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PREDICTION OF NIPTS DUE TO CONTINUOUS NOISE EXPOSURE

DANIEL L. JOHNSON, MAJOR, USAF

AEROSPACE MEDICAL RESEARCH LABORATORY

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Aerospace Medical Research Laboratory

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AEROSPACE MEDICAL RESEARCH LABORATORY
AEROSPACE MEDICAL DIVISION
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WRIGHT-PATTERSON AIR FORCE BASE, OHIO

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This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER

HENNING E. von GIERKE, Dr. Ing.
Director, Biodynamics and Bionics Division
Aerospace Medical Research Laboratory

ALVIN F. MEYER, JR.
Deputy Assistant Administrator
for Noise Control Program
United States Environmental
Protection Agency

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13. ABSTRACT

In support of the main document, "A Basis for Limiting Noise Exposure for Hearing Conservation," this report compares the relationship of noise exposure to Noise Induced Permanent Threshold Shift (NIPTS) as predicted by the currently available works of Passchier-Vermeer, Robinson, Baughn and Kryter, and the yet unpublished work of the National Institute of Occupational Safety and Health. The works of Passchier-Vermeer, Robinson, and Baughn are selected since these are the only works that completely predict the relationship between NIPTS and noise exposure for various audiometric frequencies, sound pressure levels and population percentiles. The predictions of these three methodologies are averaged in order to provide one single relationship between continuous noise exposure and NIPTS. This relationship is presented in various ways so that the effect of noise exposure on hearing can be viewed in more than one way. Discussion concerning the type of frequency weighting, the equal energy rule, and long duration exposures is also provided.

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PREFACE

The Biodynamics and Bionics Division of the Aerospace Medical Research Laboratory was given the responsibility under an Interagency Agreement with the Environmental Protection Agency, to develop a document which would serve as a basis for limiting noise for purposes of hearing conservation. The preparation of this document was accomplished by the University of Dayton Research Institute (UDRI) under Contract F33615-72-C-1402. The Aerospace Medical Research Laboratory efforts in support of this project were included under Project 7231-03-16, "Auditory Responses to Acoustical Energy Experienced in Air Force Activities."

In order to resolve certain issues that developed during preparation of the primary document, the material of this supporting document was developed. This document does not cover all facets of the relations between hearing and noise exposure, and should be used only in conjunction with the primary document "A Basis for Limiting Noise Exposure for Hearing Conservation" (AMRL-TR-73-90) (EPA-550/9-73-001-A).

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PREDICTION OF NIPTS DUE TO CONTINUOUS NOISE EXPOSURE

I. INTRODUCTION

This report was written to support certain parts of the criteria document, "A Basis for Limiting Noise Exposure for Hearing Conservation". Specifically, several different predictive methods are presented that estimate the effects of noise on hearing. The predictive results will then be manipulated until they are reduced to a format that allows a basis for administratively proposing a specific noise limit.

This report relies on the main document (AMRL-TR-73-90) for definition of terms, arguments concerning impulsive noise, relationships between Temporary Threshold Shifts (TTS) and Noise Induced Permanent Threshold Shift (NIPTS), etc.

Method of Attack. With respect to NIPTS, the duration, spectrum and intensity of the noise exposure, the sensitivity of the individual, and the lifetime noise exposure history of the individual are all important parameters. With this many parameters, it is predictable that there are varied opinions as to how NIPTS will develop in a group of people exposed to noise. If one adds to the problem various interpretations of what constitutes a significant hearing loss, then it is not surprising that a resulting jumble of noise limiting criteria will develop. The intent of this supplement is not to be interpret what constitutes a significant hearing loss until such interpretations are required in order to suggest a recommended limit. Therefore, major emphasis will be placed on the relationship of NIPTS to noise for various population percentiles.

II. RELATION OF NOISE TO HEARING LOSS

A. Relation of Noise to Hearing Loss for Constant SPL for 8 Hour Working Day

1. Exposure Situation of Data Base. This situation is the basis of much of the human data with respect to actual hearing loss. Therefore it is this situation that by necessity anchors any criterion which will relate hearing loss to noise. Once this point is selected, exposure duration is then handled such that shorter or longer exposures are expected to be as noxious as the 8 hour exposure. The 8 hour permissible exposure point, therefore, must be set with great care. Since this is the heart of the report, a considerable amount of detail will be presented that will hopefully allow selection of permissible noise exposure for an 8 hour day.

2. Selection of Data Base. Various researchers have made an attempt to develop a predictive relationship between noise exposure in the 8 hour working day and the resulting hearing losses. The relationships were investigated and either accepted or rejected based on whether or not they (a) allowed calculation of NIPTS at various percentile points and (b) considered at least speech frequencies (.5, 1 and 2 kHz) and the audiometric frequency of 4 kHz. The methods of Passchier-Vermeer, Robinson and Baughn satisfy these restrictions.

Passchier-Vermeer's method is attractive in that it correlates the data of many different reports. Inclusion of her method thus provides a rather broad data base (see Table 1 for a summary of her sources). A weakness of her method is that for much of her data base only the 25, median, and 75 percentile levels of the population were provided.

Robinson's method provides one mathematical relationship (the hyperbolic tangent) which is adjusted for the audiometric frequencies considered and the percentile levels used. The method's strength is that it allows calculation of predicted NIPTS for a wide variety of conditions. A criticism of the method might be that it uses only one careful study of an otologically screened population of British subjects. Such a population may not be typical of average US population. It is also difficult to visualize how the hyperbolic tangent could be a best approximation to NIPTS for all frequencies and conditions. Nevertheless, Robinson's methodology is well conceived and provides an additional data base.

Baughn's data provides superior insight into how NIPTS develops at various percentile points, not just the median. It has also been used as the basis for the ISO standard. Its weakness, as typical with many industrial studies, is that some residual TTS will have been measured since an occasion only 20 minutes recovery was allowed before audiometric testing was performed. Lack of recovery would tend to make the predicted NIPTS too high. A second problem is that the control (or non-noise exposed group) must be considered to have been exposed to 78 dBA or less. Therefore from Baughn's data alone, it would be impossible to show that the 78 dBA exposure was not in itself causing a significant NIPTS.

In summary, all three methods have both strengths and weaknesses and it would be hard to say which of the three methods (Robinson's, Passchier-Vermeer's or Baughn) gives the best estimates of the true situation. Therefore, the predicted NIPTS values were tabulated for each method and compared. The results, as seen in Table 2, speak for themselves. In general, there are not large (greater than 10 dB) differences between the three methods. Most differences are less than 5 dB. For this reason, all three methods were used to derive predicted values of NIPTS. The final prediction is the average of the NIPTS of each method; and, as a consequence, should give a final result that is not unduly influenced by the weakness of any single method.

TABLE 1

Work Included In Passchier-Vermeer's (1968) Analysis

W. Burns, R. Hinchcliffe, T. S. Littler,
An exploratory study of hearing loss and noise exposure in textile workers.
The Ann. of Occ. Hyg. 7 (1964) 323-333.

R. Gallo, A. Glorig,
P. T. S. changes produced by noise exposure and aging
Am. Ind. Hyg. Ass. Journal 25 (1964) 237-245.

The relations of hearing loss to noise exposure
A Report by subcommittee Z 24-x-2 (1954) 34.

N. E. Rosenwinkel, U. C. Stewart,
The relationship of Hearing Loss to Steady-State Noise Exposure
Am. Ind. Hyg. Ass. Quart. 18, (1957) 227-230.

J. Nixon, A. Glorig,
Noise Induced P. T. S. at 2000 and 4000 Hz.
J. A. S. A. 33 (1961) 904-913.

W. Taylor, J. Pearson, A. Mair, W. Burns,
Study on noise and hearing in Jute weaving
J. A. S. A. 37 (1964) 113-120.

B. Kylin,
T. T. S. and auditory trauma following exposure to steady-state noise
Acta Oto-Laryng. Suppl. 152 (1960).

F. v. Laar,
Results of audiometric research at some hundreds of persons, working in different Dutch factories
Publication: A. G. /S. A. C 23 of N. I. P. G. - TNO.

A. Spoor,
Presbyacusis values in relation to noise-induced hearing loss
Int. Aud. 6 (1967) 48-57.

C. W. Kosten and G. J. van Os,
Community reaction criteria for external noises
The Control of Noise, NPL-Symposion no. 12, P. 373-382, HMSO 1962.

TABLE 2a

Predicted NIPTS for 75 dBA

		10 Year			20 Year			40 Year		
		Passchier-Vermeer	Robinson	Baughn	Passchier-Vermeer	Robinson	Baughn	Passchier-Vermeer	Robinson	Baughn
Speech 1/3(.5, 1, 2kHz)	90	0.0	.8	-	0.0	1.1	-	0.0	1.6	-
	75	0.0	.5	-	0.0	.7	-	0.0	1.0	-
	50	0.0	.3	-	0.0	.4	-	0.0	.6	-
	25	0.0	.2	-	0.0	.3	-	0.0	.4	-
	10	0.0	.1	-	0.0	.1	-	0.0	.2	-
Speech 1/4(.5, 1, 2, 4kHz)	90	2.5	1.5	-	2.5	2.1	-	2.5	3.0	-
	75	1.5	.9	-	1.5	1.4	-	1.5	2.0	-
	50	.5	.6	-	.5	.8	-	.5	1.2	-
	25	0.0	.3	-	0.0	.5	-	0.0	.8	-
	10	0.0	.2	-	0.0	.2	-	0.0	.4	-
2K	90	0.0	1.6	-	0.0	2.0	-	0.0	3.0	-
	75	0.0	1.0	-	0.0	1.3	-	0.0	1.9	-
	50	0.0	.6	-	0.0	.8	-	0.0	1.1	-
	25	0.0	.4	-	0.0	.5	-	0.0	.7	-
	10	0.0	.3	-	0.0	.3	-	0.0	.5	-
4K	90	10.0	3.6	-	10.0	5.2	-	10.0	7.5	-
	75	6.0	2.3	-	6.0	3.4	-	6.0	4.9	-
	50	2.0	1.4	-	2.0	2.0	-	2.0	3.0	-
	25	0.0	.8	-	0.0	1.2	-	0.0	1.8	-
	10	0.0	.5	-	0.0	.7	-	0.0	1.1	-
6K	90	2.0	2.5	-	2.0	3.6	-	2.0	5.2	-
	75	2.0	1.6	-	2.0	2.3	-	2.0	3.4	-
	50	2.0	.9	-	2.0	1.4	-	2.0	2.0	-
	25	1.0	.5	-	1.0	.8	-	1.0	1.2	-
	10	0.0	.3	-	0.0	.5	-	0.0	.7	-
8K	90	0.0	-	-	0.0	-	-	0.0	-	-
	75	0.0	-	-	0.0	-	-	0.0	-	-
	50	0.0	-	-	0.0	-	-	0.0	-	-
	25	0.0	-	-	0.0	-	-	0.0	-	-
	10	0.0	-	-	0.0	-	-	0.0	-	-

TABLE 2b

Predicted NIPTS for 80 dBA

		10 Year			20 Year			40 Year		
		Passchier-Vermeer	Robinson	Baughn	Passchier-Vermeer	Robinson	Baughn	Passchier-Vermeer	Robinson	Baughn
Speech 1/3(.5, 1, 2kHz)	90	0.0	1.5	0.0	0.0	2.2	0.0	0.0	3.2	0.0
	75	0.0	.9	0.0	0.0	1.4	0.0	0.0	2.1	0.0
	50	0.0	.6	0.0	0.0	.8	0.0	0.0	1.2	0.0
	25	0.0	.3	0.0	0.0	.5	0.0	0.0	.7	0.0
	10	0.0	.2	0.0	0.0	.3	0.0	0.0	.4	0.0
Speech 1/4(.5, 1, 2, 4kHz)	90	3.5	2.7	1.3	3.5	4.0	1.0	3.5	5.6	.8
	75	2.5	1.7	1.0	2.5	2.6	1.0	2.5	3.7	.7
	50	1.5	1.1	.8	1.5	1.6	.9	1.5	2.3	.5
	25	.2	.6	.6	.2	.9	.8	.2	1.4	.4
	10	0.0	.4	.4	0.0	.6	.7	0.0	1.0	.3
2K	90	0.0	2.6	-	0.0	3.8	-	0.0	5.5	-
	75	0.0	1.6	-	0.0	2.4	-	0.0	3.6	-
	50	0.0	1.0	-	0.0	1.5	-	0.0	2.2	-
	25	0.0	.6	-	0.0	.9	-	0.0	1.3	-
	10	0.0	.4	-	0.0	.5	-	0.0	.8	-
4K	90	13.8	6.6	5.3	13.8	9.3	4.1	13.8	12.9	.9
	75	9.9	4.3	3.9	9.9	6.2	3.9	9.4	8.7	1.5
	50	6.0	2.6	3.1	6.0	3.8	3.7	5.5	5.5	2.2
	25	1.0	1.6	2.3	1.0	2.3	3.1	.5	3.4	2.8
	10	0.0	1.0	1.5	0.0	1.4	2.5	0.0	2.1	3.1
6K	90	3.8	4.6	-	3.8	6.6	-	3.8	9.3	-
	75	3.6	2.9	-	3.6	4.3	-	3.6	6.2	-
	50	3.4	1.8	-	3.4	2.6	-	3.4	3.8	-
	25	2.1	1.1	-	2.1	1.6	-	2.1	2.3	-
	10	.8	.7	-	.8	1.0	-	.8	1.4	-
8K	90	.6	-	-	.6	-	-	.6	-	-
	75	.4	-	-	.4	-	-	.4	-	-
	50	.2	-	-	.2	-	-	.2	-	-
	25	.2	-	-	.2	-	-	.2	-	-
	10	.2	-	-	.2	-	-	.2	-	-

TABLE 2c

Predicted NIPTS for 85 dBA

		10 Year			20 Year			40 Year		
		Passchier-Vermeer	Robinson	Baughn	Passchier-Vermeer	Robinson	Baughn	Passchier-Vermeer	Robinson	Baughn
Speech 1/3(.5, 1, 2kHz)	90	.9	2.8	2.5	1.0	4.1	3.3	1.1	5.8	3.9
	75	.5	1.8	1.8	.6	2.6	2.3	.7	3.8	2.7
	50	.1	1.1	1.2	.2	1.6	1.5	.3	2.3	1.9
	25	.1	.6	.9	.2	.9	1.3	.3	1.4	1.5
	10	0.0	.4	.8	.1	.6	1.0	.2	.8	1.2
Speech 1/4(.5, 1, 2, 4kHz)	90	5.2	5.0	6.5	5.1	7.0	6.1	5.2	9.5	3.7
	75	4.0	3.3	4.7	4.0	4.7	5.1	4.1	6.5	3.3
	50	2.8	2.0	3.6	2.9	2.9	4.4	3.0	4.2	3.3
	25	1.5	1.2	2.7	1.6	1.8	3.7	1.7	2.6	3.5
	10	.2	.8	1.9	.3	1.1	2.9	.4	1.6	3.6
2K	90	2.7	4.9	-	3.0	7.0	-	3.4	9.9	-
	75	1.5	3.1	-	1.8	4.6	-	2.2	6.6	-
	50	.3	1.9	-	.6	2.8	-	1.0	4.0	-
	25	.2	1.1	-	.5	1.7	-	.9	2.4	-
	10	.1	.7	-	.4	1.0	-	.8	1.5	-
4K	90	17.8	11.6	18.6	17.8	15.7	14.5	17.8	20.5	3.2
	75	14.4	7.8	13.5	14.4	10.9	13.7	14.4	14.8	5.3
	50	11.0	4.9	10.8	11.0	6.9	13.1	11.0	9.8	7.6
	25	6.0	2.9	8.0	6.0	4.3	10.8	6.0	6.2	9.7
	10	1.0	1.9	5.2	1.0	2.7	8.7	1.0	4.0	10.7
6K	90	10.5	8.4	-	10.5	11.6	-	10.2	15.7	-
	75	9.2	5.5	-	9.2	7.8	-	8.9	10.9	-
	50	7.9	3.4	-	7.9	4.9	-	7.6	6.9	-
	25	4.1	2.0	-	4.1	2.9	-	3.8	4.3	-
	10	.3	1.3	-	.3	1.9	-	0.0	2.7	-
8K	90	3.9	-	-	3.9	-	-	3.9	-	-
	75	2.7	-	-	2.7	-	-	2.5	-	-
	50	1.5	-	-	1.5	-	-	1.3	-	-
	25	1.5	-	-	1.5	-	-	1.3	-	-
	10	1.5	-	-	1.5	-	-	1.3	-	-

TABLE 2d

Predicted NIPTS for 90 dBA

		10 Year			20 Year			40 Year		
		Passchier-Vermeer	Robinson	Baughn	Passchier-Vermeer	Robinson	Baughn	Passchier-Vermeer	Robinson	Baughn
Speech 1/3(.5, 1, 2kHz)	90	2.4	4.2	5.5	3.2	5.1	6.9	4.5	8.6	7.3
	75	1.6	2.4	3.8	2.4	3.1	4.9	3.8	5.4	5.5
	50	.8	1.5	2.6	1.6	2.0	3.3	3.1	3.5	3.2
	25	.6	1.0	2.0	1.4	1.1	2.6	2.8	2.1	3.0
	10	.5	.8	1.8	1.2	.8	2.2	2.5	1.4	2.5
Speech 1/4(.5, 1, 2, 4kHz)	90	7.3	7.8	11.6	8.3	9.8	9.8	9.5	13.8	6.6
	75	6.4	5.1	8.5	7.0	6.0	8.5	8.2	9.8	6.1
	50	5.1	3.3	6.3	5.7	4.5	7.1	6.9	6.7	5.4
	25	3.7	2.1	4.4	4.3	2.8	5.7	5.5	4.3	5.9
	10	2.3	1.5	3.3	2.9	1.9	4.7	4.1	2.7	6.2
2K	90	6.8	8.8	-	9.2	12.2	-	13.4	16.4	-
	75	4.6	5.8	-	7.0	8.3	-	11.2	11.5	-
	50	2.4	3.6	-	4.8	5.2	-	9.0	7.4	-
	25	1.6	2.1	-	4.0	3.1	-	8.2	4.6	-
	10	.8	1.4	-	3.2	2.0	-	7.4	2.9	-
4K	90	23.6	18.8	30.1	23.6	24.0	18.7	23.6	29.5	4.6
	75	20.8	13.4	22.7	20.8	17.8	19.2	21.3	22.9	7.8
	50	18.0	8.7	17.4	18.0	12.1	18.6	18.5	16.3	10.4
	25	13.2	5.5	11.5	13.2	7.8	14.9	13.7	10.9	14.8
	10	8.4	3.5	7.7	8.4	5.1	12.4	8.4	7.3	17.4
6K	90	18.3	14.2	-	18.3	18.8	-	18.3	24.0	-
	75	15.6	9.8	-	15.6	13.4	-	15.6	17.8	-
	50	12.9	6.2	-	12.9	8.7	-	12.9	12.0	-
	25	6.7	3.8	-	6.7	5.5	-	6.7	7.8	-
	10	.5	2.4	-	.5	3.5	-	.5	5.1	-
8K	90	8.9	-	-	8.9	-	-	8.9	-	-
	75	6.7	-	-	6.7	-	-	6.5	-	-
	50	4.5	-	-	4.5	-	-	4.5	-	-
	25	4.5	-	-	4.5	-	-	4.5	-	-
	10	4.5	-	-	4.5	-	-	4.5	-	-

