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Prediction of NIPTS, Hearing Impairment and Handicap

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16. Abstract (Limit: 200 words) A method was developed for predicting noise induced permanent threshold shift (NIPTS) based on exposure to steady, intermittent, and impulsive noises. Information on pure tone hearing level, speech intelligibility test scores, and self rated hearing ability was derived from a random sample of the general public. The ISO Standard 1999 was found to underestimate NIPTS from exposure to continuous steady noise for an 8 hour workday. The Standard overestimated NIPTS from interrupted steady noise and impulsive/impact noise. Nonoccupational noise exposures, particularly to gun noise, were significantly able to obfuscate hearing losses resulting from the exposure to occupational noise. The new method, Effective Energy, A-weighted (EEA) was able to predict hearing loss from continuous or interrupted steady and impulsive type noises with reasonable accuracy.

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ABBREVIATIONS

dB, decibel.

EEA, Effective Energy, A-Weighted

ISO, International Standards Organization

LAeq8h, A-weighted sound pressure level of 1 second average of sound energy summed over 8 hours.

ELAeq8h, A-weighted sound pressure level of 0.5 second average sound energy summed over 8 hours and adjusted for numbers and durations of interruption of levels of noise.

NIPTS, noise induced permanent threshold shift.

TTS, temporary threshold shift.

FIGURES

SIGNIFICANT FINDINGS

1. A new procedure, EEA (Effective Energy, A-weighted), was derived for predicting NIPTS (noise induced permanent threshold shift) from acoustical measures of years of exposures to steady, intermittent, and impulsive noises. The efficacy of EEA as a general model for predicting NIPTS from a wide variety of temporal and intensity varying noise environments was demonstrated. The EEA method of predicting NIPTS has application to the setting of limits of exposure to noise for the prevention of hearing loss in industry, and in living and recreational environments.

2. ISO Standard 1999 (1990), Determination of occupational noise exposure and estimation of noise-induced hearing impairment, International Organization for Standardization, Geneva, was found to underestimate NIPTS from exposure to more-or-less continuous, for an 8-hour workday, steady noise, and to overestimate NIPTS from interrupted, during the workday, steady noise, and impulsive/impact noises. ISO Standard 1999 has significant status and influence on the preparation and acceptance of guidelines for the protection against hearing loss in industrial workers and the general public. The findings of this project indicate a need for the re-evaluation and modification of the recommendations of that document.

3. It was found that, for the higher intensities of noise, the exposure level at the threshold of NIPTS is deduced to be about the same when the reference control, non-noise exposed, groups are from the same industry as when the reference control groups are of persons with normal hearing. However, with lower noise levels, the level for threshold NIPTS is 10 to 12 dB lower when the control group is of persons with normal hearing, than for a control group selected from non-workplace-noise exposed industrial workers. Exposure to gun noise on the part of 50% or more of industrial workers appears to be the primary factor determining these findings. These findings have implications for the setting of different safe levels of exposure to occupational noise for workers who are, and who are not, also exposed to significant amounts of gun noise.

ABSTRACT

This project had two primary goals :

(1) to determine the reliability of the data bases used in the development of presently accepted methods of predicting losses in thresholds of hearing sensitivity from exposure to noise; and

(2) to determine the quantitative relation between those hearing losses and the ability to understand speech under real-life conditions.

Two approaches to these goals were followed: (1) a critical review and re-analysis of published research data relevant to the development and validation of present methods for predicting noise induced hearing loss, and (2) analysis of pure-tone hearing level, speech intelligibility test scores, and self-ratings of hearing ability in real-life obtained from a large, random sample of the general public during a U. S. Public Health Survey.

It was found that: (a) nosocusis and sociocusis, especially that from exposure to gun noise significantly obfuscates hearing losses from exposure to occupational noise, and (b) presently accepted methods, including ISO Standard 1999, for predicting, from physical noise measurements, hearing loss, underestimate the loss from 8 hour workday, steady noise, and overestimate the loss to be expected from exposures to interrupted steady noise and impulse/impact noises. A new method that predicts with reasonable accuracy hearing loss from continuous or interrupted steady and impulsive-type noises has been partially developed as part of work effort under the project.

