8	10.6	11.6	M
		3.7 2.8 3.2	2.6	2.1	4.4	3.3	3.2	4.8	σ
		11.3 8.3 9.7	10.0	10.0	14.7	9.3	11.5	16.4	R
	SI-70		77.4 66.6 56.9	1.0	2.4	4.2	5.0	6.0	M
			2.4 3.1 4.0	2.8	5.8	1.9	3.5	5.8	σ
			9.0 9.0 11.5	9.5	18.9	8.2	12.7	19.7	R
	SI-60			76.5 65.7 55.8	3.3	3.2	4.1	5.0	M
				3.0 1.6 2.3	3.2	1.9	1.5	3.2	σ
				11.0 7.6 10.6	9.7	6.8	6.2	11.5	R
	SI-50				79.7 68.9 59.2	6.6	7.4	8.3	M
					5.6 3.1 2.6	4.6	2.7	0.9	σ
					16.5 9.8 7.8	14.6	8.2	5.2	R
SILs	3L .5/1/2					73.0 62.3 52.5	0.8	1.8	M
						1.5 1.6 2.7	1.7	4.2	σ
						6.3 6.4 10.4	6.9	13.0	R
	4 .5/1/2/4						72.2 61.9 51.6	1.0	M
							3.0 0.7 1.4	2.2	σ
							9.4 4.5 6.6	8.1	R
	3H 1/2/4							71.2 60.4 50.6	M
								5.4 3.2 2.7	σ
								17.4 10.9 9.4	R

loudspeakers were 45° to the left and to the right of the listener's nose. Unaided listening was (1) binaural; (2) monaural direct, in which the speech was on the side of the listening ear, and the other ear was occluded with a muff; and monaural indirect, in which the speech was on the side of the occluded ear. Aided listening used an artificial head in the sound field with two hearing aids and connections via amplifiers and calibrated attenuators to insert earphones in the ears of the remote listener. Again three conditions were tested—binaural, monaural direct, and monaural indirect.

Four groups of 12 subjects each were tested including (1) those classified audiologically as normal (average age 22); (2) with moderate hearing losses diagnosed as conductive (average age 42); (3) sensorineural (average age 51); and (4) presbyacusic (average age 70). The groups will be indicated by N, C, S and P, respectively.

All listening was at a level 30 dB above the threshold for spondee words, 30 dB Sensation Level (SL), under each of the 6 conditions. Figure 8 shows the results, which can be summarized as follows: Compared to an earlier reference group of 20 normal hearing subjects, on the PB word/sentence competition task (Northwestern University Auditory Test 2, Carhart et al., 1963) the N and C groups sitting in the sound field (unaided) heard essentially at reference level; the S and P groups required, on average, a 14 dB better word-to-sentence differential than the N and C groups in the sound field; the N group required about the same increase in word-to-sentence differential when a hearing aid was interposed between them and the sound field; the C group required an even greater increase for the aided conditions, about 18 dB more; and the S and P groups, who required a 14 dB word-to-sentence (W/S) improvement in the unaided case, required further improvements which increased as the basic word-to-sentence (W/S) differential increased. Restated, the S and P groups are worse off than the N and C groups in listening to competing speech signals 30 dB above their speech threshold, whether listening with or without hearing aids.

These results show both a hearing deficiency penalty and an equipment-imposed penalty when listeners are placed in competing message listening conditions. This is bad news for people incurring noise-induced hearing losses which are generally sensorineural in nature. No only do they have more difficulty than their normal-hearing or conductively-deafened friends in cocktail party environments, but they cannot look forward to a hearing aid to help equalize their relative disadvantage.

The last point I want to make concerns listening to speech in noise while wearing earplugs or muffs. It has long been established that in noise levels greater than 90 dB, speech is heard better when wearing hearing protection. This early work of Kryter (1946) was for young normal hearing subjects. However, there is at least one study by Fröhlich (1970) which shows that unlike young normal hearing males, senior aviators with high-frequency sensorineural losses do not discriminate digits better in noise levels above 100 dB when wearing good noise-attenuating ear muffs. He shows that this could be expected by plotting hearing-level and hearing-level-under-muff for senior aviators on the speech area and noise masking area. This procedure shows that the muff cuts out a region of speech frequencies where the speech is well above the masking noise. It seems safe to say that acoustic-trauma listeners have more difficulty than normals in discriminating speech in quiet, in noise, and particularly in competing message situations. They do not get the full benefit enjoyed by normal listeners of increased intelligibility in high noises by wearing hearing protectors, and they cannot expect a hearing aid to help them untangle competing messages.

