

Project Title: A statistical learning model for predicting noise-induced hearing loss in humans

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**PD/PI: Dr. Roger P. Hamernik, Email: Roger.Hamernik@plattsburgh.edu;
Phone-518-564-7700**

**Co-Investigators: Wei Qiu (qiuw@plattsburgh.edu); Robert Davis
(Robert.Davis@plattsburgh.edu)**

**Grantee Organization: State University of New York at Plattsburgh
101 Broad St, Plattsburgh, N.Y. 12901**

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List of Terms and Abbreviations

Support Vector Machine (SVM)

Kurtosis [$\beta(t)$]

Gaussian (G)

Non-Gaussian (non-G)

Noise-induced hearing loss (NIHL)

Noise-induced permanent threshold shift (NIPTS)

Cumulative noise exposure (CNE)

Dose-response relation (DRR)

Abstract

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The specific aims of the proposal were: (1) To obtain noise exposure and audiometric data on a large number of workers in heavy industry; (2) To develop and test a statistical learning model [Support Vector Machine (SVM)] for the prediction of hearing loss in humans exposed to high levels of complex noise. The effectiveness of the kurtosis metric in evaluating the risk of hearing loss from complex noise exposures was addressed.

A cross-sectional approach was used in this study. The four main study procedural elements were to: 1) select workplaces based upon consistent noise and employment characteristics; 2) select and recruit subjects based upon strict quality criteria (i.e., health history and stable employment criteria); 3) obtain shift-long temporal waveforms of the noise that workers were exposed to for evaluation of noise exposures on selected subjects; and 4) obtain audiometric testing on all selected subjects. Using the data from (3) and (4), in industries that have high and low kurtosis noise environments, we evaluated several approaches to determine if the kurtosis metric is a reasonable candidate for use in modifying exposure level calculations to estimate the risk of NIHL from any type of noise exposure environment. An SVM model with a nonlinear radial basis function kernel was also built on a database consisting of individual subject shift long (8 hrs) industrial noise recordings and the associated hearing threshold levels.

The results were:

1. A large worker database (N=1,150 subjects) was acquired. The database consists of individual subject shift long (8 hrs) industrial noise recordings and their associated hearing threshold levels.
2. Current hearing risk assessment criteria (ISO-1999) underestimated the mean and median noise-induced hearing loss (NIHL) by up to 10 dB for the higher kurtosis level group [$\beta(t) > 4$].
3. The SVM model successfully predicted the NIHL resulting from complex industrial noise exposures. The inclusion of the kurtosis metric, which increased the predictive accuracy of the model by 19%, supports the need to incorporate this metric in the evaluation of a complex noise exposure for hearing conservation purposes.
4. A new approach to characterize the hazardous effects of complex noise was developed in which an energy based metric [cumulative noise exposure (CNE)] was combined with a temporal correction term (i.e., kurtosis) to evaluate human noise exposure data. The use of the kurtosis metric more accurately assessed the risk of developing high frequency NIHL in workers exposed to high level Gaussian (G) and non-Gaussian (non-G) noise.

The results above lend support for the kurtosis metric as an important variable in determining the hazards to hearing posed by a high-level complex industrial noise for hearing conservation purposes. This finding suggests that an energy metric (Leq) alone is not sufficient to predict noise-induced permanent threshold shift (NIPTS). Energy is insensitive to the effects of the temporal characteristics of a noise exposure known to be important in affecting hearing. These

results allow us to better understand the role of the kurtosis metric and SVM model in NIHL which may lead to its incorporation into a new generation of more predictive hearing risk assessment for noise exposure.

Dr. Roger P. Hamernik, Email: Roger.Hamernik@plattsburgh.edu
State University of New York at Plattsburgh
Auditory Research Laboratories , 101 Broad St, Plattsburgh, N.Y. 12901
Phone-518-564-7700

Section 1

A. Significant (Key) Findings

1. Effect of Kurtosis on Noise-Induced Hearing Loss:

The kurtosis metric is an important variable in determining the hazards to hearing posed by a high-level complex industrial noise environment for hearing conservation purposes. This finding is supported by the result which showed that the current ISO-1999 model underestimated the mean and median NIPTS by up to 10 dB for the higher kurtosis level group [$4 < \beta(t) < 196$] across the test frequencies.