REPORT

Background. Loss of hearing sensitivity from exposure to noise is a significant health problem for industrial workers, and for the general population of modern societies. Although quantitative research has been conducted for the past 50 or so years on this matter, a full understanding, from either a practical or scientific point of view, of the development of noise induced hearing losses is not yet available.

The methods that have been developed for estimating the magnitude of hearing losses to be expected from exposures to industrial, or other, noise environments can not predict with practical accuracy the losses to be expected for other than 8-hour workday exposures to steady noise. And even for that condition, presently used methods has been shown to be significantly inaccurate. It was anticipated that ISO standard 1999, published in 1990, would provide an acceptable method for this purpose. However, its efficacy remains to be established, and there are reasons to believe that it is founded on somewhat invalid data.

There are, of course, reasons for the seemingly intractable nature of this problem. Most important are the interactive relations between threshold shifting effects of presbycusis, nosocusis and sociocusis, especially that from gun noise, with the threshold shifting effects of a particular workplace noise condition. In addition, in some of the past studies of NIPTS, the levels and temporal patterns of exposures to intermittent noise were measured and reported in ways that made interpretation of the findings difficult.

This raises the question of whether one can deduce, from data of the hearing levels found in industrial workers exposed to noise, a valid method of estimating NIPTS from physical measures of noise. It is to be noted that studies of noise induced hearing losses in animals has not proven to be very useful in this regard, because, primarily, of the longitudinal nature of the development of NIPTS at the modest levels generally found for exposures to industrial noise, and the uncertainties in extrapolating the results to the human ear.

However, considerable help to this end is to be found in the findings of laboratory studies of TTS (temporary threshold shift) in human subjects from precisely known exposures to a wide variety of steady, and intensity and temporally varying noises and sounds. Also, in the more recent studies of NIPTS in industry, information about nosocusis and sociocusis in the subjects is provided, and the physical noise measures are more definitive than in the earlier studies of industrial noise.. It is believed that the most reliable NIPTS data from industry, adjusted if necessary and possible, for known variations in experimental variables and methods, together with knowledge of the characteristics of recovery from TTS, offer the best basis for achieving a general, and practical, method for estimating the NIPTS to be expected from a wide variety of industrial and 'everyday' noises.

Project Goals:

1. Evaluate the reliability of the data bases used in the development of presently accepted procedures and standards for predicting NIPTS from acoustical measures of noise exposur.

2. Analyze U. S. Public Health Service, and other, data pertaining to the ability of persons with sensorineural, including noise induced, hearing loss, to understand speech intelligibility tests and speech in real-life. Relate impairments to pure-tone hearing levels to measures of auditory handicap for the understanding of speech.

3. Develop a new, general method for accurately predicting NIPTS from exposures to steady, interrupted and impulses noise. This goal was not in the goals originally specified, but evolved from the work being done, as will be discussed below.

Work Accomplished

I. Nosocusis and Sociocusis. The appended papers, "Hearing loss from gun and railroad noise - Relations with ISO Standard", and "Effects of nosocusis, and industrial and gun noise on hearing of U.S. adults", were prepared, in part, under this project to aid in the understanding of the roles played by nosocusis

and sociocusis in the development of NIPTS from industrial noise. These findings were also helpful in the evaluation of methods for predicting NIPTS. These papers were based on analyses made of the hearing levels of some 9800 men exposed to railroad noise. The hearing levels were divided into those for men with histories of nosocusis and no nosocusis, and exposure and no exposure to gun noise. NIPTS was found from comparisons of the hearing levels of the trainmen with those of men with normal hearing, and, also, of the general, unscreened male population.

The principal findings related to the goals of this project are that: (a) gun noise and nosocusis are factors influencing the apparent magnitude NIPTS, as typically measured, and (b) procedures for 'correcting' hearing level data for these effects can be developed. These findings and there implications for the prediction of NIPTS from industrial noise are discussed in detail in the appended reprints.