TABLE 2e

Predicted NIPTS for 95 dBA

		10 Year			20 Year			40 Year		
		Passchier-Vermeer	Robinson	Baughn	Passchier-Vermeer	Robinson	Baughn	Passchier-Vermeer	Robinson	Baughn
Speech 1/3(.5, 1, 2kHz)	90	5.6	8.1	9.7	7.9	12.6	11.7	11.6	15.1	12.9
	75	4.5	5.1	6.8	6.8	8.4	8.2	10.5	10.2	9.1
	50	3.4	3.3	4.6	5.7	5.6	5.5	9.4	6.9	6.1
	25	2.3	2.1	3.7	4.6	3.5	4.5	8.2	4.6	5.0
	10	1.2	1.4	3.0	3.5	2.3	3.7	7.0	3.0	4.1
Speech 1/4(.5, 1, 2, 4kHz)	90	12.1	13.0	17.6	13.7	17.7	14.1	15.3	10.6	11.1
	75	10.8	9.1	13.0	12.5	12.9	12.0	13.6	14.3	9.3
	50	9.5	6.2	9.4	11.3	9.1	9.9	11.9	10.0	7.7
	25	7.8	4.0	6.3	9.6	6.0	7.9	9.2	6.8	8.6
	10	6.1	2.7	4.7	7.9	3.7	6.6	7.5	4.4	9.0
2K	90	12.4	14.9	-	18.2	19.6	-	27.6	24.9	-
	75	9.1	10.3	-	14.9	14.1	-	24.3	18.6	-
	50	5.8	6.6	-	11.6	9.2	-	21.0	12.7	-
	25	2.6	4.0	-	8.4	5.8	-	17.8	8.3	-
	10	0.0	2.6	-	4.2	3.8	-	13.6	5.4	-
4K	90	31.4	27.7	41.2	31.4	33.1	21.3	31.4	38.1	5.8
	75	29.7	21.2	31.7	29.7	26.6	23.6	29.7	32.0	9.8
	50	28.0	14.8	23.7	28.0	19.5	23.1	28.0	24.7	12.7
	25	24.5	9.8	14.1	24.5	13.4	18.1	24.5	17.8	19.4
	10	21.0	6.5	9.8	21.0	9.1	15.5	21.0	12.6	23.9
6K	90	25.7	22.2	-	25.7	27.7	-	25.7	33.1	-
	75	22.1	16.3	-	22.1	21.2	-	23.1	27.6	-
	50	18.5	10.9	-	18.5	14.8	-	19.5	19.5	-
	25	11.4	6.9	-	11.4	9.8	-	12.4	13.4	-
	10	4.3	4.5	-	4.3	6.5	-	4.3	9.1	-
8K	90	15.1	-	-	15.1	-	-	15.5	-	-
	75	12.1	-	-	12.1	-	-	12.5	-	-
	50	9.1	-	-	9.1	-	-	9.5	-	-
	25	9.1	-	-	9.1	-	-	9.5	-	-
	10	9.1	-	-	9.1	-	-	9.5	-	-

TABLE 2f

Predicted NIPTS for 90 dBA

		10 Year			20 Year			40 Year		
		Passchier-Vermeer	Robinson	NIOSH Data 12 Year	Passchier-Vermeer	Robinson	NIOSH Data 20 Year	Passchier-Vermeer	Robinson	NIOSH Data 34 Year
Speech 1/3(.5, 1, 2kHz)	90	2.4	4.2	1.0	3.2	5.1	10.6	4.5	8.6	13.3
	75	1.6	2.4	4.3	2.4	3.1	8.0	3.8	5.4	13.0
	50	.8	1.5	4.3	1.6	2.0	5.0	3.1	3.5	6.3
	25	.6	1.0	3.3	1.4	1.1	2.0	2.8	2.1	2.6
	10	.5	.8	1.3	1.2	.8	1.0	2.5	1.4	1.3
Speech 1/4(.5, 1, 2, 4kHz)	90	7.3	7.8	-	8.3	9.8	-	9.5	13.8	-
	75	6.4	5.1	-	7.0	6.0	-	8.2	9.8	-
	50	5.1	3.3	-	5.7	4.5	-	6.9	6.7	-
	25	3.7	2.1	-	4.3	2.8	-	5.5	4.3	-
	10	2.3	1.5	-	2.9	1.9	-	4.1	2.7	-
2K	90	6.8	8.8	-1.0	9.2	12.2	14.0	13.4	16.4	20.0
	75	4.6	5.8	4.0	7.0	8.3	16.0	11.2	11.5	27.0
	50	2.4	3.6	4.0	4.8	5.2	9.0	9.0	7.4	12.0
	25	1.6	2.1	3.0	4.0	3.1	5.0	8.2	4.6	4.0
	10	.8	1.4	0	3.2	2.0	2.0	7.4	2.9	5.0
4K	90	23.6	18.8	5.0	23.6	24.0	26.0	23.6	29.5	-10.0
	75	20.8	13.4	11.0	20.8	17.8	24.0	21.3	22.9	14.0
	50	18.0	8.7	9.0	18.0	12.1	20.0	18.5	16.3	20.0
	25	13.2	5.5	3.0	13.2	7.8	15.0	13.7	10.9	7.0
	10	8.4	3.5	1.0	8.4	5.1	13.0	8.4	7.3	5.0
6K	90	18.3	14.2	-8.0	18.3	18.8	10.0	18.3	24.0	-3.0
	75	15.6	9.8	2.0	15.6	13.4	19.0	15.6	17.8	12.0
	50	12.9	6.2	3.0	12.9	8.7	18.0	12.9	12.0	22.0
	25	6.7	3.8	4.0	6.7	5.5	12.0	6.7	7.8	9.0
	10	.5	2.4	7.0	.5	3.5	6.0	.5	5.1	10.0
8K	90	8.9	-	-	8.9	-	-	8.9	-	-
	75	6.7	-	-	6.7	-	-	6.5	-	-
	50	4.5	-	-	4.5	-	-	4.5	-	-
	25	4.5	-	-	4.5	-	-	4.5	-	-
	10	4.5	-	-	4.5	-	-	4.5	-	-

3. Other Methods. The National Institute of Occupational Health and Safety (NIOSH) also presented data which have not been smoothed. Table 2f has some of these same data incorporated for comparison. This data base was not used because (1) it only predicts NIPTS for 90 dBA, (2) the sample size was very small (22 workers for some of the age groups), and (3) some type of smoothing of the data would be required in order to make it a predictive method. The data is presented in Table 2f in order to show (1) that raw data requires treatment (such as provided by Robinson, Passchier-Vermeer or Baughn) before it is useful, and (2) the NIOSH data is not out of line with the predictive methods used in this report. There is, however, one method in the literature which differs greatly with other methodologies. This is Kryter's latest work published in the Journal of the Acoustical Society of America, 1973.

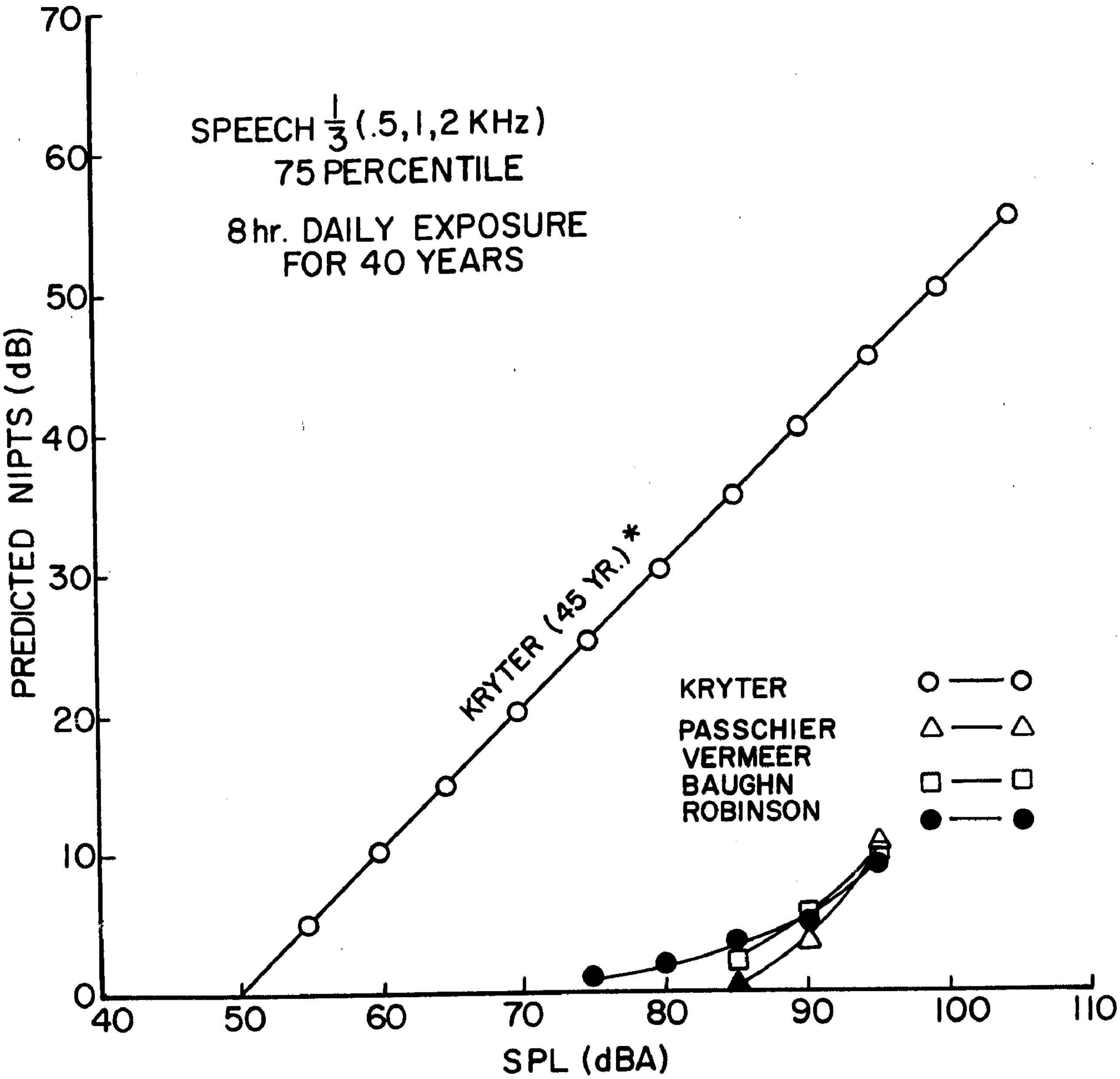
Figure 1 shows a plot of predicted NIPTS values for each of the three selected methods as well as Kryter's predicted values. Of all the studies compared, only Kryter does not seem to be in general agreement with the three methods selected. Therefore, a special discussion of his method is included. At this point, however, attention will focus only on the methods of Passchier-Vermeer, Robinson, and Baughn.

4. Simplification of Data. Now that three different methods have been selected, the question remains as to how to use the data. The data are simplified to three curves (representing different philosophies of what and whose hearing should be protected) for three audiometric frequencies. Two curves are the expected NIPTS (maximum and a 10 year exposure point) of of the sensitive ears on the 90 percentile points with respect to SPL. The other curve is the average NIPTS expected during 40 years of exposure as averaged over all the population percentiles. This third curve is approximated closely by the median NIPTS level after 20 years of exposure. The three audiometric frequencies presented were speech (average of 0. 5, 1, and 2 kHz), speech (average of 0. 5, 1, and 4 kHz) and 4 kHz. A Table relating percent of population with more than a 5 dB NIPTS at 4000 Hz versus exposure is also developed. The data are presented in the sequence in which reduced so that a user may, at his discretion, stop and use as a basis of his decision the data one or more steps before the manipulation that provides the final curves discussed above.

5. Details of Selected Methodologies.

a) Passchier-Vermeer (1971)

Passchier-Vermeer results are in graph form (see Figure 2). Tables 3 and 4 are then used to calculate the effects of age and the correction necessary for considering different percentile levels. The details of the calculations of the values in Table 2 are as follows:



* KRYTER CONSIDERS THIS HEARING LEVEL(FROM TABLE III [KRYTER (16)])

Figure 1

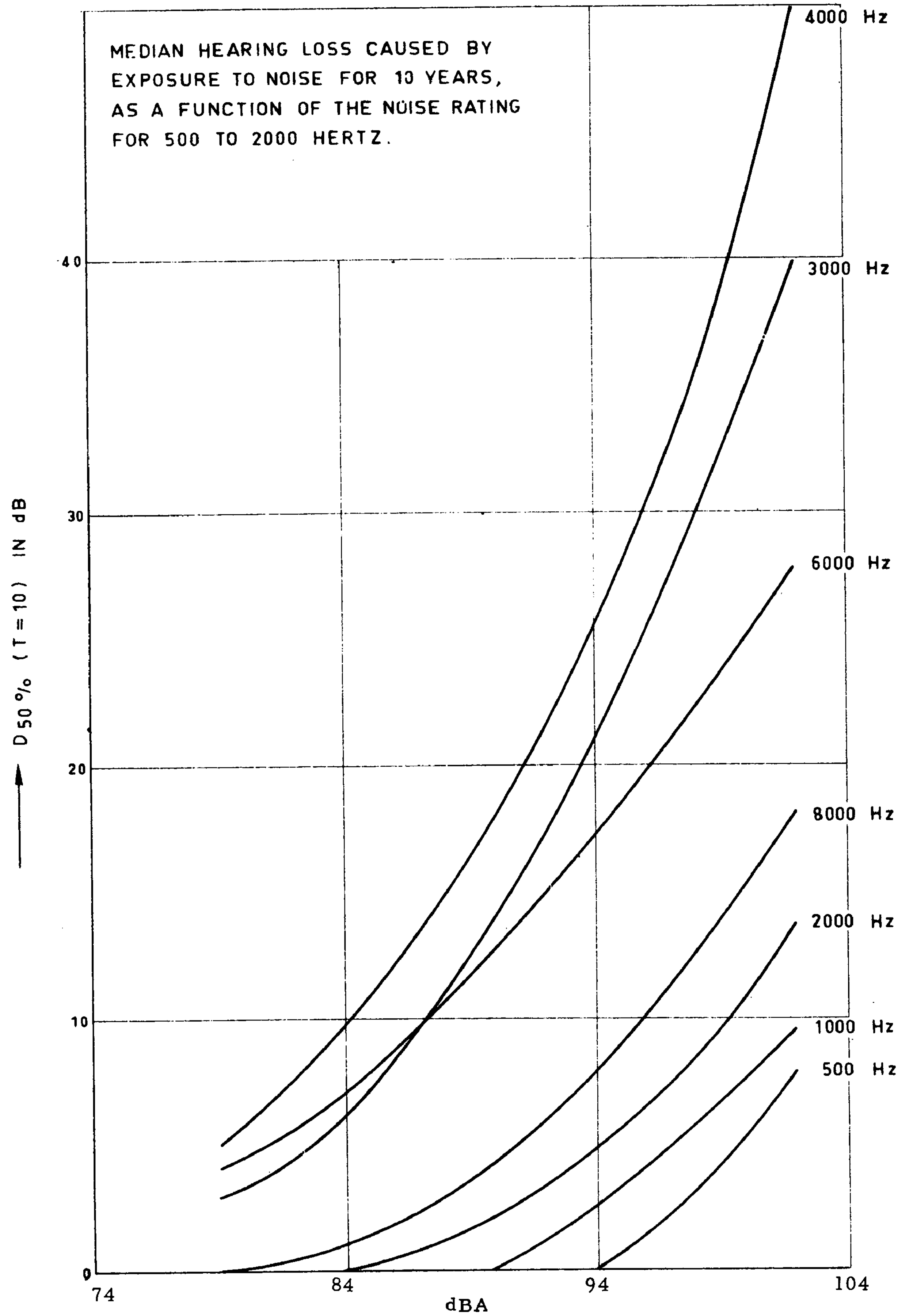

MEDIAN HEARING LOSS CAUSED BY EXPOSURE TO NOISE FOR 10 YEARS, AS A FUNCTION OF THE NOISE RATING FOR 500 TO 2000 HERTZ.
4000 Hz
3000 Hz
6000 Hz
8000 Hz
2000 Hz
1000 Hz
500 Hz
D 50 % (T = 10) IN dB
0
10
20
30
40
74
84
94
104
dBA

Figure 2

TABLE 3

(from Passchier-Vermeer)

Frequency	Increase of $D_{50\%}$ in relation to $D_{50\%}$ (T = 10) for exposure times of at least 10 years	
500 Hz	2 % per year	
1000 "	2,5 "	
2000 "	10 "	
3000 "	1 "	
4000	0 "	
6000 "	0 "	NR ≤ 92
	0.28 (NR-92) "	NR ≥ 92
8000 "	0 "	NR ≤ 92
	0.37 (NR-92) "	NR ≥ 92

TABLE 4

(from Passchier-Vermeer)

NR for 500 to 2000 Hz	Number of decibels to be added to $D_{50\%}$, in order to calculate $D_{75\%}$						
	500 Hz	1000 Hz	2000 Hz	3000 Hz	4000 Hz	6000 Hz	8000 Hz
75	0	0	0	0	4	0	0
80	0	0	1	0	3.5	1	1
85	0	0	2	2.5	3	2.5	2
90	0	0	3	4.5	2	3.5	3
94	0	0	4.5	4.5	0.5	4	3
98	0	0.5	7	4.5	0	5	3

NR for 500 to 2000 Hz	Number of decibels to be substracted from $D_{50\%}$;in order to calculate $D_{25\%}$						
	500 Hz	1000 Hz	2000 Hz	3000 Hz	4000 Hz	6000 Hz	8000 Hz
75	0	0	0	1	5	1	0
80	0	0	0	1	5	3.5	0
85	0	0	0.5	2.5	5	6	0
90	0	0	3	3.5	4	7	0
94	0.5	0.5	4	3.5	2	7.5	0
98	1.5	1.5	5	3.5	1	8	0

Reference: "Hearing Loss Due to Exposure to Steady-State Broadband Noise."

(1) Converted N. R. into dBA by adding formula dBA = N. R. + 4.
(2) Procedure used was outlined in pages 23-25.
(3) Noise-induced shift of hearing level (Dx), not approximation of noise induced hearing loss (D'x) was calculated.
(4) (Dx) values were obtained from Figure R35-A and Tables A and B.
(5) For 75 dBA, the curves of R35-A were extended slightly by straight lines.
(6) Speech hearing loss was obtained from averaging Dx for 500, 1000, and 2000 Hz frequencies.
(7) Since no method was suggested in her original report for estimating the 10 and 90 percentile levels, the corrections used to estimate the 25 or 75 percentile levels were doubled in order to approximate the 10 or 90 percentile levels. The error of this approximation will be less than 10 percent for a normal distribution. This is in agreement with Passchier-Vermeer's supplement (1969) to the main report.

In her 1971 paper "Occupational Hearing Loss", Passchier-Vermeer does provide NIPTS values for the 10 year exposure point. These values agree with the approximation used in this supplement.

b) Robinson

Robinson provides a formula and a set of Tables (see Tables 5 and 6) which can be used to calculate NIPTS. A nomogram is also presented which allows calculation of hearing levels of noise-exposed populations since the presbycusis correction is included. Details of the calculations used to obtain the values of Table 2 are as follows:

Reference: "The Relationships Between Hearing Loss and Noise Exposure."

(1) Used LA = dBA.
(2) Used procedure outlined on page 18 except that the formula:

$$H = 27.5 \left[1 + \text{TANH} \frac{\text{LA} + 10 \text{ LOG } T/TO + Un - \lambda i}{15} \right]$$

was used instead of the nomogram.
(3) Table 5 (page 6 of reference) was used to find λi for TO = 1 year.
(4) Table 6 (page 7 of reference) was used to find Un, which relates H to a percentile of the population.
(5) T = time of exposure in years and H = noise induced hearing loss.
(6) Speech hearing loss was calculated from averaging H for 500, 1000 and 2000 Hz frequencies.

c) Baughn

Baughn presents a set of Tables (see Tables 7 and 8) that give the actual hearing levels of 8 different age groups for 9 percentile levels under three exposure conditions. Considering the 78 dBA group as non-exposed groups, the calculations are as follows:

TABLE 5

Frequency parameter λ in H-function

(from Robinson)

Audiometric frequency (kHz)	λ (dB) T_o = 1 year
0.5	130.0
1	126.5
2	120.0
3	114.5
4	112.5
6	115.5

TABLE 6

Percentile parameter u in H-function

(from Robinson)

Percentile n	u
"Sensitive ears"	
1 *	13.8
2	12.1
3	11.1
5	9.8
7	8.7
Decile 10	7.6
15	6.0
20	5.0
Quartile 25	4.0
30	3.1
40	1.5
Median 50	0
60	- 1.5
70	- 3.1
Quartile 75	- 4.0
80	- 5.0
85	- 6.0
Decile 90	- 7.6
93	- 8.7
95	- 9.8
98	-11.1
99 *	-12.1
"Resistant ears"	-13.8

* Extrapolated.