2. Kurtosis and Cumulative Noise Exposure:

An innovative approach to characterize the hazardous effects of complex noise (non-G vs. G) was developed in which an energy based metric [cumulative noise exposure (CNE)] was combined with a temporal correction term (i.e., kurtosis) to evaluate the noise exposure data. A dose-response relation (DRR) for the G and non-G noise exposed groups demonstrated that the kurtosis metric more accurately assessed the risk of developing high frequency NIHL in workers exposed to high level complex noise environments.

3. Support Vector Machine:

The SVM model successfully predicted the NIHL resulting from the industrial noise exposures used in this study, i.e., the SVM model using both energy and kurtosis increased the prediction accuracy (within +/- 5 dB) of NIHL by up to 19 percent.

B. Translation of Findings

The main findings cited above represent a means to develop a more precise approach to the measurement and evaluation of noise environments that, if incorporated in hearing risk assessment criteria for noise exposure, may help reduce the incidence of occupational NIHL. This conclusion is based on the three approaches applied in the evaluation of the kurtosis metric described below:

1. Effect of Kurtosis on Noise-Induced Hearing Loss

Quantifying the statistical properties (i.e., kurtosis) of high-level complex industrial noise environments can provide for a more reliable estimate of the long-term auditory consequences of an exposure. This conclusion is based on our findings which showed that the use of an energy metric (L_{eq}) in combination with the kurtosis [$\beta(t)$] of the amplitude distribution of a noise environment can be used to more accurately estimate the hazards to hearing from the complex noise environments found in industry. Energy alone is not sufficient to predict NIPTS (as applied in current noise regulation standards: the International Standards Organization-ISO-1999 model). Energy is insensitive to the effects of the temporal characteristics of a noise exposure known to be important in affecting hearing.

2. Kurtosis and Cumulative Noise Exposure:

The value of the kurtosis is further supported by evidence which showed that it can be used in modifying exposure level calculations to estimate the risk of NIHL from any type of noise exposure environment, i.e., the noise exposure SPL combined with a kurtosis correction term to match a DRR in those exposed to a G and non-G noise environment proved to be a valid metric for assessment of risk for NIHL.

3. Support Vector Machine:

The inclusion of the kurtosis metric, which increased the predictive accuracy of the SVM model by 19%, supports the need to incorporate this metric in the evaluation of a complex noise exposure for hearing conservation purposes. The SVM model can improve our ability to predict the extent of hearing loss in humans exposed to high levels of complex industrial noise for hearing conservation purposes.

C. Outcomes/Impact

Potential Outcomes:

The research described in this proposal demonstrated that a different approach currently in use to measure a worker's noise exposure is necessary to accurately estimate the subsequent hearing loss from that exposure. Specifically, by quantifying the statistical properties (i.e., kurtosis) of any industrial noise exposure the hazards to hearing (i.e., incidence and magnitude) can be more accurately estimated. The results obtained from the three approaches (1-3 above) used in this study provide preliminary evidence for continued research to address the validity of the kurtosis metric for noise evaluation and the associated hearing loss incurred from complex noise exposures, i.e., the kurtosis may serve as an all inclusive metric, concomitant with an energy metric (Leq), to characterize the potential adverse consequences (i.e., auditory trauma) from a complex industrial noise environment. The results, which provide for a better understanding of the role of the kurtosis metric and SVM model in NIHL, may lead to its incorporation into a new generation of more predictive hearing risk assessment for noise exposure provided that human exposure and hearing loss data can continue to be acquired from suitably designed epidemiological studies.