II. Assessment of Methods for Predicting NIPTS. Published studies of NIPTS in which the noise was more-or-less continuous during 8-hour workdays were examined. The protocols, methods of measuring hearing levels and noise exposure levels, and the findings of these studies were reviewed and evaluated as planned. However, in order to most effectively achieve this goal of the project, it was deemed appropriate to also re-analyze the 'raw' data available from these studies and re-determine therefrom NIPTS values.

III. Development of a New Method. It became clear to the Principal Investigator during this process, that the findings were also applicable to the development a new, and better, method, for predicting NIPTS, particularly if some recourse was made to known principles of auditory fatigue, and to data found in laboratory experiments of TTS from exposure to intermittent noise. The development of a new prediction method was not a specific goal of the project, although it was anticipated by the Principal Investigator that if the findings of project so warranted, a Grant request to allow for such an effort would be, and was, subsequently made.

In any event, it appeared to the Principal Investigator that the reviews and data analyses required to meet these two objectives were so inter-twined they

should be approached together. The Principal Investigator has devoted nearly full-time for the past eight months to those ends.

Methods of Data Analysis. The data were tabulated.for those published studies of NIPTS in which noise exposures, hearing levels, and other experimental variables were adequately measured and defined. Some adjustments to the raw data, if appropriate, were made for the audiological test procedure used, and the effects of nosocusis and exposure to gun noise. NIPTS was found for the individual studies by subtracting the median or mean hearing levels of workers exposed to known levels of noise from the median or mean hearing levels of, when provided, non-factory-noise exposed worker-cohort control groups and, also, from general-public-cohort control groups with normal hearing. NIPTS was also determined for the 10th, 25th, 75th and 90th percentiles of the distribution of NIPTS for those studies in which hearing level data for those percentiles were furnished.

A multiple regression analysis was made of the growth, as found in a number of studies, of NIPTS as a function of years of exposure, keeping daily exposure levels constant. A mathematical equation describing this growth function was used to adjust the workday exposure levels of the various studies for this factor. NIPTS data, at 500, 1000, 2000, 3000, 4000, and 6000 Hz,, for the different studies were plotted against noise exposure expressed as workday levels plus the years-of-exposure factor. For these plots, synthesis trend curves were visually estimated, and then mathematical termed from log-linear and polynomial regression analyses.

Analyses were made of the data from studies of TTS and, to the extent possible, NIPTS as functions of exposures to continuous, interrupted and impulse noise. Basic stimulus-response, and recovery-from-response, characteristics of the ear, as functions of temporal and spectral conditions, were applied to the data to obtain a best-fit between thresholds shifts and different conditions of noise exposure. A general procedure for calculating the effective energy, with respect to causing NIPTS, from exposure to continuous steady, interrupted steady or impulse noise was derived. This quantity was labelled EEA, effective energy, A-weighted, and its daily unit of measurement ELAeq8h.

In-depth reviews were made of various procedures that have been developed for predicting NIPTS from calculations based on physical measures of exposure to noise, and the hearing level data on which they were based. Comparisons were made between the NIPTS values found for different noise exposure conditions and NIPTS as predicted by the proposed EEA and several previously published calculation procedures.

Findings. A paper with full discussion of the results of these analyses and the conclusions to be drawn therefrom is being prepared. Tentative findings and conclusions.are as follows:

1. The effective, for NIPTS, energy in years of exposure to industrial noise was found from analyses of data for a number of studies to be proportional to the average workday A-weighted noise energy, in decibels, plus 8 times the logarithm of years of exposure.

2. NIPTS was found by subtracting from the hearing levels of groups of workplace-noise exposed workers, the hearing levels for like-aged control groups from industry, with both groups unscreened for exposure to gun noise. The 50%ile level for threshold, 0 dB, NIPTS at 4000 Hz from 1 year of 8-hour workday exposures to more-or-less continuous steady noise, was found to be about LAeq8h 90, with somewhat higher thresholds levels at different test frequencies.

3. NIPTS from exposure to gun fire in the military services and hunting and target shooting is a significant factor determining the distributions of the hearing levels of the workplace noise and control groups used to investigate NIPTS from industrial noise. It is estimated, from limited data, that 50% or more of industrial workers have been exposed to significant amounts of gun noise.