TABLE 7 (from Baughn)

INTERPOLATED AND EXTRAPOLATED FROM FIELD
(Speech (.5, 1, 2 kHz)

Int. Dec. Points	AGE 18 - 23				AGE 24 - 29				AGE 30 - 35				AGE 36 - 41		
	3F/3				3F/3				3F/3				3F/3		
	80	85	90	95	80	85	90	95	80	85	90	95	80	85	90
1	-.8	-.4	-.1	.4	.2	1.0	1.7	2.7	.6	1.4	2.5	3.9	1.0	2.0	3.1
2	.55	1.1	1.4	1.2	1.7	2.6	3.4	4.6	2.2	3.1	4.3	6.0	2.6	3.8	5.1
3	1.5	2.1	2.4	3.0	2.8	3.8	4.6	6.0	3.3	4.3	5.6	7.5	3.8	5.0	6.5
4	2.5	3.1	3.5	4.1	3.8	4.9	5.8	7.3	4.4	5.5	6.9	8.9	4.9	6.3	7.8
5	3.7	4.4	4.8	5.5	5.2	6.4	7.4	9.0	5.8	7.0	8.6	10.8	6.4	7.9	9.6
6	4.3	5.1	5.6	6.4	6.0	7.4	8.6	10.4	6.7	8.1	10.0	12.5	7.4	9.2	11.1
7	5.0	5.9	6.5	7.4	7.0	8.6	10.0	12.2	7.8	9.5	11.6	14.6	8.6	10.7	13.0
8	6.0	7.1	7.7	8.9	8.4	10.3	11.9	14.5	9.3	11.3	13.8	17.4	10.3	12.7	15.5
9	7.8	9.2	10.1	11.6	10.9	13.4	15.5	18.9	12.2	14.7	18.1	22.7	13.4	16.6	20.2

Int. Dec. Points	AGE 42 - 47				AGE 48 - 53				AGE 54 - 59				AGE 60 - 65		
1	1.6	2.7	3.9	5.3	2.7	3.7	4.9	6.7	4.1	5.3	6.8	8.4	6.8	8.0	9.2
2	3.3	4.6	5.9	7.6	4.5	5.7	7.2	9.2	6.2	7.6	9.3	11.2	9.3	10.7	12.1
3	4.5	5.9	7.4	9.2	5.9	7.1	8.7	10.9	7.7	9.2	11.0	13.1	11.0	12.6	14.1
4	5.7	7.2	8.8	10.8	7.2	8.6	10.3	12.7	9.2	10.8	12.8	15.0	12.8	14.5	16.1
5	7.3	8.9	10.7	12.9	8.9	10.4	12.3	14.9	11.1	12.9	15.0	17.5	15.0	16.9	18.7
6	8.5	10.3	12.4	15.0	10.4	12.1	14.3	17.3	12.9	15.0	17.4	20.3	17.4	19.6	21.7
7	9.9	12.0	14.4	17.4	12.0	14.0	16.6	20.1	15.0	17.4	20.3	23.6	20.3	22.8	25.2
8	11.8	14.3	17.2	20.8	14.5	16.7	19.8	24.0	17.9	20.8	24.2	28.2	24.2	27.2	30.1
9	15.3	18.7	22.5	27.1	18.7	21.8	25.8	31.3	23.3	27.1	31.5	36.8	31.5	35.5	39.3

TABLE 8 (from Baughn)

4000 Hz

Int. Dec. Points	AGE 18 - 23			AGE 24 - 29			AGE 30 - 35			AGE 36 - 41		
	78	86	92	78	86	92	78	86	92	78	4 M 86	92
1	.37	2.09	2.8	1.37	5.7	7.67	3.0	9.77	12.6	5.2	14.7	17.9
2	1.44	4.09	5.74	3.46	9.88	13.15	6.15	15.6	18.9	9.6	20.9	24.4
3	2.34	5.66	8.40	5.46	12.9	17.54	9.15	20.09	23.8	13.4	25.8	29.6
4	3.28	7.13	11.48	7.46	15.96	23.01	11.87	23.99	30.5	16.8	30.4	35.7
5	4.1	8.7	14.0	9.1	19.0	27.4	14.3	27.9	35.0	20.0	34.9	40.6
6	5.08	10.6	17.5	11.10	22.4	32.61	17.12	32.09	39.9	23.6	39.1	45.5
7	6.85	13.05	21.8	14.2	26.6	38.91	21.31	37.11	45.9	28.6	43.2	50.3
8	7.95	16.18	26.6	16.8	28.5	46.03	25.17	43.52	52.5	33.4	51.0	56.0
9	10.7	23.66	37.2	22.2	45.03	61.38	32.6	53.01	64.8	42.4	60.0	64.1

Int. Dec. Points	AGE 42 - 47			AGE 48 - 53			AGE 54 - 59			AGE 60 - 65		
1	8.32	19.3	23.9	12.1	24.1	30.5	17.2	30.3	37.3	24.0	35.8	44.0
2	13.5	26.7	30.8	18.7	31.6	37.1	24.5	38.2	43.4	32.3	43.6	50.4
3	18.2	31.6	35.9	23.9	37.1	41.7	30.9	43.4	47.2	39.2	48.1	53.3
4	22.1	36.1	41.4	28.5	41.8	46.7	35.3	48.1	51.6	44.1	52.0	56.3
5	26.0	41.0	46.0	32.8	46.4	50.8	40.1	52.3	54.9	49.0	55.9	58.6
6	30.2	45.1	50.1	37.4	50.6	54.4	44.9	56.5	58.2	53.9	59.3	62.1
7	35.6	50.0	54.3	42.6	54.8	58.4	49.7	60.1	62.6	57.8	63.7	66.2
8	41.3	56.2	59.8	48.9	60.3	63.0	56.1	64.9	65.9	63.7	66.5	69.7
9	50.4	64.8	66.2	58.4	67.7	69.1	65.0	71.7	71.4	70.6	72.7	75.0

(1) Use Table 7 (6a of reference) and Table 8 (9 of reference) from Baughn's data.
(2) NIPTS for speech was considered as the difference in hearing of a certain percentile of people, who are exposed to a noise level greater than 80 dBA minus the hearing level of that same percentile of people who are exposed to only 80 dBA.
(3) Percentile levels were given in units of 10 percent only. The 25 and 75 percentile points were obtained by averaging 20 and 30, and 70 and 80 percentile values, respectively.
(4) The data was given by age groups with 6 year differences. Linear interpolation was used where necessary to obtain exposures for 10, 20 and 40 years.
(5) HL values for 4000 Hz at 80, 85 and 90 dBA calculated from Baughn's data by linear interpolation between the 78 and 86 dBA data points or the 86 and 92 dBA data points. Values at 95 dBA were obtained by linear extrapolation from the 86 and 92 dBA points. NIPTS due to some exposure level, e.g., 85 dBA, was calculated as the HL at 85 dBA minus the HL at 78 dBA for the same percentile and age group.

6. Manipulation of Data. These values were manipulated and simplified as follows: Tables 9, 10 and 11 were constructed by averaging the NIPTS values of Table 2 over a 40 year lifetime (age 20 to age 60). After the NIPTS values were averaged over time for various population percentiles, the results were averaged over the total population. A graphic method was used to calculate "Average NIHL during 40 Years Exposure". The 0, 10, 20 and 40 year data points were plotted on graph paper. The area under the curve drawn through these points was measured and then divided by 40 to obtain the "average NIHL during 40 Years' Exposure." A graphic method in which the .9, .75, .5, .25, and .1 percentile points were plotted was used to calculate "Average Loss of Total Population During 40 Years of Noise Exposure". The area under the resultant curve was measured and normalized to obtain the desired value.

From this average, Table 12 was developed. Tables 13 and 14 come directly from the data of Table 2. Table 13 provides the expected NIPTS after 10 years of noise exposure that will not be exceeded by 90 percent of the population (.9 Percentile level). Table 14 depicts the maximum NIPTS that will be encountered during a typical 40 year exposure which starts at age 20. Normally this occurs at 60 years of age, but for 4000 Hz, Passchier-Vermeer's method shows that this occurs after both 10 and 40 years of exposure time, while Baughn's data indicates that this occurs at the 10 year exposure point.

The resulting NIPTS values of Tables 12, 13 and 14 are now averaged over the three methods. This grand average is presented in Figures 3 - 8. Figures 3, 4 and 5 compare the 3 different ways (Max NIPTS, .9 percentile; NIPTS after 10 year exposure, .9 percentile; and average NIPTS of total population during 40 years) of considering the data at three

TABLE 9

Average NIPTS during 40 Years Exposure

1/3 (.5, 1, 2 kHz)

dBA		Population Percentiles .9	.75	.5	.25	.1	Average Loss of Total Population
	Passchier-Vermeer	0	0	0	0	0	0
80	Robinson	2.0	1.3	.8	.4	.2	.9
	Baughn	0	0	0	0	0	0
	Passchier-Vermeer	.9	.5	.2	.2	.1	.4
85	Robinson	3.6	2.4	1.4	.8	.5	1.6
	Baughn	2.8	2.0	1.3	1.1	.9	1.6
	Passchier-Vermeer	3.0	2.3	1.6	1.4	1.2	1.9
90	Robinson	5.5	3.2	2.1	1.2	.9	2.5
	Baughn	6.0	4.3	3.0	2.3	1.9	3.5
	Passchier-Vermeer	9.2	6.3	5.5	4.4	3.5	5.8
95	Robinson	11.0	7.5	4.4	3.1	2.1	5.2
	Baughn	10.2	7.2	5.0	3.8	3.4	5.7

TABLE 10

Average NIPTS during 40 Years Exposure
1/4 (.5, 1, 2, 4 kHz)

		Population Percentiles					Average Loss ot Total Population
dBA		.9	.75	.5	.25	.1	
	Passchier-Vermeer	3.4	2.5	1.5	.2	0	1.4
80	Robinson	3.6	2.3	1.5	.8	.6	1.7
	Baughn	.8	.7	.7	.6	.6	.7
	Passchier-Vermeer	5.1	4.0	2.9	1.6	.3	2.9
85	Robinson	6.3	4.2	2.7	1.6	1.0	3.2
	Baughn	5.1	4.0	3.5	3.0	2.7	3.7
	Passchier-Vermeer	8.1	6.9	5.7	4.3	3.0	5.7
90	Robinson	9.3	6.4	4.3	2.7	1.9	4.9
	Baughn	8.8	7.2	6.0	4.9	4.3	6.3
	Passchier-Vermeer	14.7	12.1	11.1	9.4	7.9	11.1
95	Robinson	15.8	11.7	7.7	5.3	3.6	8.5
	Baughn	13.3	10.7	8.5	6.9	6.4	9.0

TABLE 11

Average NIPTS during 40 Years Exposure

4000 Hz

dBA		Population Percentiles .9	.75	.5	.25	.1	Average Loss of Total Population
	Passchier-Vermeer	13.8	9.9	6.0	1.0	0	5.5
80	Robinson	8.7	5.6	3.5	2.2	1.4	4.2
	Baughn	3.4	3.0	2.9	2.5	2.4	3.0
	Passchier-Vermeer	17.8	14.4	11.0	6.0	1.0	10.6
85	Robinson	14.2	9.6	6.4	4.0	2.9	7.4
	Baughn	11.9	10.2	10.1	8.9	8.2	10.0
	Passchier-Vermeer	23.6	20.8	18.0	13.2	8.4	17.0
90	Robinson	21.6	16.2	11.1	7.3	4.8	12.0
	Baughn	17.3	15.9	14.9	12.9	11.6	14.7
	Passchier-Vermeer	31.4	29.7	28.0	24.5	21.0	26.9
95	Robinson	30.4	24.2	27.6	12.1	8.3	18.3
	Baughn	22.8	21.2	19.1	16.4	15.3	19.0

TABLE 12

Average Loss of Total Population during 40 Years of Exposure

	1/3 (.5, 1, 2 kHz)				
	75	80	85	90	95
Passchier-Vermeer	-	0	.4	1.9	5.8
Robinson	-	.9	1.6	2.5	5.2
Baughn	-	0	1.6	3.5	5.7
Average		.3	1.3	2.6	5.5

	1/4 (.5, 1, 2, 4 kHz)				
	75	80	85	90	95
Passchier-Vermeer	-	1.4	2.9	5.7	11.1
Robinson	-	1.7	3.2	4.9	8.5
Baughn	-	.7	3.7	6.3	9.0
Average		1.2	3.2	5.6	9.5

	4000 Hz.				
	75	80	85	90	95
Passchier-Vermeer	-	5.5	10.6	17.0	26.9
Robinson	-	4.2	7.4	12.0	18.3
Baughn	-	3.0	10.0	14.7	19.0
Average		4.2	9.3	14.6	21.6

TABLE 13

Noise Induced Hearing Loss
90 Percentile Level - 10 Years

	1/3 (.5, 1, 2 kHz)				
	75	80	85	90	95
Passchier-Vermeer	0	0	.9	2.4	5.6
Robinson	.8	1.5	2.8	4.2	8.1
Baughn	0	0	2.5	5.5	9.6
Average	.3	.5	2.1	4.0	7.8

	1/4 (.5, 1, 2 & 4 kHz)				
	75	80	85	90	95
Passchier-Vermeer	2.5	3.5	5.2	7.3	12.1
Robinson	1.5	2.7	5.0	7.8	13.0
Baughn	0	1.3	6.5	11.6	17.6
Average	1.3	2.5	5.6	8.9	14.2

	4000 Hz				
	75	80	85	90	95
Passchier-Vermeer	10.0	13.8	17.8	23.6	31.4
Robinson	3.6	6.6	11.6	18.8	27.7
Baughn	0	5.3	18.6	30.1	41.2
Average	4.5	8.6	16.0	24.0	33.4

TABLE 14

Maximum Hearing Loss from Noise .9 Percentile

	1/3 (.5, 1, 2 kHz)				
	75	80	85	90	95
Passchier-Vermeer	0	0	1.1	4.5	11.6
Robinson	1.6	3.2	5.8	8.6	15.1
Baughn	0	0	3.9	7.3	12.9
Average	.5	1.1	3.6	6.8	13.2
Worst Case	Use Robinson's Data				

	1/4 (.5, 1, 2 & 4 kHz)				
	75	80	85	90	95
Passchier-Vermeer	1.9	3.5	5.2	9.5	15.3
Robinson	3.0	5.6	9.5	13.8	19.6
Baughn	0	1.3	6.5	11.6	17.6
Average	1.6	3.5	7.1	11.6	17.5
Worst Case	Use Robinson's Data				

	4000 Hz				
	75	80	85	90	95
Passchier-Vermeer	10.0*	13.8*	17.8*	23.6*	31.4*
Robinson	7.5	12.9	20.5	29.5	38.1
Baughn	0	5.3*	18.6*	30.1*	41.2*
Average	5.8	10.7	19.0	27.7	36.9
Worst Case	10.0	13.8	20.5	30.1	41.2

*This maximum value is for 10 years. (Otherwise the maximum occurs at 40 years).

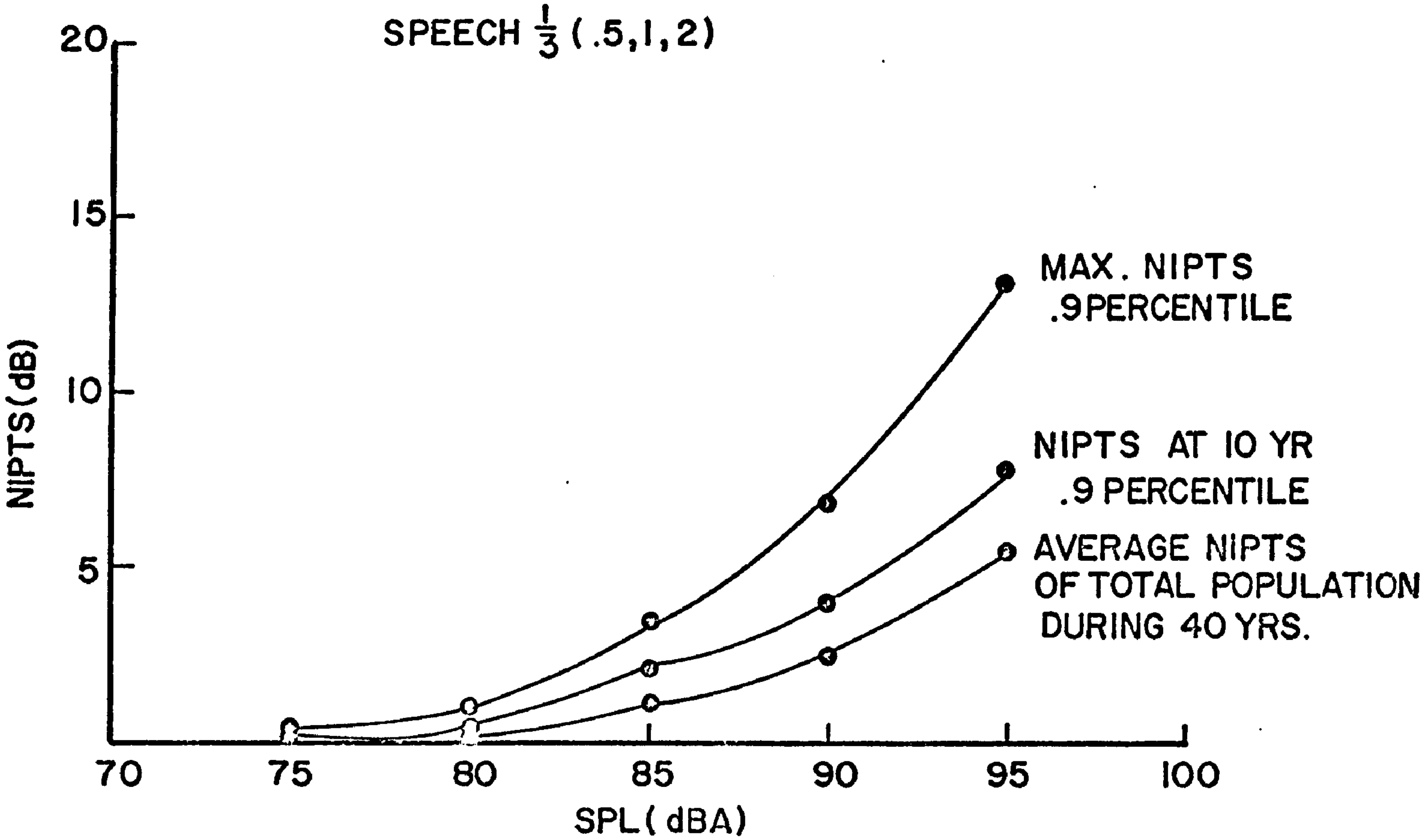


Figure 3. Predicted NIPTS Averaged over the Methodologies of Passchier-Vermeer, Baughn and Robinson.

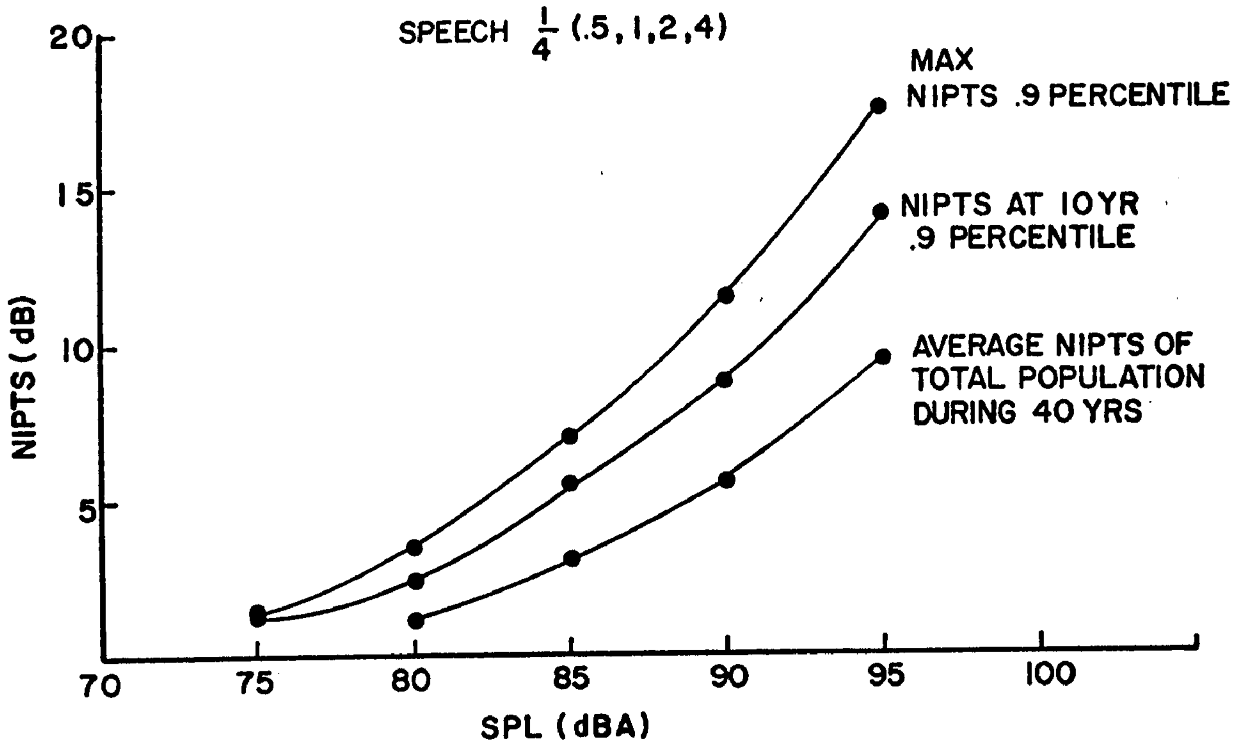


Figure 4. Predicted NIPTS Averaged over the Methodologies of Passchier-Vermeer, Baughn and Robinson.