Section 2

Scientific Report

A. Specific Aims: The specific aims of the proposal were: (1) To obtain noise exposure and audiometric data on a large number of workers in heavy industry; (2) To develop and test statistical learning models for the prediction of hearing loss in humans exposed to high levels of complex noise. The effectiveness of the kurtosis metric in evaluating the risk of hearing loss from complex noise exposures will be determined. (Kurtosis is a statistical metric that quantifies the deviation of a distribution from the Gaussian. In our case the 'distribution' is the noise amplitude.)

B. Summary of progress made toward the achievement of stated aims

The original proposal specified that audiometric and noise exposure data would be collected on 1,250 subjects employed in Chinese heavy industries. To date we have acquired these data on 1,150 subjects.

Over the course of our grant cycle, the subcontracting team from Peking University was unable to obtain the proposed number of subjects to complete the study. Of the individual noise recordings collected from 1,388 subjects, only 240 subjects met the strict criteria for inclusion in the study after the third year of our grant cycle. We collected 160 more subjects from Peking University in the fourth year (the no-cost extension year).

We decided to end our contract with Peking University after the third year of the grant cycle and award, at our campus expense, a sub-contract to Dr. Meibien Zhang, the Director of Occupational Health Department (Chinese CDC) in the province of Zhejiang, China and his associates for the purpose of gathering noise/hearing data to expand our database to address the aims of this proposal. Over the past year, a member of our Auditory Research Laboratory met with Dr. Zhang to train his research team in the noise measurement procedures, and subject selection process. We were confident in their ability to conduct the research given their established record of conducting NIHL research in various Chinese heavy industries.

The cooperation of the CDC resulted in the collection of noise recordings and audiometric data from 750 subjects over the past year, as part of our 1 year no-cost extension. To date, completed noise and audiometric data have been obtained on 1,150 subjects by the research teams from Peking University (N = 400) and the Chinese CDC (N = 750). The CDC will continue to obtain noise recordings and audiometric data through March 2013 to obtain the required number of subjects originally proposed in this grant. The data will be added to the existing database and analyzed for planned publications which address the research aims.

C. Study Design

A cross-sectional approach was used in this study. The four main procedural elements were: 1) select workplaces based upon consistent noise and employment characteristics; 2) select and recruit subjects based upon strict quality criteria (i.e., health history and stable employment criteria); 3) obtain shift-long temporal waveforms of the noise that workers were exposed to for

evaluation of noise exposures on selected subjects; and 4) obtain audiometric data on all selected subjects. The details of each approach are addressed below.

(1) Workplace Selection for Inclusion in the Study

Workplace selection for this study was based upon criteria designed to assure both G and non-G noise exposure and a sufficient subject pool meeting subject criteria. Each workplace included in the study had: 1) a workforce that was stable over a number of years; 2) work processes and machinery that were stable for a number of years; 3) sufficiently high G and non-G noise exposure work areas, and 4) no use of hearing protective devices (HPD) by workers prior to the recent use of HPDs mandated in the last one-two years of employment. These selection criteria were designed to facilitate accurate cumulative noise exposure assessments over each worker's career. In these industries, workers are employed in high level noise environments which include a wide range of energy [$L_{Aeq8h} = 85$ to 115 dBA; kurtosis level [$3 \leq \beta(t) \leq 196$; mean = 30.5, s.d = 26.1], and exposure duration (1 – 30 yr). Industries were selected that were known to produce some of the highest noise levels with corresponding high levels of kurtosis. Most of the noise environments in these industries consist of what we have defined as complex noise, i.e., unsteady continuous and impact noise.

(2) Subject Selection and Recruitment

All candidate subjects were required to complete a noise exposure and health questionnaire that was followed up by a face-to-face interview for quality control (to clarify and affirm responses). Subject criteria were designed to assure that observed hearing loss is directly attributed to the measured industrial noise exposures and not related to other medical problems. The ideal subject is one whose high-level noise exposure was limited to that experienced on the job and who has been employed at that same job for his entire employment history.