4. Procedures for predicting NIPTS that have been deduced from hearing level data for factory-noise exposed worker and control groups that were not screened for exposure to gun-noise, can be expected to prdeict NIPTS with variable accuracy and meaning, depending on the intensity of workplace noise. For example, at 4000 Hz, 50%ile, from 50 years exposure to workplace noise

the estimations of NIPTS, with 50% of the workers using, and 50% not using guns, would be as follows:

(a) for the workers exposed to workplace noise of about 80 to 95 LAeq8h, and who did not use guns, about 5 to 15 dB more workplace NIPTS could be expected than predicted;

(b) for the workers who did use guns and were exposed for 50 years to workplace noise of about 80 to 95 LAeq8h, about 1 to 6 dB more workplace NIPTS could be expected than predicted;

(c) for the total group of workers exposed to workplace noise of about LAeq8h 95 and above, NIPTS from the gun noise would, in general, not be a factor in determining the magnitude or distribution of NIPTS for the group; and

(d) for the total group of workers exposed to workplace noise of about LAeq8h 80 or less, the magnitude and distribution of NIPTS for the group would, in general, be determined by the hearing levels of the workers who had been exposed to gun noise.

5. NIPTS was also found by subtracting from the hearing levels of groups of workplace noise exposed workers, the hearing levels of like-aged control groups from the general population screened for nosocusis and exposure to noise. For this comparison, only data for groups workers who had been screened for nosocusis were used, and noise exposure levels were adjusted on the basis of estimated exposures to gun noise. The threshold level, for 50%ile NIPTS at 4000 Hz from 1 year of 8-hour workday exposures to more-or-less continuous steady noise, was found to be, about LAeq8h 80, with somewhat higher NIPTS thresholds, at different test frequencies. Other data indicated that for intermittent and, especially, impulse noises, the threshold levels would be significantly higher. It was found that the results were reasonably consistent among these studies, but that significantly less NIPTS was predicted for comparable levels of exposure to noise by a method developed by Robinson from a study of the hearing levels of British industrial workers (Burns and Robinson).

6. Robinson's formula for predicting NIPTS is believed to underestimate NIPTS because, primarily, the data base on which it was based involved a volunteer-subject selection process that probably tended to exclude those workers who had the higher amounts of noise induced hearing loss. In the Burns and Robinson study, a printed "handout" was provided to factory management. This

handout advised that the British government was undertaking a research program to help determine whether industrial deafness might attract benefit under their Industrial Injuries Act. .For actual testing, management rejected those workers who volunteered for testing, but for whom management believed their present noise exposure was not amenable to quantitative description, or whose past noise exposure was different from that of their present occupation

It is hypothesized that these procedures may have tended to eliminate workers who were suffering from the higher amounts of NIPTS. A factor contributing to that end would be a reluctance to volunteer on the part of those workers, who knew, or suspected, they had a significant hearing handicap on the belief that the results might prejudice their employment status. It is also possible that managers tended to excluded those volunteers with the more obvious hearing handicaps on beliefs, possibly unjustified, that the handicaps were probably due to past-job, or other, noise environments, or to medical-background factors.

In any event, it is clear that the subjects in the Burns and Robinson study were workers selected from those who came forward as willing to have their hearing tested, whereas in all of the other studies of NIPTS herein analyzed, the hearing level data came from test records of, and/or tests given essentially to all, after any screening for nosocusis or exposure to adventitious noise, noise exposed workers in an industry, or to subjects selected on a random basis from that worker population. It could be argued that the screening for nosocusis and the adjustments for gun noise exposure, which were exemplary in the Burns and Robinson study, were totally inadequate in the other studies of screened workers and accounts for the observed differences between the results. However, this is not a likely explanation, especially for the 10-15 dB lesser NIPTS found at the higher noise exposure levels in the Burns and Robinson study, compared to that found in all the other studies. At these higher noise levels, the effects of the factory noise, and not nosocusis or sociocusis, could be expected to be the dominating factor controlling hearing levels in all of these studies.