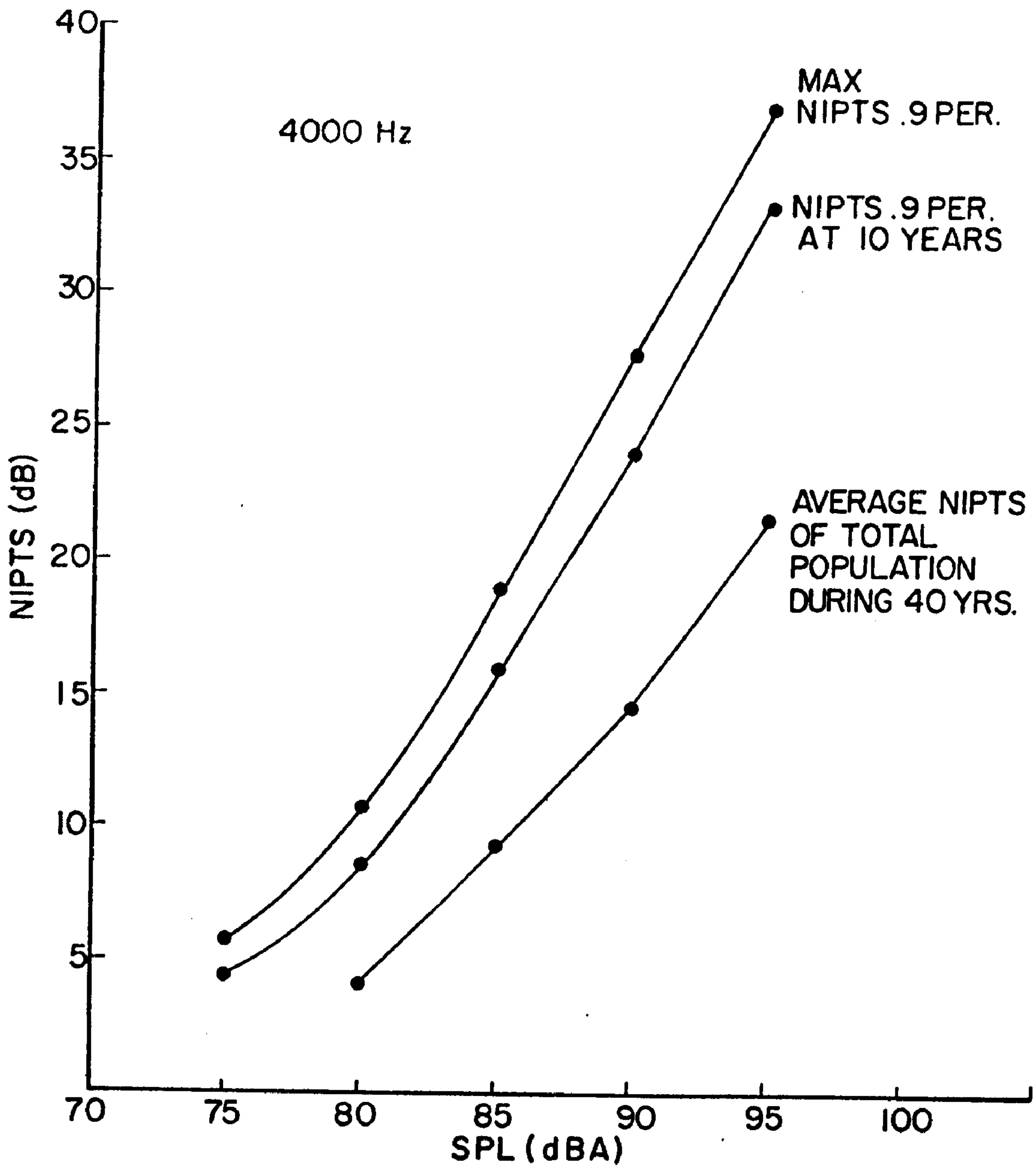
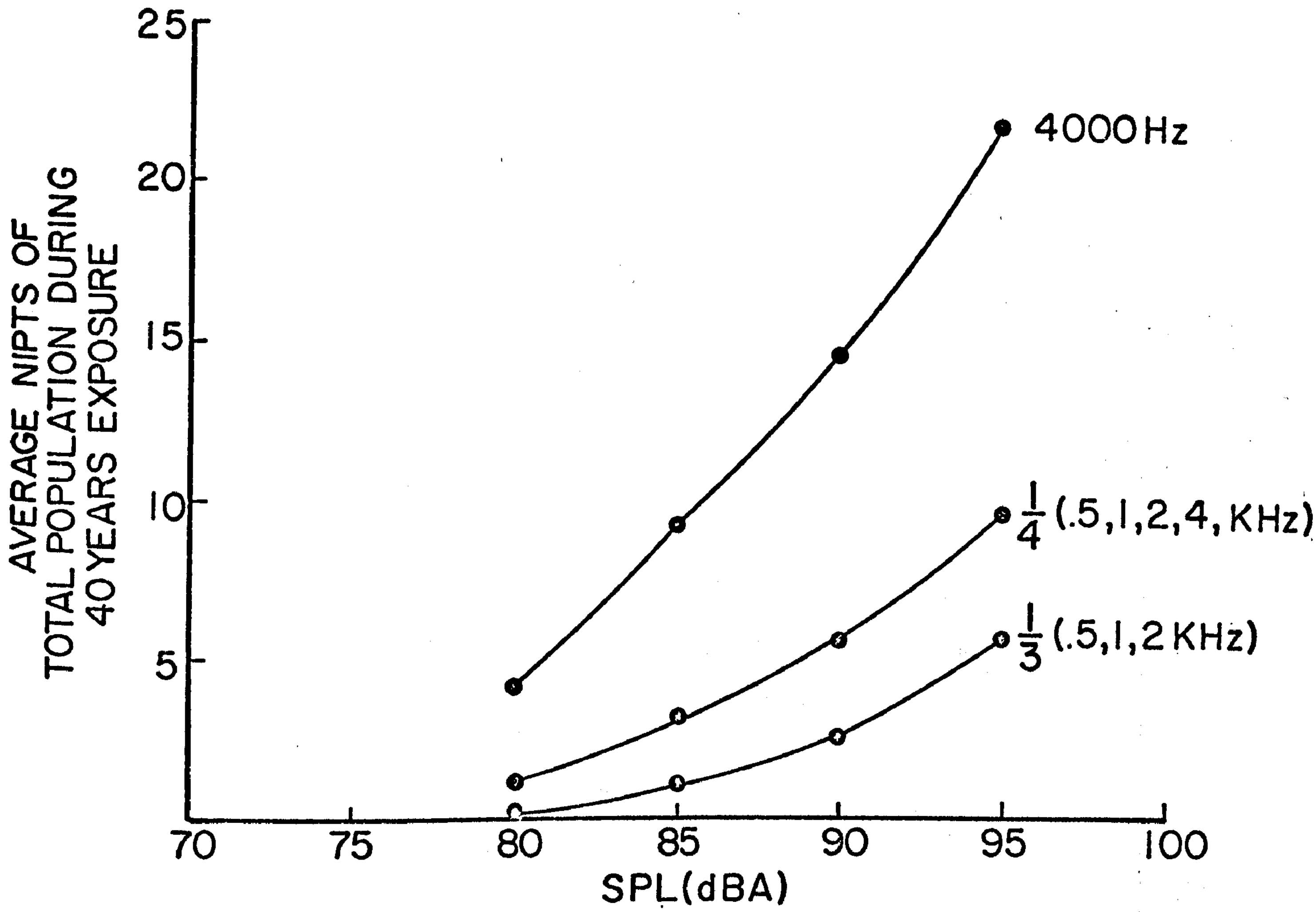
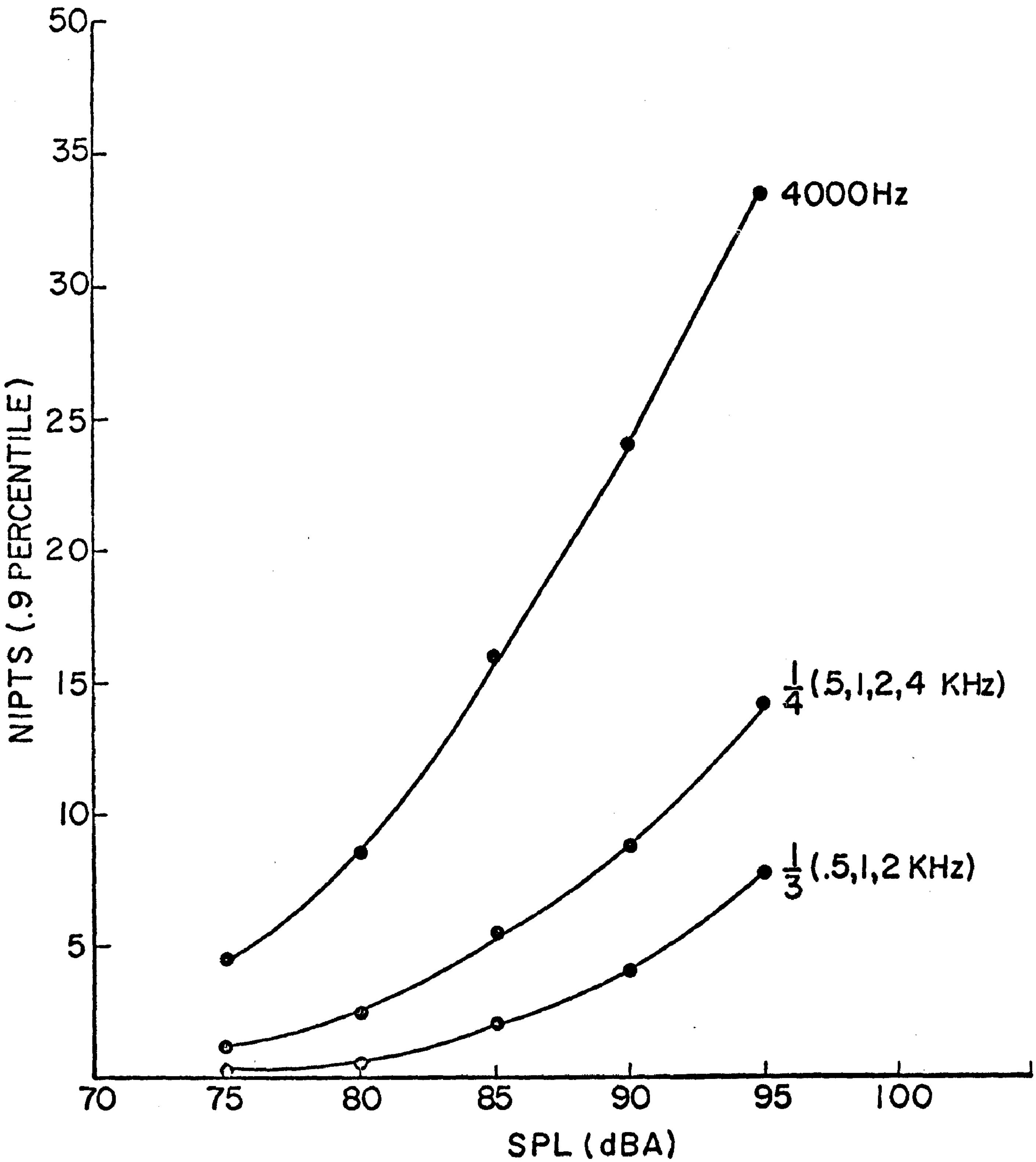


Figure 5. Predicted NIPTS Average over the Methodologies of Passchier-Vermeer, Baughn and Robinson.



AVERAGE NIPTS OF
TOTAL POPULATION DURING
40 YEARS EXPOSURE
25
20
15
10
5
70
75
80
85
90
95
100
SPL(dBA)
4000 Hz
1/4 (.5,1,2,4, KHz)
1/3 (.5,1,2 KHz)

Figure 6.



50
35
30
25
20
15
10
5
NIPTS (.9 PERCENTILE)
4000Hz
$\frac{1}{4}$(.5,1,2,4 KHz)
$\frac{1}{3}$(.5,1,2 KHz)
70
75
80
85
90
95
100
SPL (dBA)

Figure 7.

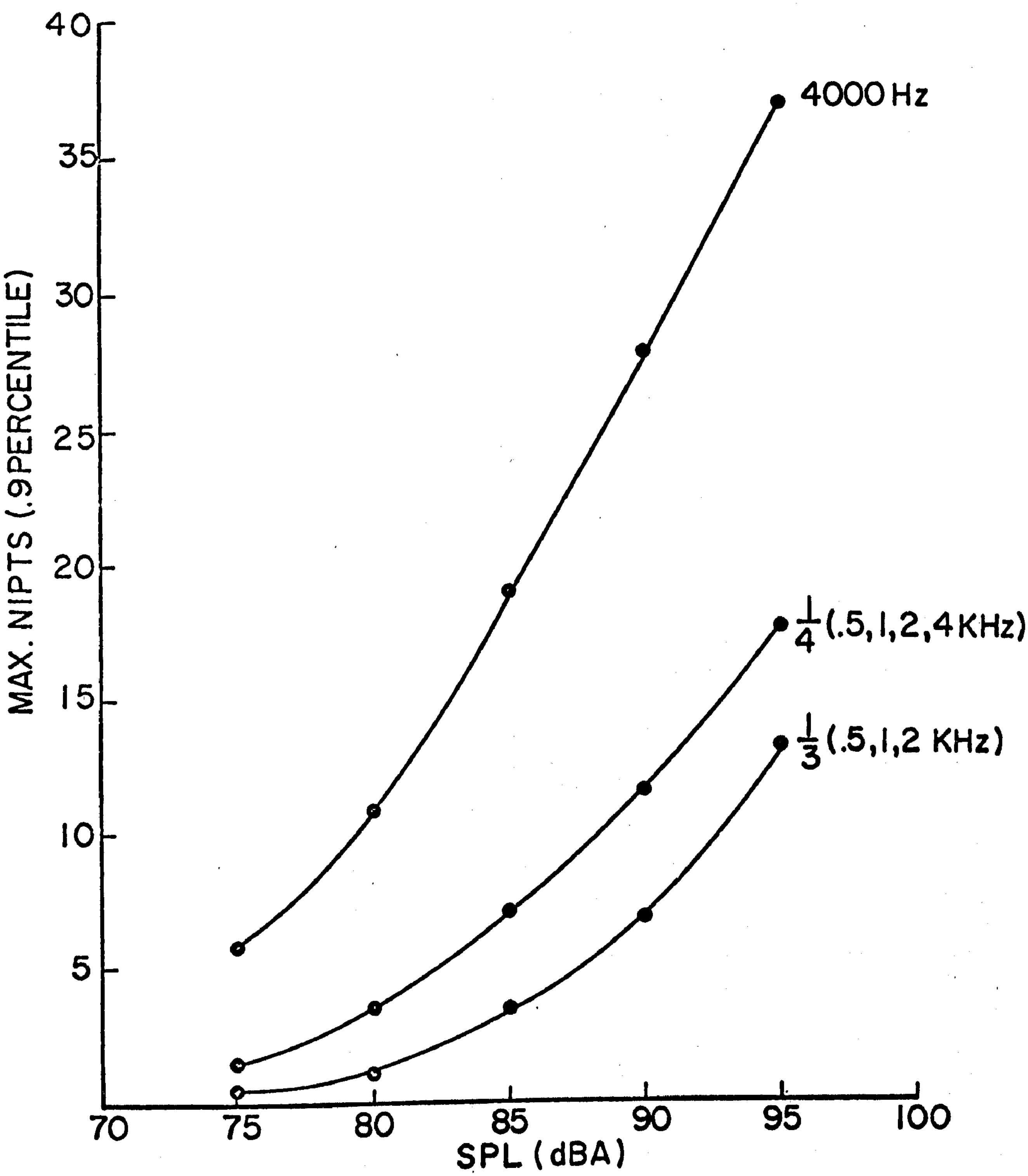

40
35
30
25
20
15
10
5
MAX. NIPTS (.9PERCENTILE)
4000 Hz
1/4 (.5,1,2,4 KHz)
1/3 (.5,1,2 KHz)
70
75
80
85
90
95
100
SPL (dBA)

Figure 8.

selected audiometric frequencies. It is these sets of figures, along with a set of Hearing Risk tables and one other table to be discussed later, that are considered sufficient to select the permissible A-weighted SPL for the 8 hour noise exposure. Before such a selection is made, however, certain other observations should be considered in detail.

7. Considerations.

a) NIPTS at 4000 Hz may decline with exposure for the very sensitive ears, while increasing for resistant ears. Figures 9, 10, 11 are a plot of the Hearing Levels of Baughn's data for .9, .5, and .1 percentile levels. Figure 12 is a plot of the difference between 85 dBA exposed groups and 78 dBA exposed groups. As expected, during the first years of exposure the sensitive ears (.9 percentile) show a large increase in NIPTS while the resistant ears (.1 percentile) show little increase. After 40 years of exposure, the situation is completely reversed. If only the effect on the sensitive ears is considered, the NIPTS for the noise resistant ears could be improperly neglected.

It was for this reason that the "average NIPTS during 40 years" was calculated. For instance, using the results for Table 11 for 85 dBA, Baughn's method gives approximately 12 dB average NIPTS for the sensitive (.9) ears and approximately 8 dB average NIPTS for the resistant (.1) ears. Apparently the entire population, not just some super-sensitive individuals, are significantly affected by noise during some part of their lifetime at the 4000 Hz audiometric frequency. Essentially, Table 11 was prepared to show this effect.

One of the obvious reasons for the decline of NIPTS is seen from Figure 11. As the total loss of hearing increases, regardless of the reason, the influence of noise diminishes as there is only so much hearing to be lost. The unanswerable question that remains is "what causes such a large hearing loss as evidenced by Baughn's (78 dBA) supposedly non-noise exposed group?" Is it aging, pathological conditions, non-occupational noise exposure greater than 80 dBA, the fact that 78 dBA may still be capable of causing a very significant loss in sensitive ears, or some combination of these factors? Figure 13 is a plot of Baughn's 78 dBA (.9) population versus the 1960-62 Public Health Survey (PHS) data. For the most part, Baughn's 78 dBA (.9) group shows less hearing loss than the PHS group, until age 50, at which point the two groups become equal. One can conclude that Baughn's 78 dBA (.9) group does not differ significantly from the general population. Baughn did not screen for pathological conditions, so one would definitely expect that such conditions would be an influence in both groups. The effect of aging cannot be neglected. The rate of hearing loss for both the 78 dBA group and the PHS (.9) group is approximately 1.5 dB/yr. Such a steep increase does not occur for median hearing levels for 4000 Hz once a certain age is reached (such as 50-70 years). It may not, therefore, be so unlikely that for this sensitive 10 percent of the population, aging alone causes a very