The duration of the workers exposure to noise without the use of HPD's was determined from the noise exposure questionnaire and interview. The subjects in this study used HPDs only in the last one to two years of employment. Hearing conservation programs in China have only been implemented within the last several years. The use of HPD was virtually non-existent before that time. All subjects must have worked within the same job category and work (noise exposure) area for their entire employment history, and were excluded from the study for any of the following reasons: 1) prior employment (with a different employer) in a high noise environment; 2) military service or shooting activities; 3) reported hearing complaints; 4) present auditory symptoms; 5) family history of hearing loss; 6) history of ear disease; 7) use of ototoxic drugs; and 8) history of diabetes. As self reports of prior noise exposure and hearing problems can be unreliable, personnel medical and employment history records were reviewed in conjunction with questionnaire responses and interviews in evaluating whether potential participants were acceptable. Subjects who did not meet the above criteria were excluded from the study. These criteria helped to ensure that the observed change in the subjects hearing threshold level during his/her employment in the target industries were primarily attributable to the subject's age, length of time in noise, and the noise measured during the study. A review of their work history records on file was performed to ensure that their current position is their first job with high-level noise exposure.

(3) Real-time Sound Recording: Collection and Analysis of Noise Exposure Waveforms

Personal noise dosimeters (Institute of Acoustics, Hangzhou Aihua Instruments Co. AWA5610B, class II) were used to collect noise exposure levels on individuals. The dosimeters were equipped with a microphone (Aihua, Hangzhou, AWA14421) fixed on the collar of each subject. The dynamic range of the dosimeters was 40 to 140 dB(A). The noise dosimeters could work continuously for fifteen hours. The $Leq(A)$ was recorded and calculated every two seconds. Prior to any measurements each dosimeter was calibrated using a 94 dB SPL, 1 kHz tone (Aihua Instruments, Model AWA6221B calibrator). Noise data collected in the dosimeter were transferred to an IBM-compatible computer. The eight-hour continuous equivalent, A-weighted sound pressure level [$Leq(A)_{8h}$] was calculated for each measurement. The workers were divided into groups based on the type of noise exposure, factory, workshop, type of work and type of machine they were using. In the continuous G noise environment, four or five workers in each group were selected for shift-long personal noise exposure level measurements using the dosimeter over a workday lasting eight or ten hours. In the complex noise environment (non-G), subjects were measured over the course of one entire work shift. The $Leq(A)_{8h}$ for each subject in a group was averaged to produce a group mean daily noise exposure level [dB(A) SPL]. The statistical metric “kurtosis”, which quantifies the 'peakedness' of an amplitude distribution, was determined for all noise exposures using a digital recorder (Kenwood, MGR-A7) connected to a dosimeter (Aihua, AWA5610B) to collect real-time samples of each subject's noise exposure in each industrial plant. Recordings were made at the level of the subject's ear. Nineteen, five-minute samples of the real-time signal from the non-G complex noise environments and twenty from G noise environments were recorded with 16 bit resolution at an 11 kHz sampling rate and fed to an IBM computer for subsequent analysis. The kurtosis of the noise signal was computed over consecutive 40 s time windows of each five-minute noise record using MATLAB software and the mean value was used to establish the kurtosis value for each series of noise records.

A detailed analysis of the temporal noise record that workers were exposed to and their audiograms was made to compare the actual NIHL in each worker with the predictions in ISO-1999. Noise environment characterization was achieved through: (1) full-shift noise signatures measured for each subject, (2) multiple subjects from each job category, and (3) historical review of each included job category to assure that no major changes in work organization or machinery used have taken place. Thus, we were able to account for within and between worker variability for each job, and construct a reasonably stable measure of noise exposure over the historical period covered by selected workers. Complete work shift noise waveforms were recorded for all subjects. Each subject had personal noise exposure data collected twice within the course of one month. The second record was used to make a rough estimate of exposure variability.

Each shift-long personal noise exposure evaluation included two types of noise monitoring equipment. The first is a standard noise dosimeter (AWA 5610B) adapted to an output line of the microphone (AWA 14421). The second digital recorder (Kenwood MGR-A7), adapted to a precision dosimeter (AWA 5610B), obtained a full waveform record of the subject's noise exposure over a single work shift (~ 8 hr) period. Both the dosimeter and recorder was calibrated before and after each sampling with a sound calibrator (AWA6221A) according to the manufacturer's instructions.