7. Passchier-Vermeer also developed a procedure for predicting NIPTS. She derived this method from analyses made of hearing level data from a number

of the earlier studies of NIPTS. However, for these studies Passchier-Vermeer did not consistently determine NIPTS re normal hearing, but incorrectly assumed that the hearing levels for the control groups involved were for normal ears (personal correspondence, 6 August 1992, from Dr. Passchier-Vermeer to the Principal Investigator). This significantly led to an underestimation of apparent NIPTS.

8. ISO Standard 1999 for predicting NIPTS is based of the average of the NIPTS predicted for 8-hour workday exposures to more-or-less continuous noise according to the methods of Robinson and Passchier-Vermeer. Inasmuch as, both of these latter methods appear to underestimate NIPTS for those conditions, it can be concluded that ISO 1999 will also underestimate NIPTS for those conditions.

9. Laboratory studies of TTS and NIPTS, and most industrial studies of NIPTS, indicate that NIPTS from exposures to shorter-than-8 hour durations and interrupted steady, and, especially, impulse noises will be overestimated from an equal-energy measure.of daily exposures. The equal-energy measure of noise exposure is central in the application of the Robinson, Passcbier-Vermeer and and ISO standard 1999 methods for predicting NIPTS. This would indicate that these methods would overestimate NIPTS for these noise conditions.

10. A proposed quantitative measure, EEA, for predicting NIPTS from years of workday exposures to continuous or interrupted (within some specified period, e.g. 8 hours) steady, or impulsive, noises is based on joint consideration of: (a) basic characteristics of the ear to respond to acoustic energy, and to recover from fatigue due to such stimulation; and (b) TTS data collected in laboratory research, plus NIPTS data from a study of the hearing levels of industrial workers exposed to interrupted steady and impulsive noises. Mathematical terms derived for EEA express the A-weighted energy of noise exposures adjusted for reduced hazard of NIPTS because of recovery from stimulation of the ear between occurrences of noise events. .

11. Compared to EEA, ISO 1999 underestimates NIPTS to be expected from 8-hour workday exposures to steady noise by about 0 to 10 dB, depending on test frequency, but overestimates NIPTS from shorter-than-8 hour durations and interrupted exposures to steady noise.

12. NIPTS measured from exposures to industrial impact noise is significantly under, or over, estimated (depending on which of two available formulae are used) by ISO 1999, but not by EEA. NIPTS measured from exposures to industrial impulse noise is significantly overestimated, by as much as 40 dB or so by ISO 1999, but not by EEA. These findings are illustrated in Figure 1.