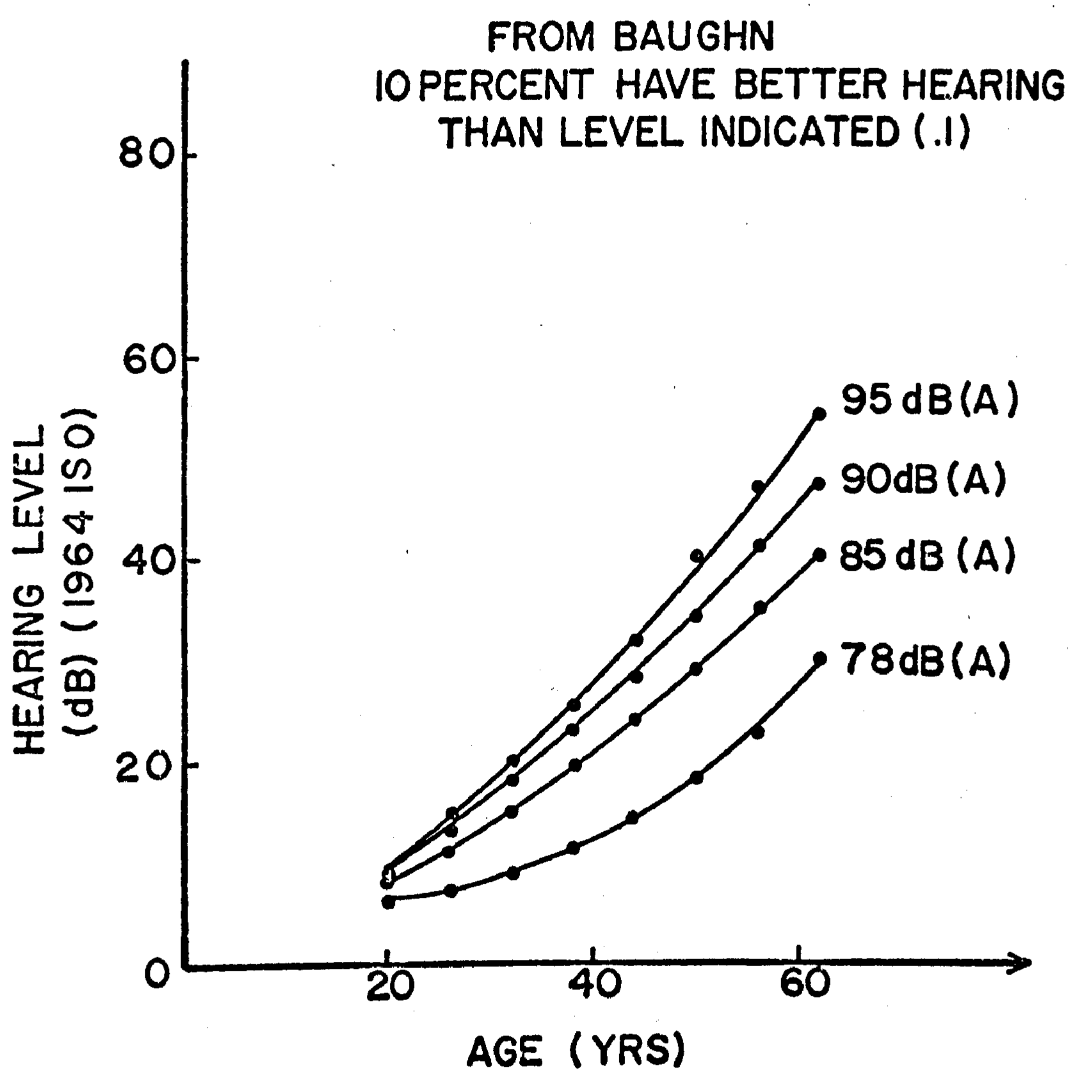

FROM BAUGHN
10 PERCENT HAVE BETTER HEARING
THAN LEVEL INDICATED (.1)
HEARING LEVEL
(dB) (1964 ISO)
80
60
40
20
0
20
40
60
AGE (YRS)
95 dB(A)
90dB(A)
85 dB (A)
78dB(A)

Figure 9

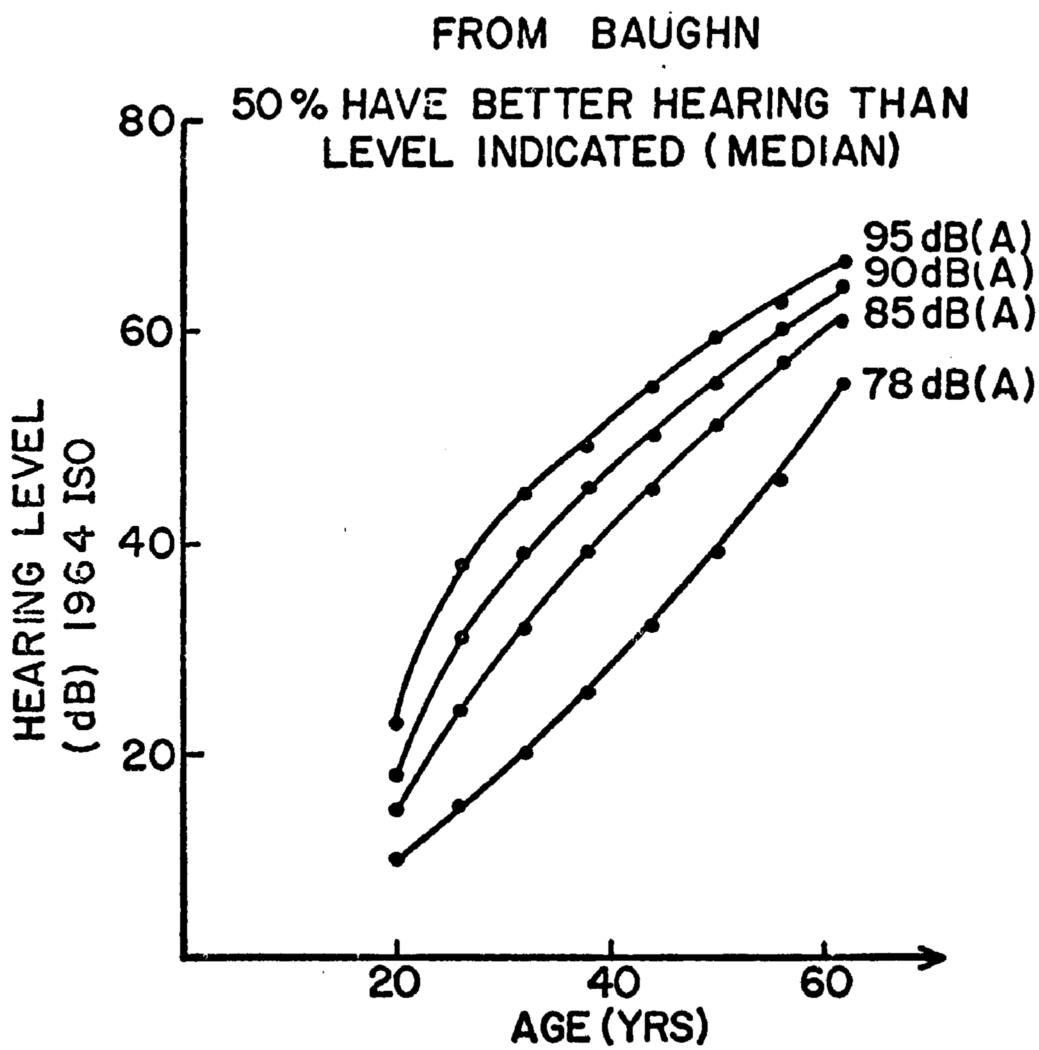

FROM BAUGHN
50% HAVE BETTER HEARING THAN
LEVEL INDICATED (MEDIAN)
80
60
40
20
HEARING LEVEL
(dB) 1964 ISO
95 dB(A)
90dB(A)
85dB(A)
78 dB(A)
20
40
60
AGE (YRS)

Figure 10.

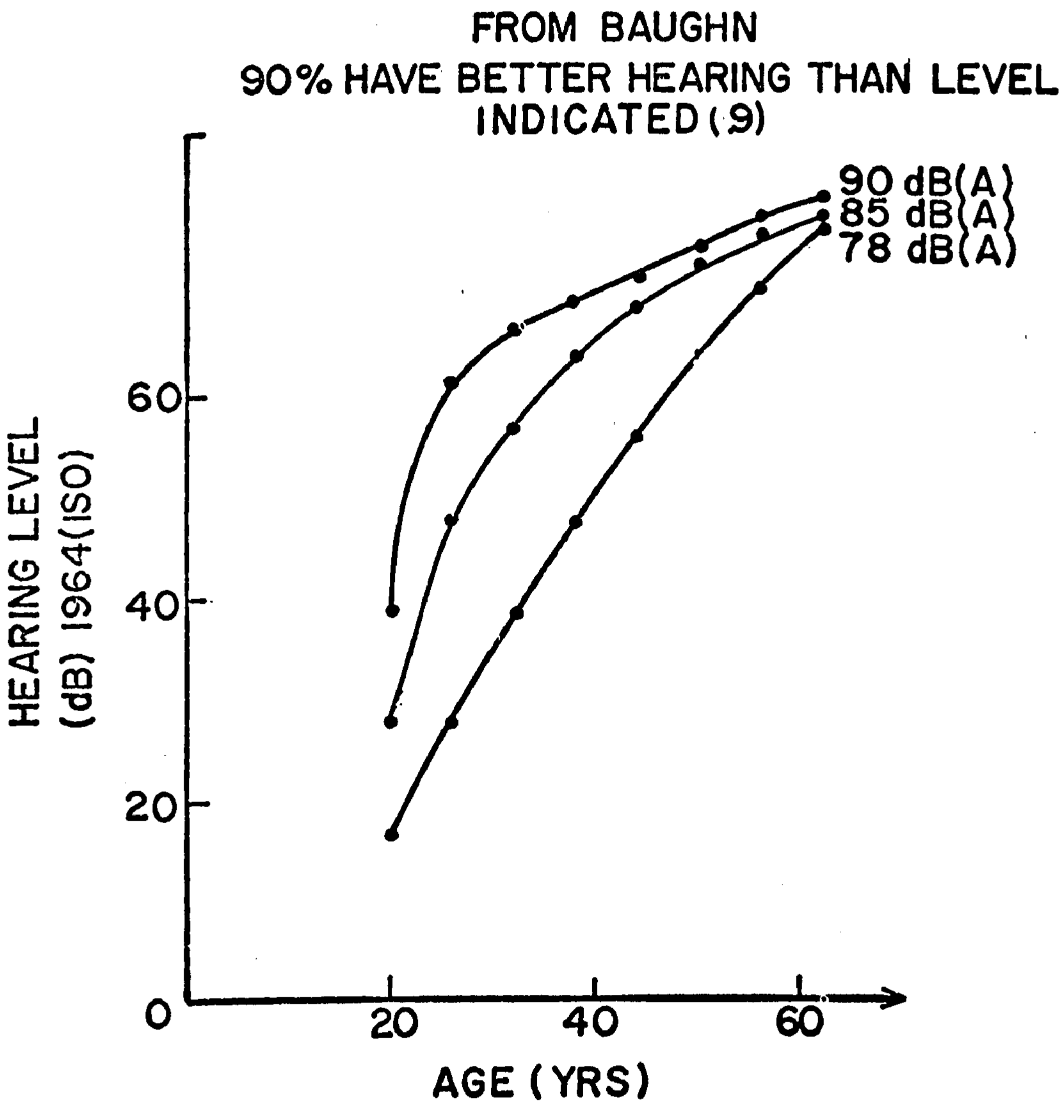

FROM BAUGHN
90% HAVE BETTER HEARING THAN LEVEL INDICATED (9)
90 dB(A)
85 dB(A)
78 dB(A)
HEARING LEVEL
(dB) 1964(ISO)
60
40
20
0
20
40
60
AGE (YRS)

Figure 11.

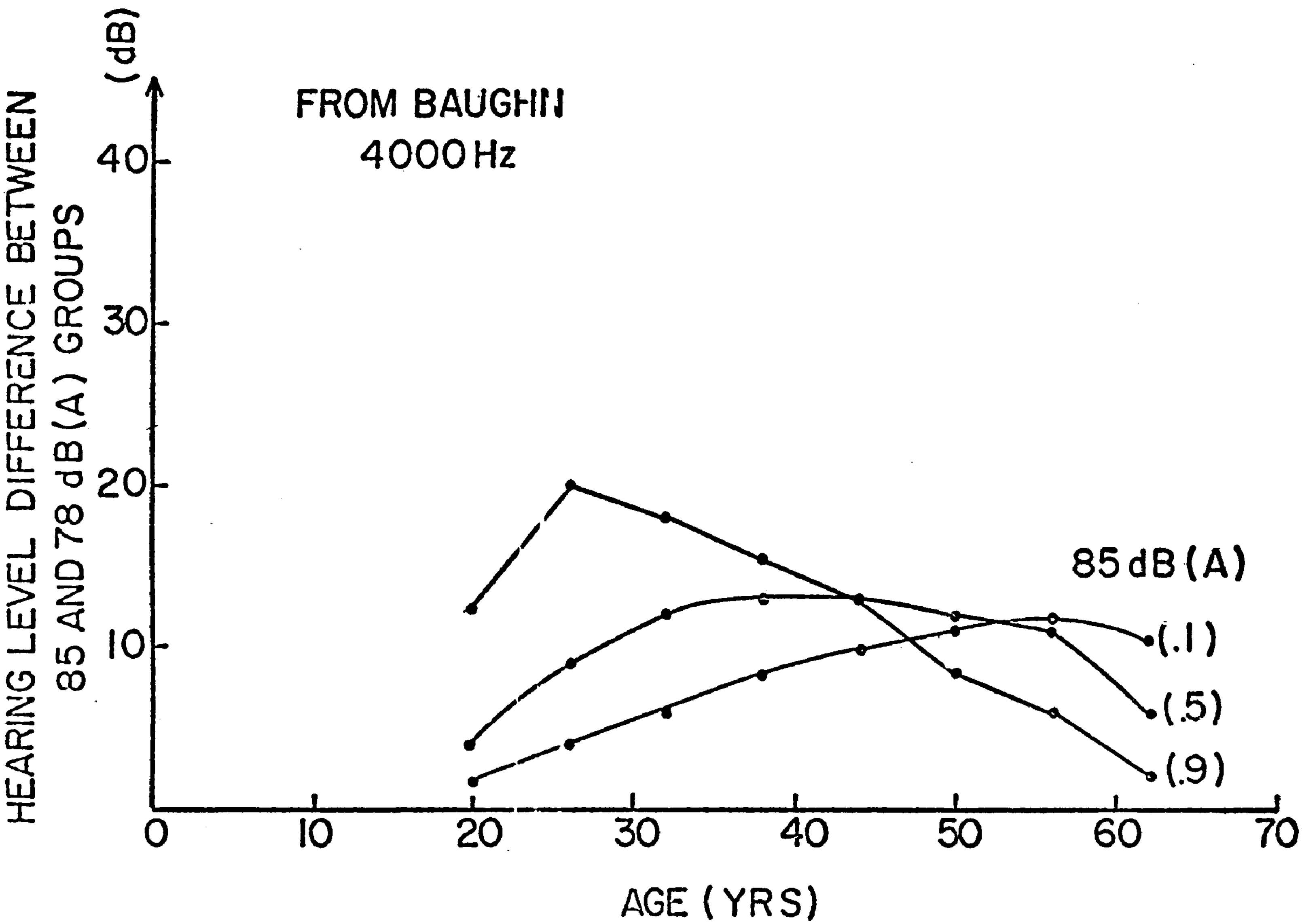
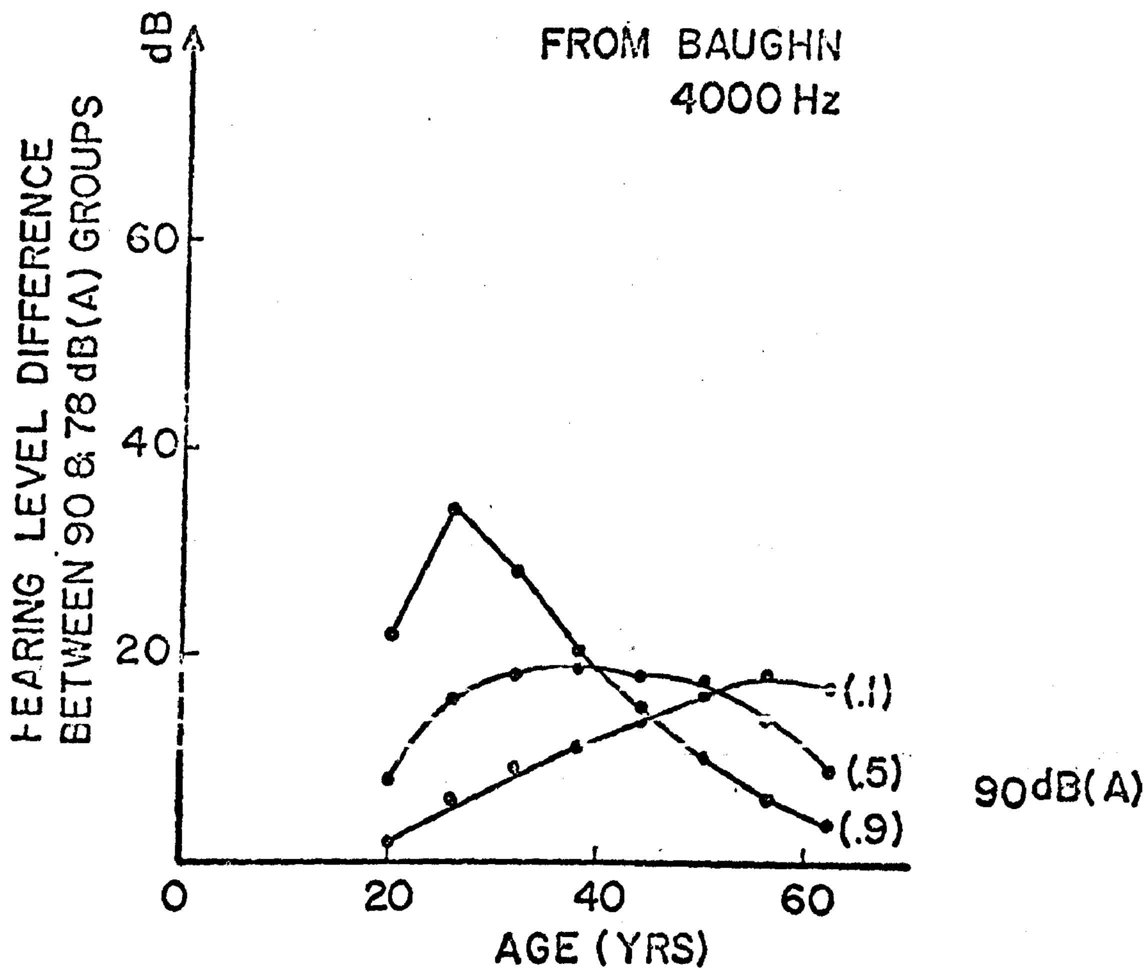

FROM BAUGHN
4000 Hz
HEARING LEVEL DIFFERENCE BETWEEN 85 AND 78 dB(A) GROUPS (dB)
40
30
20
10
0
10
20
30
40
50
60
70
AGE (YRS)
85 dB(A)
(.1)
(.5)
(.9)

Figure 12.



FROM BAUGHN
4000 Hz
dB
HEARING LEVEL DIFFERENCE
BETWEEN 90 & 78 dB(A) GROUPS
60
40
20
0
20
40
60
AGE (YRS)
(.1)
(.5)
(.9)
90dB(A)

Figure 13.

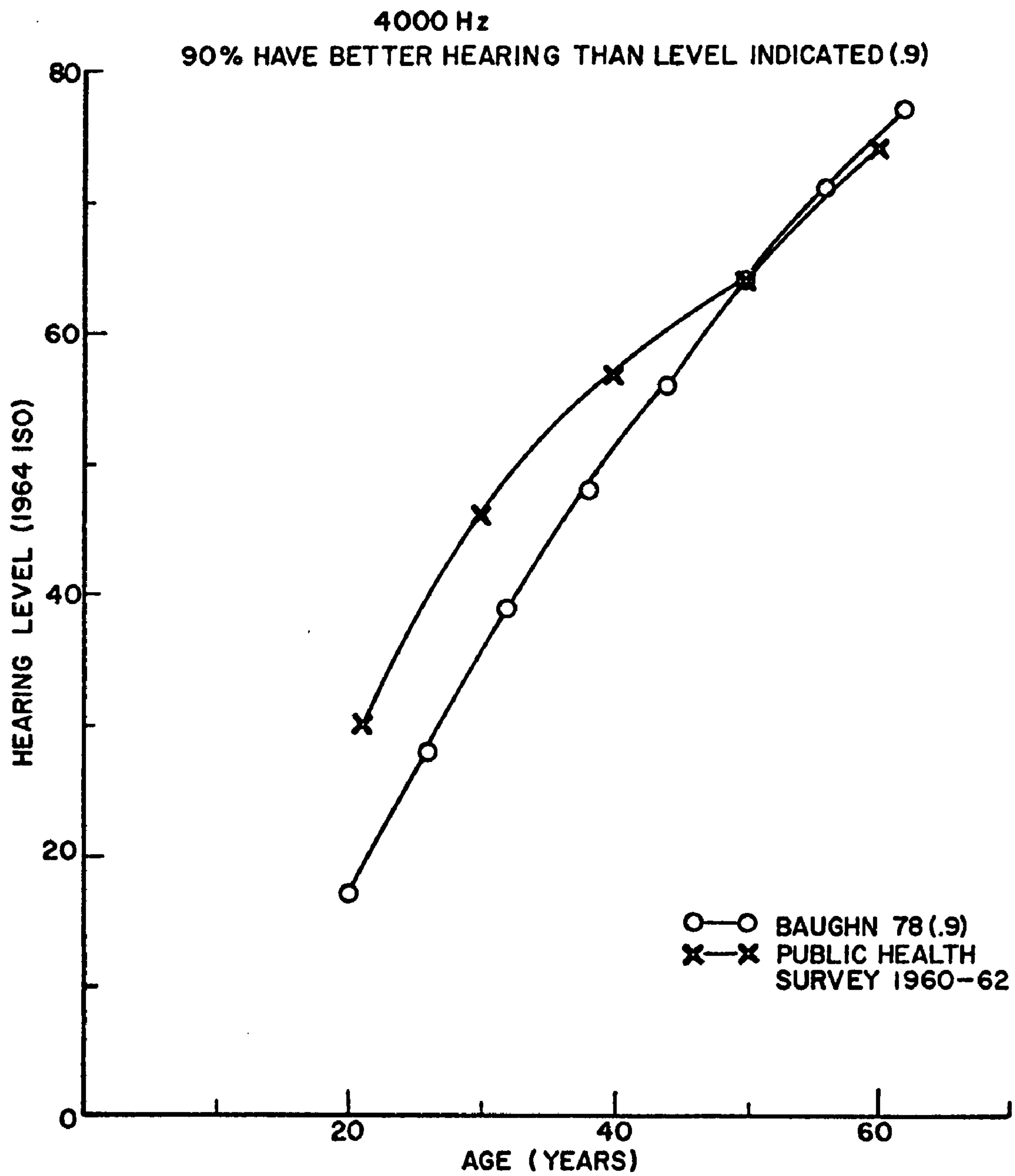

4000 Hz
90% HAVE BETTER HEARING THAN LEVEL INDICATED (.9)
HEARING LEVEL (1964 ISO)
80
60
40
20
0
20
40
60
AGE (YEARS)
BAUGHN 78 (.9)
PUBLIC HEALTH SURVEY 1960-62

Figure 14

significant change even in the early years. These arguments are not brought forth to prove that the rapid loss of hearing at 4000 Hz for this segment of the population is not largely due to noise exposure, but rather to emphasize the converse; over-protecting the population against noise exposure to prevent the rapid rise in hearing loss at 4 Hz for 10 percent of the population may be entirely futile. Such over-protection could easily come about if one made the assumption that the 78 dBA is the main cause of the large hearing losses in the sensitive 10 percentile.

b) Selection of a standard deviation for sensitivity to hearing loss. Figures 12 and 13 demonstrate the difficulty of considering only mean data at some exposure time and from these data estimating various percentile levels by assuming a standard deviation. In order to predict Baughn's data, the standard deviation must be constantly changed for increasing exposure time. This emphasizes the care that must be taken if a noise limitation is selected to protect 90 percent of the population instead of the median. The 90 percentile points can be seriously misestimated.