The microphone was placed on the collar of each subject at the beginning of an eight-hour work shift and collected at the end of the shift. Since the reliability of the noise data depends on the

subject's cooperation in the proper use of the recorder, each subject was informed about the purpose of measurement and the importance of wearing it continuously for the full measurement period. The importance of the accuracy of noise data in assessing the need for noise control and the consequences of tampering with the microphone (shouting into it or knocking it on doors, etc.) was explained. With few exceptions, noise records were artifact free. Such artifacts will affect the value of kurtosis in the analysis window and skew the analytical results. Thus, the recorded noise data was preprocessed prior to analysis to eliminate these artifacts.

An artifact detecting and eliminating program was used to automatically track and delete artifact segments in the recorded noise data. Data were entered from the subject's history/medical questionnaire into a database using Epidata 3.1 software. The duplicated database was checked for errors and sent into an SPSS (version 13) software package for subsequent analysis. Software was developed for analyzing the eight-hour long noise waveforms collected on each subject. The software was designed to extract: (1) the frequency and time domain kurtosis, a statistical metric shown to correlate with NIPTS, and (2) the joint peak-interval histogram from complex noise environments. Conventional level and spectral metrics were also extracted in a variety of formats. These metrics taken together provide considerable temporal information that complements the energy and spectral metrics when the latter are insufficient to determine the hazard of a noise exposure.

(4) Audiometric Testing

Each subject had two audiometric examinations within one month. The second audiogram was used as a check on the initial measurements. Any discrepancy of more than 10 dB at any frequency necessitated additional testing and investigation and possible rejection of the subject.

All audiometric testing took place immediately following a two-day respite from the industrial environment. These examinations included air-conduction pure-tone audiometry at .5, 1, 2, 3, 4 and 6 kHz in each ear. In addition, an otologic examination and tympanometry testing were conducted to rule out conductive hearing impairment in each ear. Pure-tone audiometric thresholds were measured with an automatic microprocessor clinical audiometer (MADSEN ITERA) calibrated to appropriate ISO standards and equipped with TDH-39 headphones mounted in MX-41/AR cushions. These tests were conducted in an audiometric sound suite with background sound pressure levels at or below the OSHA maximum allowable octave-band levels for audiometric test rooms. Prior to their day of testing, each subject was instructed to avoid all sources of loud noise (e.g., loud music, gunfire, machinery, etc.) for the 48 hours prior to testing.

D. Achieved Aims:

1. Effect of Kurtosis on Noise-Induced Hearing Loss

Data analysis was conducted using 240 subjects collected from Dongfeng Motor Company, Shiyan, China. Figure 1 and Table 1 show the mean and median NIPTS results for subjects (N = 240) divided by kurtosis level for Gaussian [$\beta(t) \leq 4$] and non-Gaussian [$\beta(t) > 4$] noise exposures for L_{Aeq} ranging from 85 to < 94 dB(A) and duration (1-30 years). The kurtosis differentiated between the hazardous effects produced by G [$\beta(t) \leq 4$] and non-G [$\beta(t) > 4$] noise environments, and noise environments with high and low mean and median kurtosis levels [$\beta(t) \leq 10$ and > 10], and 2) the ISO-1999 predictive model is not as accurate estimating the amount of

median NIPTS incurred from high level kurtosis industrial noise as it is to low level kurtosis industrial noise. The ISO-1999 predictions significantly [$F = 10.60$, $p < 0.05$] underestimated the median NIPTS at 2, 4, and 6 kHz for the high kurtosis level [$\beta(t) > 4$] group but not for the low kurtosis level group [$\beta(t) \leq 4$]. The ISO-1999 model was also more closely aligned with the mean and median NIPTS incurred by the lower [$\beta(t) \leq 4$; mean = 2 dB] than higher [$\beta(t) > 4$; mean = 4.5 dB] kurtosis level group across the test frequencies. The results indicated that the ISO-1999 model underestimated the mean and median NIPTS by up to 10 dB for the higher kurtosis level group [$\beta(t) > 4$] across the test frequencies.