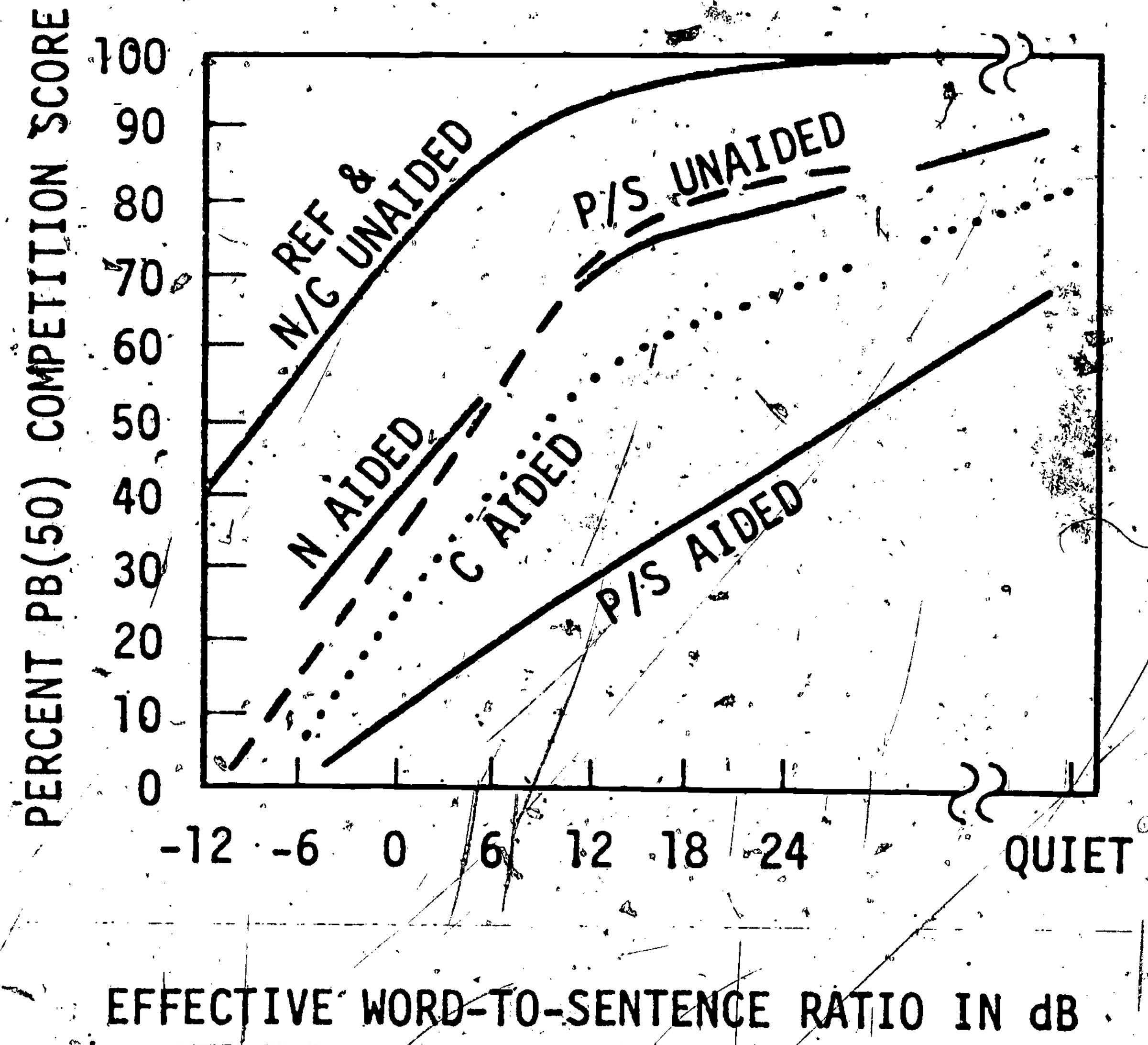

Figure 8. Percentage of 50PB words correct in the presence of competing sentences at various word-to-sentence differentials. The parameters are: REF=20 reference normal hearing listeners; N/C = normal or conductive pathology experimental listeners; P/S = presbyacusic or sensorineural pathology experimental listeners. Aided refers to listening via hearing-aid circuitry. Unaided refers to listening normally in a sound treated room. From Tillman, Carhart, and Olsen (1970).

In summary, I have tried to tell you in this presentation that the octaves chosen to calculate the SIL and/or the weighting networks that could be built into a sound level meter to measure the interference of noise with speech vary as a function of what level of speech communication you desire to design for. Correspondingly, the tests you use to evaluate a listener or a system vary in the same manner, sentence intelligibility tests being best for a basically bad system, word or nonsense syllable tests for a good system, and competing message tests or judgment tests for an excellent system. Persons with noise-induced hearing loss cannot hear as well as normals when wearing plugs or muffs in moderate to high levels of noise nor can they by wearing a hearing aid unscramble competing messages (at a cocktail party) as well as normals.

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