8. <u>Risk of Noise Relative to Hearing Level Exceeding a Predetermined Level or Fence.</u> Up to this point discussion of hearing risk, as it relates to an increase of the numbers of individuals who show a hearing loss greater than some fence value, has not been undertaken. The use of hearing risk as it relates to fences has been used for some time. One of the major drawbacks to the use of fences, however, is that a single fence only considers or protects hearing of individuals whose hearing is already near the fence values. Since fences have customarily been set relatively high with respect to the median hearing level, the hearing of the majority of the population is not considered.

Simply stated, the object of the fence is not to protect the excellent hearing from becoming just good, but the fair hearing from becoming bad. The argument that the excellent hearing will automatically be protected if the fair hearing is protected may not be true. Figure 15 is such a counter example. Thus the use of hearing risk should not be the only basis for selecting a noise limit for hearing conservation. Nevertheless hearing risk is one way to give meaning to NIPTS values and for this reason Tables 15 and 16 were prepared. Table 15 shows the hearing risk in percentage as calculated by Robinson. The 87, 92 and 97 dBA values were taken directly from Robinson and the 80 dBA values were calculated using his method. Table 16 shows the same data as calculated from Baughn's curves. A typical curve from Baughn's data is shown in Figure 16. The data agree well only if a 10 dB is added to each of Robinson's fence values. This, as proposed by Robinson, will account for the fact that Robinson's data have been carefully screened for pathological hearing losses while Baughn's data have not. Baughn's data, in this regard, will certainly be more typical of the normal population exposed to non-occupational noise. Therefore, the 10 dB correction will be added to Robinson's fence values in this report.

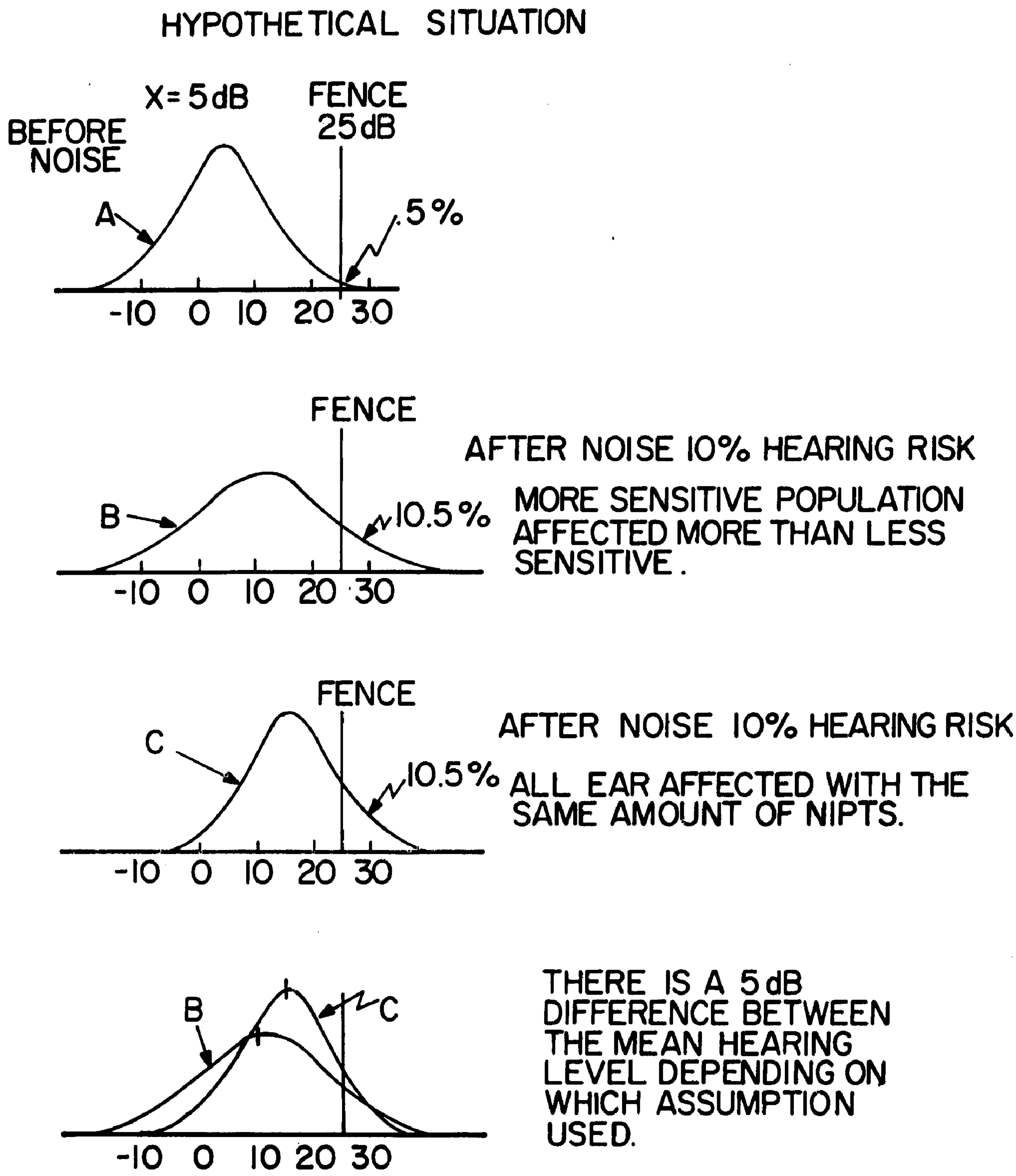

HYPOTHETICAL SITUATION
X= 5 dB
FENCE 25 dB
BEFORE NOISE
A
.5 %
-10 0 10 20 30
FENCE
AFTER NOISE 10% HEARING RISK
B
10.5 %
MORE SENSITIVE POPULATION AFFECTED MORE THAN LESS SENSITIVE.
-10 0 10 20 30
FENCE
AFTER NOISE 10% HEARING RISK
C
10.5 %
ALL EAR AFFECTED WITH THE SAME AMOUNT OF NIPTS.
-10 0 10 20 30
B
C
THERE IS A 5 dB DIFFERENCE BETWEEN THE MEAN HEARING LEVEL DEPENDING ON WHICH ASSUMPTION USED.
-10 0 10 20 30

Figure 15

TABLE 15

Robinson's Method

Noise risk for population at various ages for exposure at constant noise level commencing at age 30.

	Fence Height (ISO)	Noise Risk (%) at age 22	25	30	40	50	60
80	20	2	2	4	6	9	10
87	10*	3	5	8	14	17	18
92		6	10	15	22	28	28
80	25	1	2	2	3	6	9
87	15*	2	2	4	7	13	19
92		3	5	8	15	23	31
80	30	0	0	1	1	3	6
87	20*	0	1	2	4	7	13
92		1	2	4	8	14	24
80	35	0	0	0	0	1	2
87	25*	0	0	0	1	3	7
92		0	1	2	4	8	14

*Use these fence values for non-pathological population.

TABLE 16
Hearing Risk

Baughn's Data

Noise Level dBA	Fence Height (ISO)	22	25	30	40	50	60	70
85	15	10	10	10	11	10		
90		14	14	18	21	15		
95		22	25	30	30			
85	20	4	9	13	14	12	8	
90		7	13	22	26	22	17	
95		13	26	37	38	36	24	
85	25	1	3	5	7	9	11	
90		4	8	13	17	19	20	
95		6	13	21	29	32	29	
85	35	0	0	1	2	3	6	
90		0	1	2	3	6	13	
95		1	3	5	8	12	22	

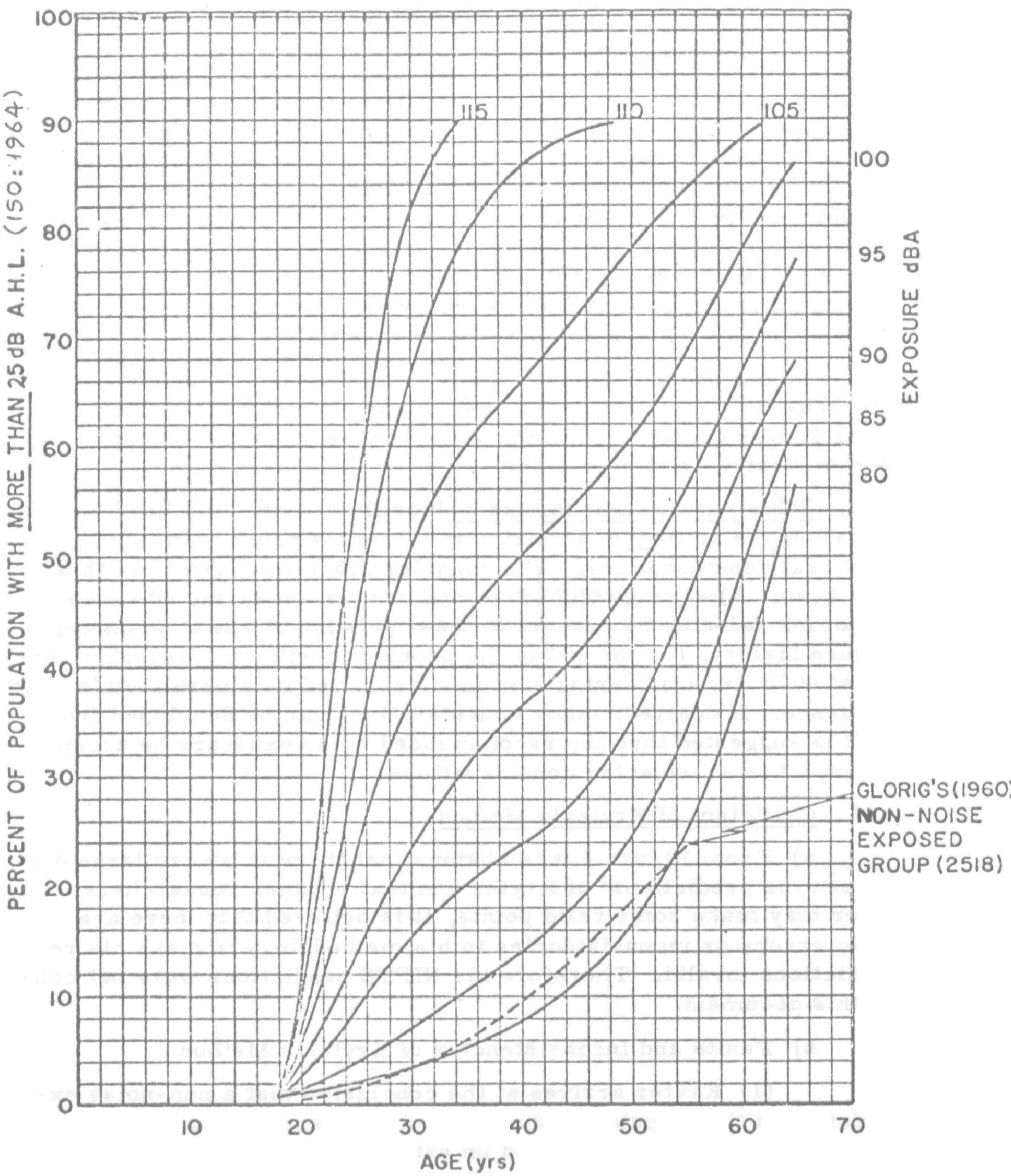

PERCENT OF POPULATION WITH MORE THAN 25 dB A.H.L. (ISO:1964)
AGE (yrs)
EXPOSURE dBA
115
110
105
100
95
90
85
80
GLORIG'S (1960) NON-NOISE EXPOSED GROUP (2518)

Figure 16.

9. Percent of the Population with more than a 5 dB NIPTS at 4000 Hz Versus 8 Hour Noise Exposure Level. Since in general the audiometric frequency at 4000 Hz is the most sensitive indicator of hearing changes, a special table was derived to indicate the percentage of the population expected to exceed a measurable NIPTS (greater than 5 dB) for a daily 8 hour noise exposure of more than 40 years. The expected NIPTS for each of the Sound Pressure levels was calculated or obtained graphically. The NIPTS values of the three methodologies (Passchier-Vermeer, Baughn, and Robinson) were averaged for the various percentile points. These points were plotted on probability paper and a line was drawn through them with a French curve. The intersect point with the 5 dB NIPTS line gives the percent of the population that will exceed a measurable hearing change at that exposure level. Table 17 is a summary of such data.

It must be emphasized that this method is approximate only and is very sensitive to errors in the basic data. To emphasize this variability Table 18 was constructed in the same way as Table 17 except each individual methodology was used alone.

10. Selection of Limit for the 8 Hour Day. Data have been presented that should allow the setting of a maximum allowable noise exposure (8 hour) based on several considerations. The considerations emphasized in this report have been: (a) average NIPTS of total population during 40 years, (b) NIPTS not exceeded by 90 percent of the population at any time during their exposure history, (c) percent of the population with a measurable hearing change at 4000 Hz, (d) hearing risk as determined by a permissible hearing loss or fence. If desired, other considerations can be developed from the data. It is suggested that any recommended noise exposure be acceptable with respect to all selected considerations.

11. Criticism of Kryter's Method.

a) From Figure 1 it is obvious that there is a very large disparity between the predictions of Kryter and that of other researchers. While Kryter may make some valid points, it is believed that there are enough basic errors or inconsistencies in his methodology to make his resulting predictions invalid. Therefore his NIPTS predictions were not considered in this document.

b) Faults and Inconsistencies of Kryter's Method

(1) Kryter arrives at the conclusion that a non-noise exposed population is that population that has not been exposed to a continuous 8 hour noise of 55 dBA. This is based on extrapolation from Baughn's Data and the Public Health Survey of 1962. The faults of this method are:

(a) Baughn's data are for 92, 86, and 78 dBA. From just these 3 points which span a range of 14 dB only it is very questionable that it is justifiable to extrapolate another 23 dB downward to determine

TABLE 17

Derivation of % of Population with greater than 5dB NIPTS after 40 years exposure.

L_{eq}		72	75	80	82	85
NIPTS Averaged over three methods Percentiles	.9	3.8	5.8	9.2	11	13.5
	.75	2.2	3.6	6.5	8.4	11.5
	.5	.7	1.7	4.4	6.4	9.8
	.25	.4	.6	2.2	4.2	7.8
	.1	0	.4	1.7	3.1	5.2
% of Population with more than 5 dB NIPTS		4	15	44	66	92

TABLE 18

Precent of Population with more than 5 dB NIPTS versus L_{eq}

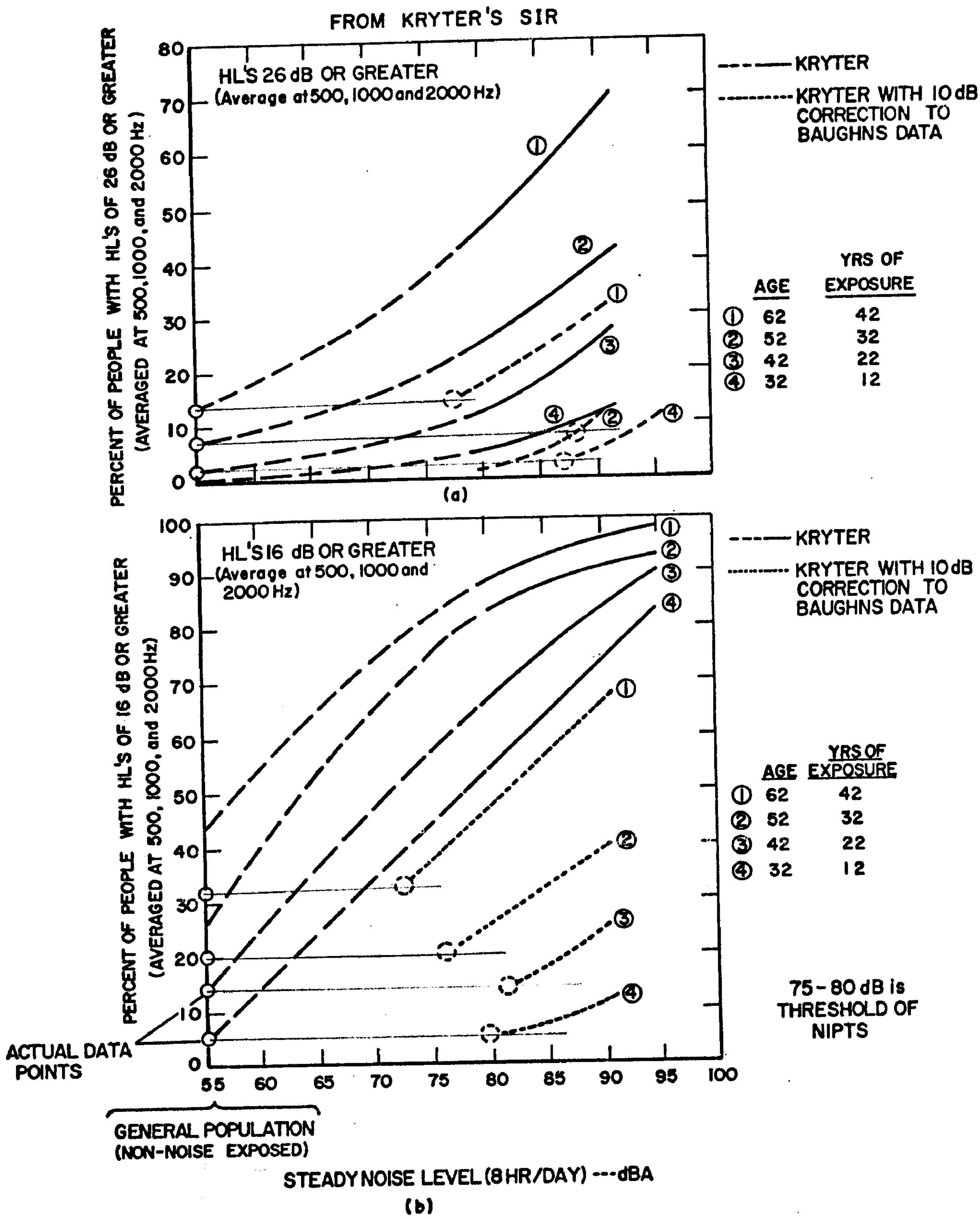
Individual Methods

	L_{eq}	72	75	80	82	85
Averaged NIPTS of 3 Methods	% > 5 dB NIPTS * 4000 Hz	4	15	44	66	92
Individual Methods	Passchier-Vermeer, Unmodified	14	28	50	66	78
	Passchier-Vermeer Straight Regression Line	0	1	21	50	75
	Baughn	N/A	N/A	N/A	34	77
	Robinson	12	17	54	66	83

where the threshold SPL that causes NIPTS is located. Furthermore, most of the three points do not even align in a straight line, thus requiring the extrapolation be made by a series of complex curves (see Figure 17).