Table 1. The median (50th percentile) and extreme (10th and 90th percentile) NIPTS as a function of noise exposure level, duration, and median kurtosis level in workers in Chinese industry. The calculated ISO-1999 (1990) estimated prediction for median NIPTS is indicated for each exposure condition. The median NIPTS results in this table are illustrated in Figure 1.

Work Duration	Kurtosis	L _{Aeq} Range (dBA)	N	Percentile	NIPTS@ frequency (kHz)				
					2	3	4	6	
1~30 years	Median Kurtosis ≤ 4	$85 \leq L_{Aeq} < 94$	33	50 th percentile	10.25	10	13.75	10.5	
				10 th percentile	6	0.1	1.6	2.5	
				90 th percentile	19.6	26.45	35.5	36.6	
				Mean/s.d	11.67/6.0	12.39/12	17.48/15	14.31/13	
	Median Kurtosis > 4		207	50 th percentile	12*	11.5	17.5*	13*	
				10 th percentile	6	1	2.5	0.5	
				90 th percentile	20.5	35.1	43	37.5	
				Mean/s.d.	13.41/8.07	15.57/13.81	20.67/16.31	16.87/15.42	
				240	ISO prediction	3.94	9.93	13.21	8.84

*Indicates a statistically significant effect ($P < 0.05$) between the ISO-1999 prediction and the mean and median NIPTS.

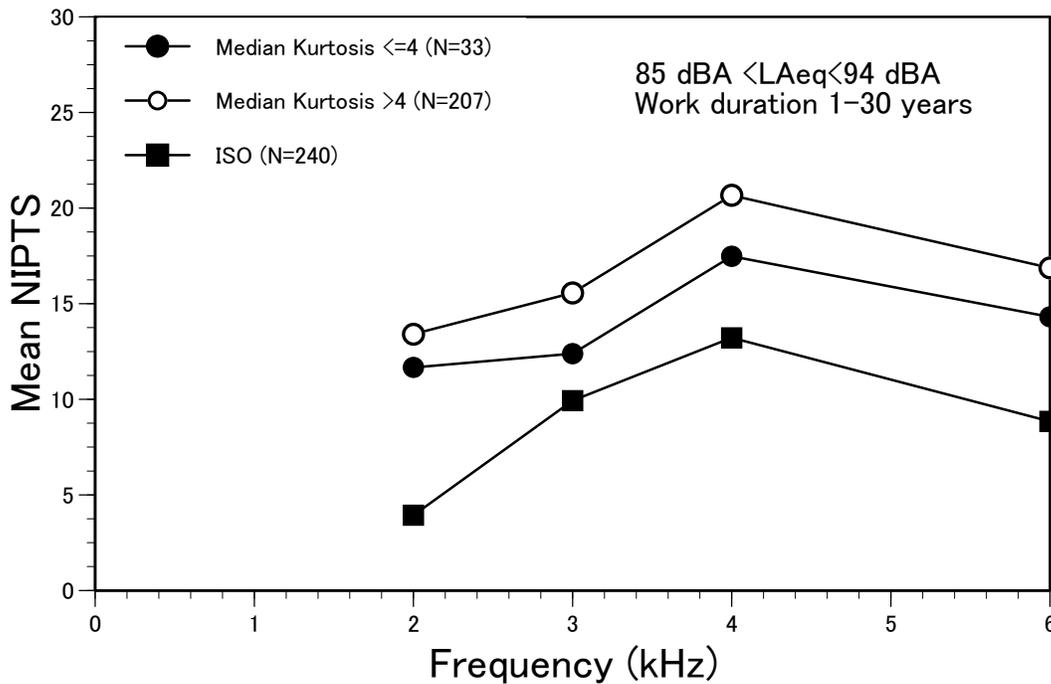
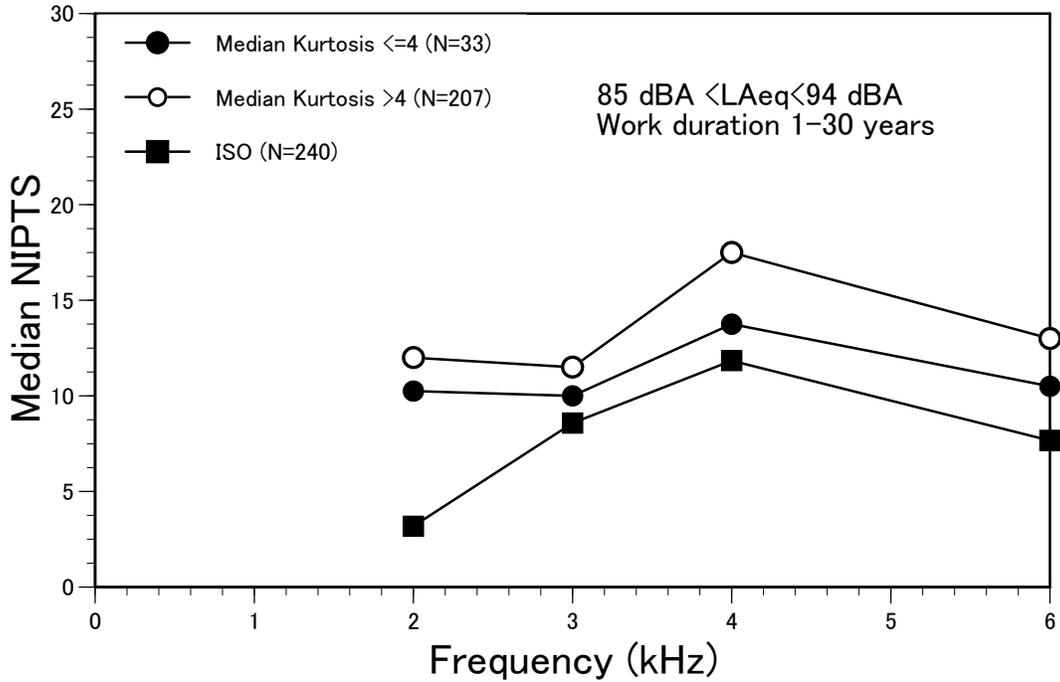