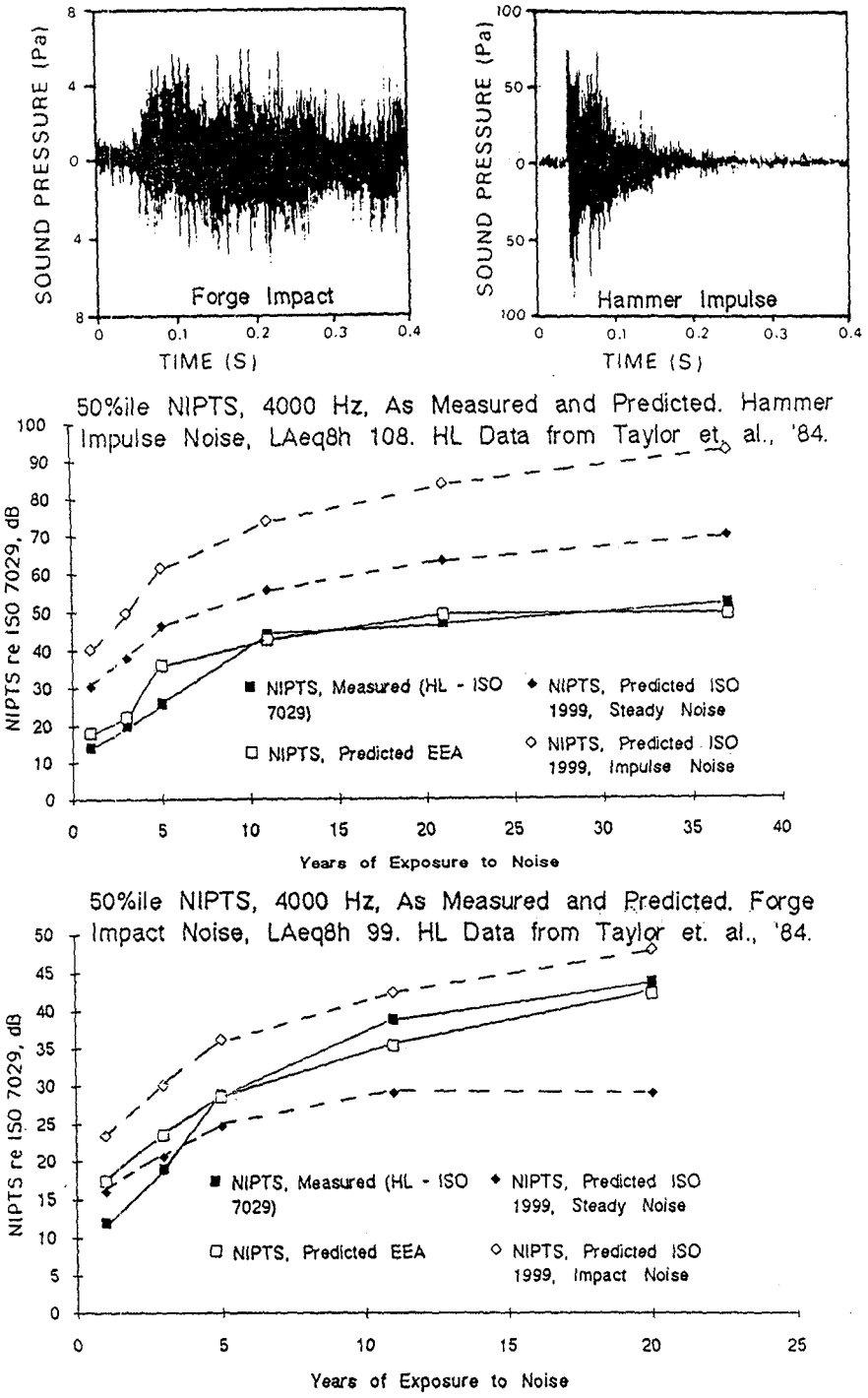

Figure 1. Measured, and predicted by EEA and ISO 1999, NIPTS from impulses of forge hammer (upper graph) from impacts of forge-press (lower graph). Oscillographs of pressure waves of noises at top. Basic data from Taylor et. al..

IV. Handicap for Understanding Speech. Hearing levels, speech intelligibility test scores, and self-ratings of hearing ability for several thousand subjects from a Public Health Survey have been transferred to personal and University computers.from data banks furnished by the U.S. Public Health Service. The distribution statistics for the hearing levels, speech intelligibility scores, and self-ratings of speech understanding in real-life, and zero-order and multiple regression coefficients, and beta weights between the hearing level and speech understanding data have been calculated.

The findings from this task should help achieve a better, more quantitative, basis for setting criteria of hearing handicap than is now available. That goal is an important matter for the evaluation of the impact of losses in hearing sensitivity upon auditory-related work and social activities,.and general well-being.

Since the completion of the reduction of data from the Public Health Survey,, described above, the Principal Investigator has worked full-time on the tasks: (a) Assessment of Methods for Predicting NIPTS, and (b) Development of a New Method. As a result, he was unable during that period to undertake any further analysis or interpretation of the data concerned with speech understanding.

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PRESENT AND POSSIBLE FUTURE PUBLICATIONS

K. D. Kryter, Hearing loss from gun and railroad noise-Relations with ISO Standard 1999, J. Acoust. Soc. Am., 90,,3180-3195, 1991. (Copy Appended)

K. D. Kryter, Effects of nosocusis, and industrial and gun noise on hearing of U.S. adults., J. Acoust. Soc. Am., 90, 3196-3201. (Copy Appended)

A paper, Noise induced hearing loss and a method for its prediction, is near completion. When completed, it is planned to submit it for journal or monograph publication.

A journal paper on relations between pure-tone hearing levels and handicap for speech understanding will be prepared when interpretation of the data that have been analyzed in this project to date, and relevant data from the published literature, are completed.