(b) Kryter uses two different reports, which probably have different biases, to determine the "NIPTS Threshold." In fact Baughn admits that he had a systematic error of at least 5 dBA and perhaps more in his absolute thresholds. For instance TTS was a problem as Baughn had to test people during working hours. The problems do not unduly jeopardize the validity of Baughn's data when compared with itself as at least some of the biases will be expected to cancel. But when Baughn's data are compared to other data, such differences will not tend to cancel and must be fully considered. Looking at the PHS curves and Baughn's 78 dBA curves versus age, (Figure 18), it can be noted that they look very similar except Baughn's 78 dBA curve is displaced upward by 10 dBA. Kryter would attribute this upward shift to the fact that the 78 dBA exposure was still causing a substantial hearing loss. But plotted also in Figure 18 is the median of Baughn's pre-exposure audiograms of new 18 year old employees. Note that even for this group, there is still an 8 dB variation in the Public Health Survey data and Baughn's. This variation shows that there were indeed systematic differences between the studies. These differences may have come from audiometric techniques, differences in the population of this midwest area versus the nation as a whole, or some other subtle bias; however, it is clear that the 78 dB exposure is not, a priori, the cause of the 10 dB discrepancy between Baughn's data and the Public Health Survey data.

(c) In order to demonstrate the sensitivity of Kryter's method to systematic error between the two sets of data, consider that the hearing levels of Baughn's subjects were systematically 10 dB too high. This 10 dB error has significant implications with respect to Kryter's NIPTS threshold prediction. See Figure 17 for a typical correction if Baughn's data are reduced by 10 dB. Such a 10 dB reduction now brings the "NIPTS Threshold" up to 75-80 dBA with far less extrapolation. This puts Kryter more in line with other researchers. It should also be apparent that the gain in "NIPTS Threshold" was 20-25 dB for a change of only 10 dB in Baughn's raw data. This indicates that with an arbitrary fence of so many dB, the results obtained are very sensitive to the absolute thresholds of the data used. One only has to look at the literature to see how often a 10 dB or greater difference has occurred between researchers as to what is the median threshold level. The 10 dB difference between the 1951 ANSI standard and the 1969 ANSI standard for the speech frequencies is an obvious example. It should be noted that even if the systematic difference in Baughn's data was as small as 5 dB, which is the minimum amount of error predicted by Baughn, Kryter's methodology would still predict that the threshold of the effect is at 65-70 dBA, not 55 dBA. Therefore, even if one would agree with Kryter that his methodology is adequate, one must correct his threshold value of 55 dBA by at least 10-15 dBA and probably much more.



FROM KRYTER'S SIR
HL'S 26 dB OR GREATER
(Average at 500, 1000 and 2000 Hz)
PERCENT OF PEOPLE WITH HL'S OF 26 dB OR GREATER
(AVERAGED AT 500, 1000, and 2000 Hz)
KRYTER
KRYTER WITH 10 dB CORRECTION TO BAUGHNS DATA
AGE
YRS OF EXPOSURE
① 62 42
② 52 32
③ 42 22
④ 32 12
(a)
HL'S 16 dB OR GREATER
(Average at 500, 1000 and 2000 Hz)
PERCENT OF PEOPLE WITH HL'S OF 16 dB OR GREATER
(AVERAGED AT 500, 1000, and 2000 Hz)
KRYTER
KRYTER WITH 10 dB CORRECTION TO BAUGHNS DATA
AGE
YRS OF EXPOSURE
① 62 42
② 52 32
③ 42 22
④ 32 12
75 - 80 dB is THRESHOLD OF NIPTS
ACTUAL DATA POINTS
GENERAL POPULATION
(NON-NOISE EXPOSED)
STEADY NOISE LEVEL (8 HR/DAY) ---dBA
(b)

Figure 17

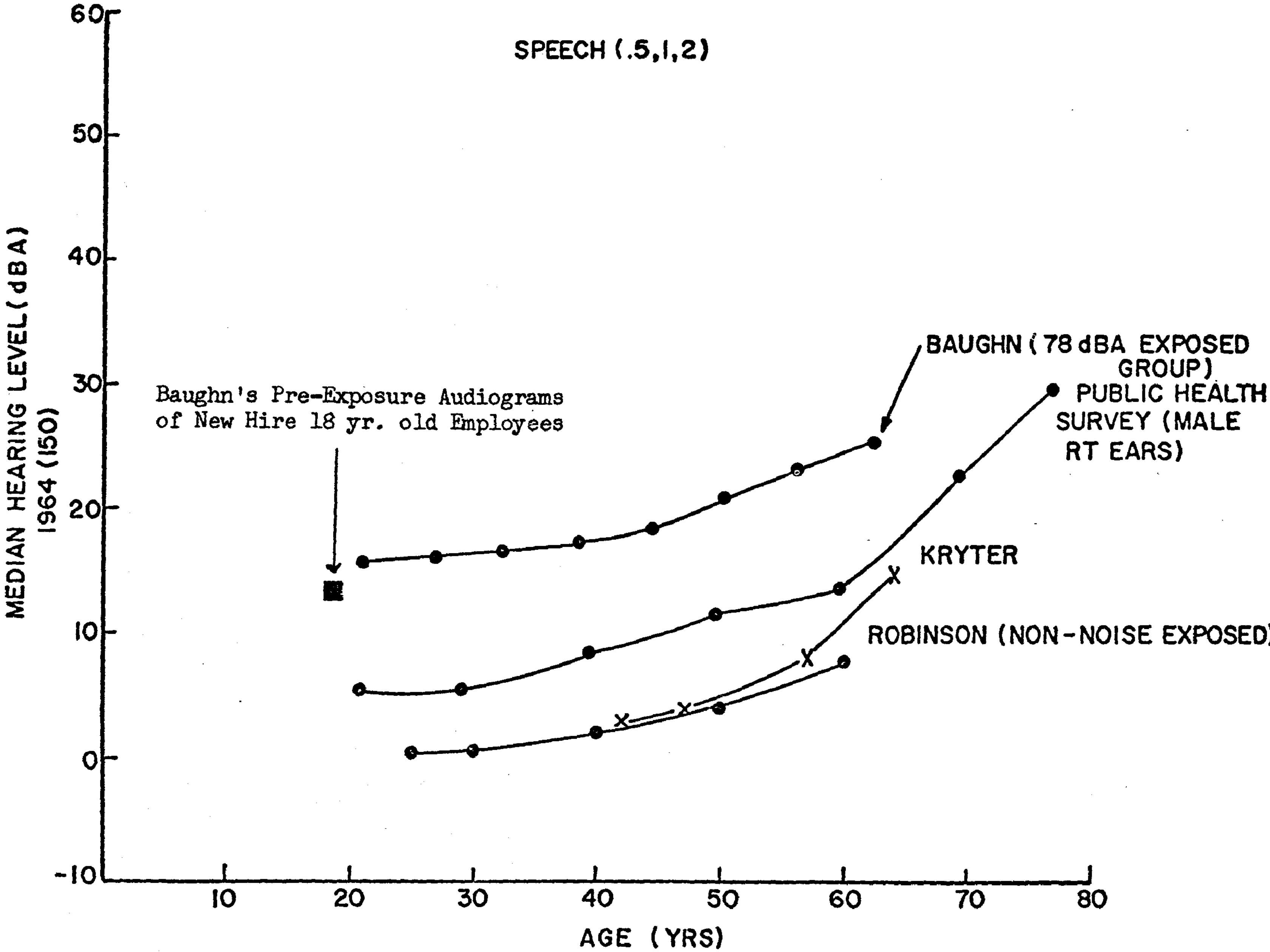

SPEECH (.5,1,2)
MEDIAN HEARING LEVEL (dBA) 1964 (ISO)
AGE (YRS)
Baughn's Pre-Exposure Audiograms of New Hire 18 yr. old Employees
BAUGHN (78 dBA EXPOSED GROUP)
PUBLIC HEALTH SURVEY (MALE RT EARS)
KRYTER
ROBINSON (NON-NOISE EXPOSED)
60
50
40
30
20
10
0
-10
10
20
30
40
50
60
70
80

Figure 18.

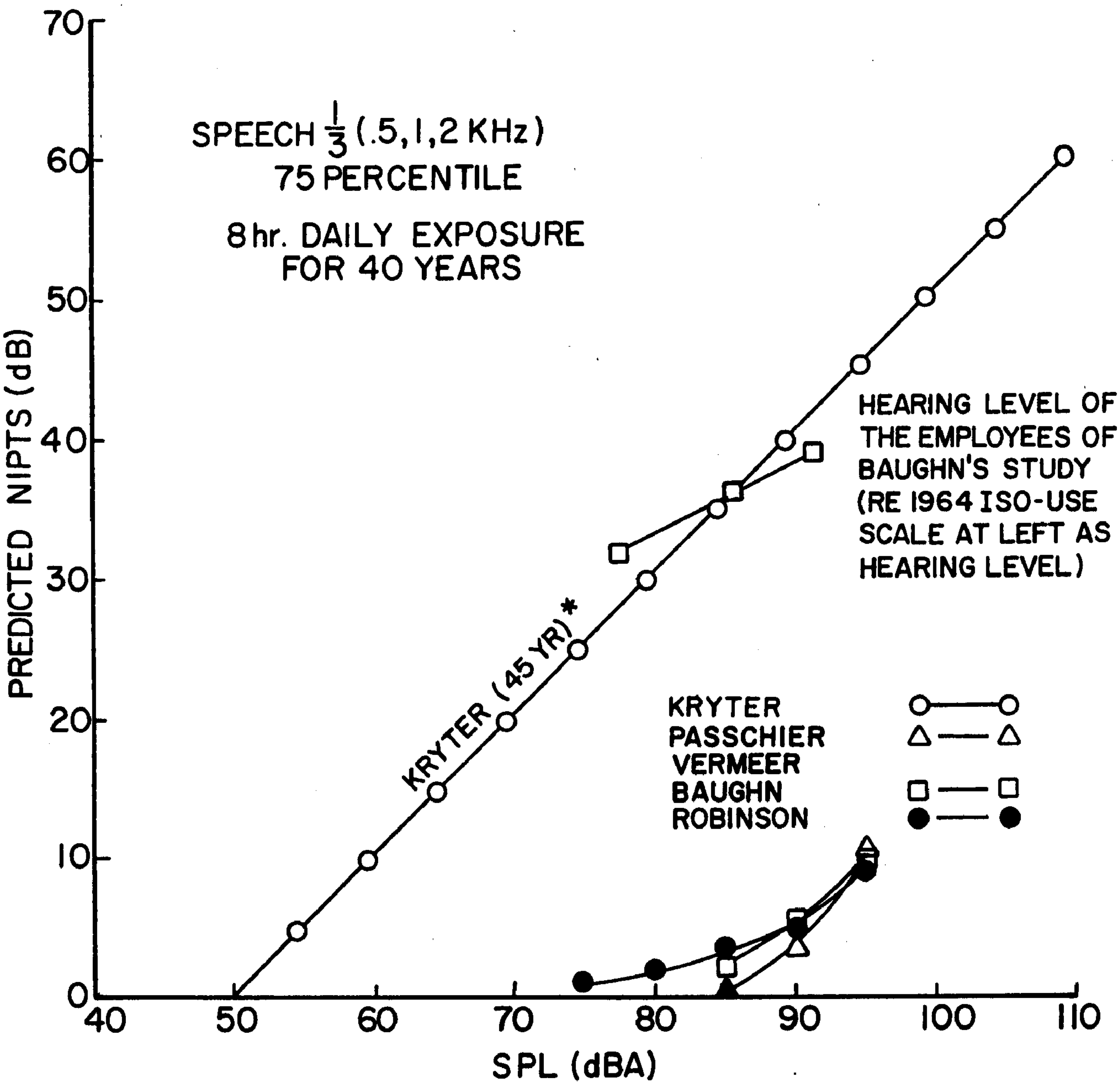
(2) On Figure 18, Kryter's recommended presbyacusis curves are plotted along with Robinson's. Note that Robinson's values are below Kryter's. Yet Robinson has found that NIPTS for speech (0. 5, 1 and 2 kHz) essentially disappears for less than 75 dBA exposure. This does not fit with Kryter's assumption that 75 dBA is causing a very significant shift in hearing.

(3) Another inconsistency of Kryter's NIPTS predictions can be seen if these values are compared to the actual hearing levels of Baughn's workers. Figure 19 is such a comparison. Somehow Kryter has taken Baughn's data and manipulated the data such that the predicted NIPTS is the same as the total hearing loss of these individuals. Since hearing loss consists of both NIPTS and aging, the only way to predict such a large value of NIPTS, as I see it, is to predict that hearing will not change with age. This is clearly wrong, of course, and even Kryter predicts 15 dB loss from presbyacusis at age 65.

12. D-Versus A-Weighting of Frequency. At first glance, the use of a D-weighting scale instead of an A-weighting might seem attractive. The D-weighting added approximately a 10 dB penalty to the frequencies that are more likely to cause NIPTS at the super-sensitive 4000 Hz audiometric frequency. If one's goal is to protect the 3, 4 and 6 kHz frequencies equally with the lower frequencies of 0. 5, 1 and 2 kHz, then perhaps the D-weighting would be desirable. However, D-weighting also emphasizes the frequencies above 5600 Hz by 6-9 dB, and thus would tend to give these high frequencies more influence than they properly deserve. The very low frequencies are also emphasized more. Thus protection of the speech frequencies of 0. 5, 1 and 2 kHz is slightly deemphasized. Qualitatively, the argument reduces to this: if one desires that the risk of hearing loss should be equal for the speech frequencies of 0. 5, 1 and 2 kHz and for the frequency of 4 kHz, then the D-scale may be a slightly better approximation. If one is willing to allow 5 dB more loss at 4 kHz than at the speech frequencies (0. 5, 1 and 2) then the dBA is the better approximation. The general feeling among most investigators is that the frequencies of 0. 5, 1 and 2 are somewhat more essential; therefore it is recommended that the A-scale be used for purposes of hearing conservation. The D-scale can be used to predict the effects of noise on hearing, but the proper adjustments must be made to provide the same safety to the lower speech frequencies.

13. Duration of the Exposure.

(1) Less than 8 hours. The relationships between NIPTS and SPL discussed up to this point have been based on an 8 hour working day exposure. The auditory system can tolerate higher SPLs provided that the exposure time is shorter (6). It is not entirely clear, but it is suspected that the SPL should be reduced if the ear is exposed to noise for durations greater than 8 hours.



* KRYTER CONSIDERS THIS HEARING LEVEL (FROM TABLE III [KRYTER (16)])

Figure 19

The decision as how to relate SPL to duration in order to obtain equally noxious noise exposure depends upon how the auditory damage progresses with time. Three popular theories are equal energy (ISO standard for example), equal pressure (Kryter for example) or a compromise between equal energy and equal pressure (NIOSH for example). The equal energy rule predicts an equal hazard if the SPL is reduced 3 dB for each doubling of duration (SPL varies inversely as 10 log t). The equal pressure rule dictates that the SPL must be reduced 6 dB for each doubling of time (SPL varies inversely as 20 log t). The NIOSH compromise suggests that the SPL should be reduced by 5 dB for each doubling of time (SPL varies inversely as 16. 6 log t). The selection of one rule over another is not a trivial question. For instance, considering the 8 hour exposure as the baseline, equal pressure allows the permissible SPL for a one-minute exposure to be 27 dB higher than that allowed for equal energy.

There is a lack of unequivocal NIPTS data that would suggest which rule to use. Therefore, equal TTS has been the only method for assessing equal hazard. This is why a considerable effort was given in the main criteria document to the relationship of TTS (via animal and human studies) to NIPTS.

Experimental results have not yet completely clarified the problem. Spieth and Trittipoe (7) indicate that the equal pressure rule provides equal TTS for high level, short duration exposures. Ward (8) has found that equal energy best predicted an equal amount of TTS for chinchilla during 4 exposure conditions.

Some sense can be made out of the apparent contradictions if the CHABA curves are studied. Figure 20 is a replot of the CHABA curves that relate equal TTS at various Sound Pressure Levels (SPL), durations and audiometric frequencies. All curves, only for thepurposes of comparison, were related to the same SPL value for the 8 hour duration. Various schemes for relating SPL to duration are then plotted. The results show two main points. These are, (1) No simple function of log t best matches the CHABA values for all time durations and (2) the selection of the function used varies with the audiometric frequency that is to be protected. At this time, it is not suggested that a function other than the log t be used since it would effectively eliminate the ability to provide dosimeters and perhaps unduly complicate the situation. The use of equal noxious TTS values is not that firmly secure to warrant such refinements. Spieth and Trittipoe results can be explained, however, since the durations with which they were concerned were short. For exposures of 16 minutes and less, TTS at 4 kHz does start to follow the equal pressure law.

Using Figure 20 as a basis, the decision as to which rule to use reduces to which audiometric frequencies will be protected. If 4000 Hz is to be protected, then the equal energy rule will be the best approximation. If only the speech frequencies of 0. 5, 1 and 2 kHz are to be protected,

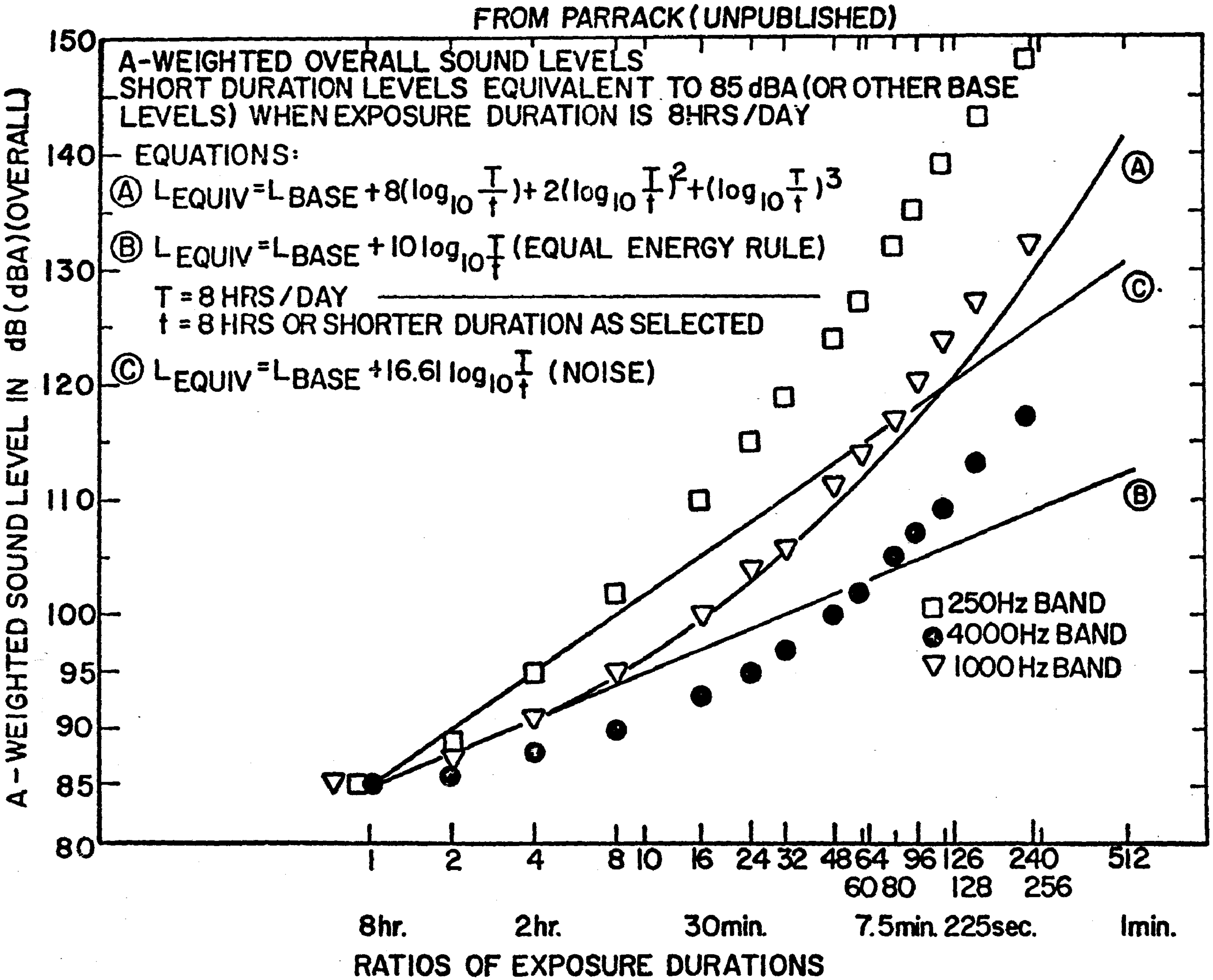

FROM PARRACK (UNPUBLISHED)
A-WEIGHTED OVERALL SOUND LEVELS
SHORT DURATION LEVELS EQUIVALENT TO 85 dBA (OR OTHER BASE LEVELS) WHEN EXPOSURE DURATION IS 8HRS/DAY
EQUATIONS:
Ⓐ $L_{EQUIV} = L_{BASE} + 8(\log_{10}\frac{T}{t}) + 2(\log_{10}\frac{T}{t})^2 + (\log_{10}\frac{T}{t})^3$
Ⓑ $L_{EQUIV} = L_{BASE} + 10\log_{10}\frac{T}{t}$ (EQUAL ENERGY RULE)
T = 8 HRS/DAY
t = 8 HRS OR SHORTER DURATION AS SELECTED
Ⓒ $L_{EQUIV} = L_{BASE} + 16.61\log_{10}\frac{T}{t}$ (NOISE)
A-WEIGHTED SOUND LEVEL IN dB (dBA) (OVERALL)
150
140
130
120
110
100
95
90
85
80
Ⓐ
Ⓒ
Ⓑ
250Hz BAND
4000Hz BAND
1000 Hz BAND
1 2 4 8 10 16 24 32 48 64 96 126 240 512
60 80 128 256
8hr. 2hr. 30min. 7.5min. 225sec. 1min.
RATIOS OF EXPOSURE DURATIONS

Figure 20.

the NIOSH rule of 5 dB change in SPL for each doubling of time is a very good compromise. Either rule will overprotect for short time durations and as such will add an additional safety factor into any standard for hearing conservation. It should be noted that given an exposure level and duration, Figure 20 can be used to directly predict the relation between such a condition and the dBA SPL of 8 hours duration that will cause the same amount of TTS (or therefore NIPTS). The usefulness of such a figure is limited, however, as typically a total daily noise exposure does not occur in such a simple manner. Therefore, some approximation scheme such as equal energy must be used. Correction factors for such variables as the intermittency of the noise are then required.

(2) Durations more than 8 hours. There is a noticeable lack of actual NIPTS data on 24 hour exposure situations, therefore most of what is known is based upon TTS data.

Smith et al. (9) exposed groups of men for 25 hours to a 70 Hz tone or a 300 Hz tone at 113 dB SPL. In general TTS ranged from 0 to 20 dB. Yuganov et al. (10) simulated a 24 hour space mission with an ambient noise of about 75 dB (not enough details are given to convert to dBA but a rough estimate would be 80 dBA) and found a TTS of 10 to 20 dB with recovery in 1-2 hours. Mills (11) exposed himself to a 93 dB SPL signal for about 30 hours and measured 25-27 dB TTS which required 2-4 days for total recovery. Melnick (12) exposed subjects for 16 hours to the 300-600 Hz octave band at 95 dB SPL and found the maximum TTS to be 15-20 dB. Recovery was complete within 20 hours past exposure. The Environmental Protection Agency (EPA) is currently sponsoring research at the Aerospace Medical Research Laboratory (AMRL) to further investigate this question with human subjects. At this time, however, there is no evidence that the effect of continuous noise is more noxious that what would be predicted by use of the logarithm of time. In fact, several investigators (Mills, Melnick) have suggested that TTS reaches limiting value that may occur between 16-48 hours. Studies accomplished on animals (Mills and Talo (13); Melnick (12); and Carder and Miller, (14) all predict that TTS will reach an asymptote or a limiting value. Exposures have been for as long as three weeks to three months, with the TTS reaching its limit within the first day (Carder and Miller (14) and Mills (in Press)). What is not so clear is the question, Does hearing damage stop when such a limiting value that is independent of duration is reached?" Based on Carder and Miller's animal findings that similar recovering curves occurred once the asymptotic values were reached, the answer appears to be a qualified yes if the TTS is less than 20-30 dB. Recent work not yet published (Mills (in Press)) indicates that for greater TTS than 30 dB, such recovery may change with exposure time. Since TTS will normally be less than 30 dB only for exposures less than 85 dBA, this limit will be considered valid only for exposures less than 85 dBA. The significance of such a limit is that there may be little difference between a continuous lifetime exposure (24 hours exposure daily with no quiet periods) or 24 hour exposures with rest periods in between each exposure. Up to now, the term 24 hour exposure has been used rather loosely to mean either case. We will continue to use it in this context for exposures less than 85 dBA with the justification that the asymptotic behavior of TTS allows such an approximation to be made.

The equal energy rule would predict that the 24 hour exposure should be 5 dB less than the 8 hour exposure. The NIOSH rule would predict an 8 dB difference. The animal results of Carder and Miller show better correlation with the NIOSH rule. The results of Melnick (1972) on humans show that the equal energy hypothesis gives a better correlation (it is even slightly conservative).

Preliminary results at AMRL have not shown the necessity of deviating from the equal energy concept. Therefore a 5 dB reduction in dBA is considered the best approximation at this time for extrapolating 8 hour data to 24 hours.

If the SPL is below the value which causes measurable TTS at 8 hours, then there is no evidence that there will be measurable TTS at 24 hours.

14. Estimation of the Accuracy in Relating NIPTS to Noise Exposure.

a) Underestimation Errors.

(1) Worst case of three methods.

Averaging the NIPTS predictions over the three methods will provide in some cases lower NIPTS predictions than one method by itself. In order to estimate the worst conceivable situation, the worst case values are included in Table 14. This table already consists of the maximum NIPTS expected for the .9 percentile level during some part of a 40 year exposure lifetime. Therefore selecting the highest predicted NIPTS value of the three methods should set an approximate upper bound on the possible estimation of NIPTS. That such an upper bound varies at the maximum by only 4 dB from the average provides additional confidence that any prediction errors in the average data presented are not likely to underestimate the risk of noise by more than 4 dB.

(2) Percentile estimates.

The estimation of NIPTS for some percentile has been accomplished by subtracting the hearing level of that percentile of the non-noise exposed group from the hearing level of the respective percentile of the noise exposed group. The .9 percentile group is thus that group whose hearing level is worse than 90 percent of the population. If the .9 percentile point moves 10 dB because of noise exposure, then it is considered that the .9 percentile group had NIPTS of 10 dB. However, this 10 dB shift could have been caused by some of the exposed ears shifting from a .1 percentile hearing level to the .9 percentile hearing levels before the noise exposure, then these exposed ears would have received a true NIPTS of 30 dB. Undoubtably there are a few individuals who have this occur. There is no way to account for such individual susceptability and it must be emphasized that all estimates are for statistical groups of the population, not individuals. Changes in the .9 percentile hearing level is still considered the best indicator of the true NIPTS not exceeded by 90 percent of the population, however, for two reasons. First, the .9 percentile in a noise situation normally does exhibit the greatest shift when exposed to noise. Apparently the people that make up this group are those most sensitive to the noise exposure. Second, changes in the .9 percentile hearing level should be considered more significant in that the hearing of this group is already worse than 90 percent of the population. A shift in this percentile point is thus liable to have more significance than a shift in the .1 percentile point.

It can be noted that the average NIPTS over 40 years of exposure circumvents this problem. The errors introduced in saying that 90 percent of the population will have less NIPTS than some value X when this NIPTS value was obtained by changes in the .9 percentile hearing level are difficult to estimate. If the changes in the .9 percentile hearing level are small, then one can reasonably expect that the error will be small. But as stated earlier, a better way to look at this problem is to consider that the .9 percentile hearing level changes are the most important measure. In this light, we will not unduly worry about this error.

b) Overestimation Errors.

(1) "Least effect" of three methods.

Averaging over the three methods will also provide higher NIPTS predictions than some one method alone. Similiar to the worst case discussed previously, the maximum difference between a single method and the average is small. In fact this difference is < 2 dB for the speech frequencies (either 1/3 (0.5, 1, 2 kHz) or 1/4 (0.5, 1, 2, 4 kHz) and < 6 dB for 4000 Hz.

(2) Bias introduced in manipulation of the basic data.

Figure 21 shows how Passchier-Vermeer used the data available to her for NIPTS at 4000 Hz. On this figure a curved line is used to connect the data points represented. One criticism of her work is that a linear least squares regression line could have been used just as well. As can be seen in Figure 21, a linear regression line will predict that the median NIPTS threshold is at 80 dBA, not 7 or 8 dB lower as would be expected by extrapolating Passchier-Vermeer's existing curve. It can only be left up to individual judgement as to which approach is correct. Using a linear regression line, the NIPTS (.9 percentile) would be expected to be 0 dB for 75 dBA (8 hour) exposure and 8 dB for an 80 dBA (8 hour) exposure. This compares to a NIPTS (.9) of 10 dB for 75 dBA and 13.8 for 80 dBA. At 85 dBA either approach predicts the same amount of NIPTS. Therefore the greatest possibility of error at the 4000 Hz audiometric frequency is below 85 dBA. The average of the three methods produced 6 dB for 75 dBA,

MEDIAN AND MEAN HEARING LOSS CAUSED BY EXPOSURE TO NOISE FOR AT LEAST 10 YEARS, AS A FUNCTION OF SOUND LEVEL.

(From Passchier-Vermeer)

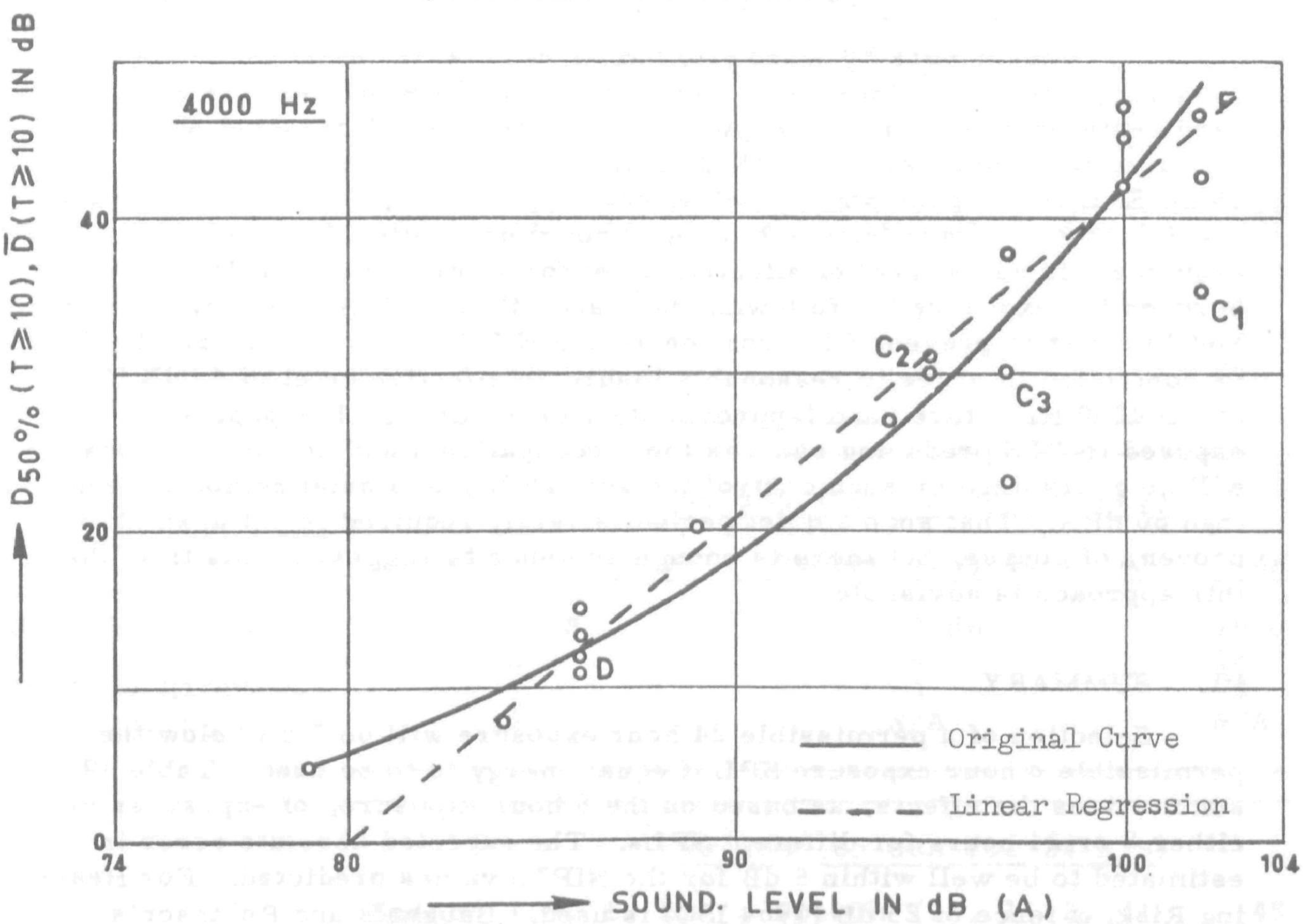


Figure 21.

so the maximum error at 75 dBA is 6 dB. Likewise, it can be shown that at 80 dBA this possible error is 3 dB. Note that the magnitude of these errors is the same as was obtained by looking at the "least effect" of the three methods.

c) In summary, the 4 kHz and (.9 percentile) data presented in Table 17 can reasonable be considered accurate within a range of +4 dB and -6 dB (or more simply ± 5 dB) of the values given as long as the L_{eq} range under consideration is between 70 and 90 dBA.

B. Requirement for "Quiet"

Recent work by Ward (15) has shown that the quiet intervals between high intensity noise-bursts must be below 60 dB SPL for the octave band centered at 4000 Hz if recovery from Temporary Threshold Shift (TTS) produced is to be independent of the quiet period SPL. Ward suggests 55 dB SPL as the point where the "effective quiet" might be. Assuming then that (1) TTS recovery from a 90 dBA (8 hour) occupational exposure also requires this same level of effective quiet for some part of the 16 hours between the exposure the following day, and (2) total TTS recovery is important in order to prevent TTS from becoming NIPTS, noise exposure should be controlled in order to reasonably insure an effective quiet of 55 dB SPL at the 4000 Hz octave band (approximately 62-65 dBA). The population exposed to TTS producing sources (both occupational and non-occupational) will be guaranteed by such control the availability of a quiet period of less than 60 dBA. That such a quiet period is really required is not absolutely proven, of course, but there is enough evidence to suggest at this time that this approach is advisable.

III. SUMMARY

Selection of a permissible 24 hour exposure will be 5 dB below the permissible 8 hour exposure SPL if equal energy is to be used. Table 19 summarizes the effects, as based on the 8 hour exposure, of exposures of either 8 or 24 hours for different SPLs. The expected absolute error is estimated to be well within 5 dB for the NIPTS values predicted. For Hearing Risk, a fence of 25 dB (1964 ISO) is used. Baughn's and Robinson's Hearing Risk values are averaged. For the 85 and 90 dBA (8 hour) exposure conditions, the resulting average is within ± 3 percentage points of Hearing Risk predicted by either method. For an 80 dBA condition, Robinson's estimate (10 percent) and Baughn's estimate (0 percent) were averaged to obtain 5 percent. While these values might seem rather divergent, it is noteworthy that NIOSH predicted 3 percent for this level. The Hearing Risk at 60 years of age was used. Hearing Risks at younger ages are less than these values (see Tables 15 and 16).

Table 19 Summary of effects expected for continuous noise exposure of 8 hours to the levels stated.

	75 dBA (70 dBA for 24 hrs)		
	Speech (.5, 1, 2)	Speech (.5, 1, 2, 4)	4K
Max NIPTS (.9)	1 dB	2 dB	6 dB
NIPTS at 10 yr (.9)	0	1	5
Average NIPTS	0	0	1
Max Hearing Risk*	N/A	N/A	N/A

	80 dBA (75 dBA for 24 hrs)		
	Speech (.5, 1, 2)	Speech (.5, 1, 2, 4)	4K
Max NIPTS (.9)	1 dB	4 dB	11 dB
NIPTS at 10 yr (.9)	1	3	9
Average NIPTS	0	1	4
Max Hearing Risk*	5%	N/A	N/A

	85 dBA (80 dBA for 24 hrs)		
	Speech (.5, 1. 2)	Speech (.5, 1, 2, 4)	4K
Max NIPTS (.9)	4 dB	7 dB	19 dB
NIPTS at 10 yr (.9)	2	6	16
Average NIPTS	1	3	9
Max Hearing Risk*	12%	N/A	N/A

	90 dBA (85 dBA for 24 hrs)		
	Speech (.5, 1, 2)	Speech (.5, 1, 2, 4)	4K
Max NIPTS (.9)	7 dB	12 dB	28 dB
NIPTS at 10 yr (.9)	4	9	24
Average NIPTS	3	6	15
Max Hearing Risk*	22.3%	N/A	N/A

* 25 dB ISO Fence

IV. CONCLUSIONS

The main purposes for preparing this report were twofold.

(1) The first purpose was to resolve the question of what and/or whose data should be used to depict the relationship between loss of hearing sensitivity and noise. The question was resolved by using three leading predictive methodologies and averaging the results. This averaging has been criticized by some as unscientific. The argument is that one should pick the most scientifically sound method and use it alone. But the problem then remains of how to select the single best method. Averaging the three methods avoids such a selection. But even more important, averaging the three methods prevents the possibility of selecting the worst method. Therefore, the averaging technique was considered as the best way to handle the problem of data selection.

(2) The second purpose of this supplement was to discuss the methodology of Kryter (16). Criticism of Kryter's paper is provided by several reviewers in the same issue of the Journal of the Acoustical Society of America. At this time there are too many basic inconsistencies in Kryter's method for his results to be included in this report.

REFERENCES

1. Passchier-Vermeer, W. Hearing Loss Due to Exposure to Steady-State Broadband Noise. Rept. No. 35, Institute for Public Health Eng., The Netherlands, 1968.

2. Robinson, D. W. The Relationships Between Hearing Loss and Noise Exposure. National Physical Laboratory Aero Report Ae32, England, 1968.

3. Baughn, W. L. Relation Between Daily Noise Exposure and Hearing Loss as Based on the Evaluation of 6835 Industrial Noise Exposure Cases. In Press as AMRL-TR-73-53, Aerospace Medical Research Laboratory, Wright-Patterson AFB, Ohio.

4. Passchier-Vermeer, W. "Steady-State and Fluctuating Noise: Its Effects on the Hearing of People" in Occupational Hearing Loss, D. W. Robinson, Ed. Academic Press, N. Y., 1971.

5. Robinson, D. W. "Estimating the Risk of Hearing Loss due to Continuous Noise". In Occupational Hearing Loss, D. W. Robinson, Ed. Academic Press, N. Y., 1971.

6. Kryter K. D. W., J. D. Miller, and D. H. Eldridge. Hazardous Exposure to Intermittent and Steady-State Noise. J. Acoust. Soc. Am., Vol. 39, No. 3, p. 451, 1966.

7. Spieth, W. and W. J. Trittipoe. Intensity and Deviation of Noise Exposure and Temporary Threshold Shifts. J. Acoust. Soc. Am., 30, 710, 1958.

8. Ward, W. D. and D. A. Nelson. On the Equal-Energy Hypothesis Relative to Damage-Risk Criteria in the Chinchilla. In Occupational Hearing Loss, D. W. Robinson, Ed. Acad. Press, N. Y., 1971.

9. Smith, P. F., M. S. Harris, J. S. Russotti and C. K. Myers, Effects of Exposure to Intense Low Frequency Tones on Hearing and Performance. Submarine Medical Research Laboratory, Naval Submarine Medical Center Report No. 610, 1970.

10. Yuganov, Ye, M. et al. Standards for Noise Levels in Cabins of Spacecraft During Long Duration Flights. (Tech. Transl. F-529, National Aeronautics and Space Administration, Washington, D. C., 1969.)

11. Mills, John H., Roy W. Gengel, Charles S. Watson and James D. Miller, "Temporary Changes of the Auditory System Due to Exposure to Noise For One or Two Days". J. Acoust. Soc. Am., Vol. 48, pp. 524-530, 1970.

12. Melnick, W. Investigation of Human Temporary Threshold Shift (TTS) from Noise Exposure of 16 Hours Duration. (Presented at the Acoustical Society of America, December 1972 meeting.)

13. Mills, J.H. and S.A. Talo. Temporary Threshold Shifts Produced by Exposure to High-Frequency Noise. Journal of Speech and Hearing Research, Vol. 15, September 1972, pp. 624-631.

14. Carder, H.M. and J.D. Miller, "Temporary Threshold Shifts From Prolonged Exposure to Noise," Journal of Speech and Hearing Research, Vol. 15, September 1972, pp. 603-623.

15. Ward, W. Dixon. The concept of "Effective Quiet," presented at the 85th Meeting of the Acoustical Society of America, April 1973.

16. Kryter, K.W., "Impairment to Hearing from Exposure to Noise". J. Acoust. Soc. Am., Vol. 53, No. 5, May 1973, pp. 1211-1234.

☆U.S.Government Printing Office: 1973 — 758-426/78