Figure 1. The mean and median NIPTS results for the entire population (N = 240) divided by kurtosis level for Gaussian [$\beta(t) \leq 4$] and non-Gaussian [$\beta(t) > 4$] noise exposures ranging by level ($L_{Aeq} = 85 \sim 94$ dBA) and duration (1-30 years).

2. Statistical Learning Model for the Prediction of Hearing Loss from Noise Exposure: Support Vector Machine:

A Support Vector Machine (SVM) model with a nonlinear radial basis function kernel was built on a database consisting of individual subject shift long (8 hr) industrial noise recordings and their associated hearing threshold levels. Of the 1,150 subjects, 750 were used as the training data set and 400 as the test data set. The 1,150 completed subjects were from 24 heavy industrial workshops in China [Mean Leq = 92.52 ± 5.16 dB(A); Min. = 85 dB(A) and Max. = 115 dB(A)]. The SVM model, with and without the kurtosis metric, was run to evaluate the effectiveness of the kurtosis metric as an indicator of the predictive accuracy of noise-induced hearing loss (NIHL) resulting from exposure to complex industrial noise. The results of this analysis are presented in Table 2 below:

Table 2. Prediction Accuracy (PA) of SVM model.

Frequency	0.5kHz	1kHz	2kHz	3kHz	4kHz	6kHz
PA (%) using $E+L$	68.32	75.45	72.25	76.62	73.63	70.87
PA (%) using $E+\beta(t)+L$	84.93	88.73	91.26	86.05	87.35	89.36

In Table 2, E indicates noise energy in both the time and frequency domain; $\beta(t)$ represents the kurtosis in time domain; and L is the length of employment in the noise environment. The results of the SVM model emphasize the following points:

(i) The SVM model using both energy and kurtosis can increase the prediction accuracy (within +/- 5 dB) of NIHL by up to 19 percent; and (ii) The average prediction accuracy, based on 10 random training/test data runs, for the SVM prediction model was 88% with the kurtosis metric and 72% without the kurtosis metric. The SVM model successfully predicted the NIHL resulting from the industrial noise exposures used in this study. The inclusion of the kurtosis metric, which increased the predictive accuracy of the model by 19%, supports the need to incorporate this metric in the evaluation of a complex noise exposure for hearing conservation purposes. The data that are being acquired will contribute to improving our ability to predict the extent of hearing loss in humans exposed to high levels of complex industrial noise.

3. Kurtosis and Cumulative Noise Exposure:

We illustrated the use of the kurtosis statistic in combination with the $L_{Aeq,8h_i}$ to unify a diverse set of hearing loss and noise level data (Zhao et al. 2010). In this study, an innovative approach to characterize the hazardous effects of complex noise (non-G vs. G) was developed in which an energy based metric [cumulative noise exposure (CNE)] was combined with a temporal correction term (i.e., kurtosis) to evaluate human (N = 195) noise exposure data (i.e., Gaussian noise with $Leq(A)_{8h}$ varied from 96 to 105 dB, and a non-Gaussian, complex noise with $Leq(A)_{8h} = 95$ dB). Audiometric and noise exposure data were acquired on a population of screened workers from Chinese industries exposed to either a G continuous noise (N = 163) or non-G noise (N = 32). Each subject was given a general physical and an otologic examination. Hearing

threshold levels (0.5 - 8.0 kHz) were age adjusted (ISO-1999) and the prevalence of NIHL at 3, 4, or 6 kHz was determined. A dose-response relation (DRR) for the G and non-G noise exposed groups was constructed (as shown in Fig. 2). By introducing the kurtosis variable into the temporal component of the CNE calculation, the two dose response curves were made to overlap (see Fig. 3), essentially yielding an equivalent noise-induced effect for the two study groups. The results above suggest that the kurtosis metric may be a reasonable candidate for use in modifying exposure level calculations to estimate the risk of NIHL from any type of noise exposure environment. We plan to continue this analysis using the completed database to determine if the prevalence of NIHL for the G and non-G exposed subjects is changed by the addition of the kurtosis adjusted metric.

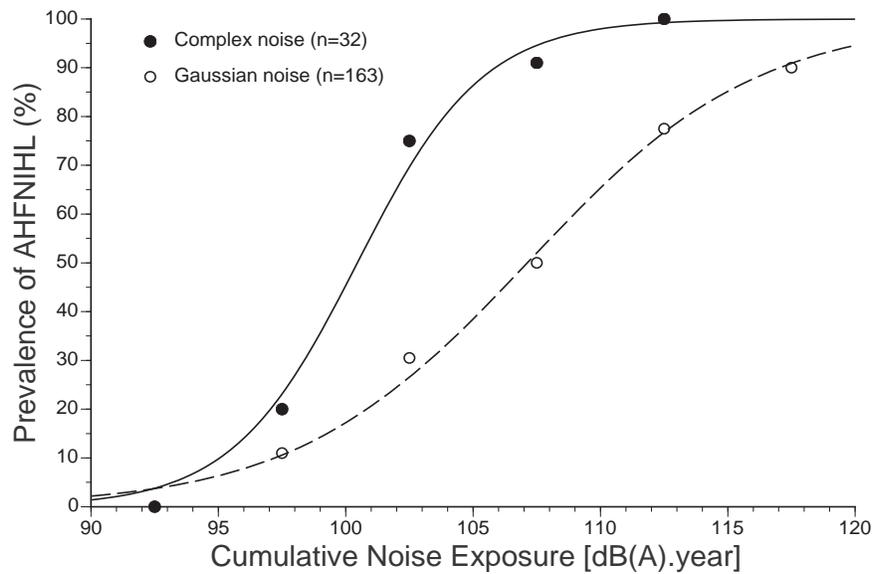


Figure 2. The dose-response relation for long-term complex and Gaussian noise exposure.

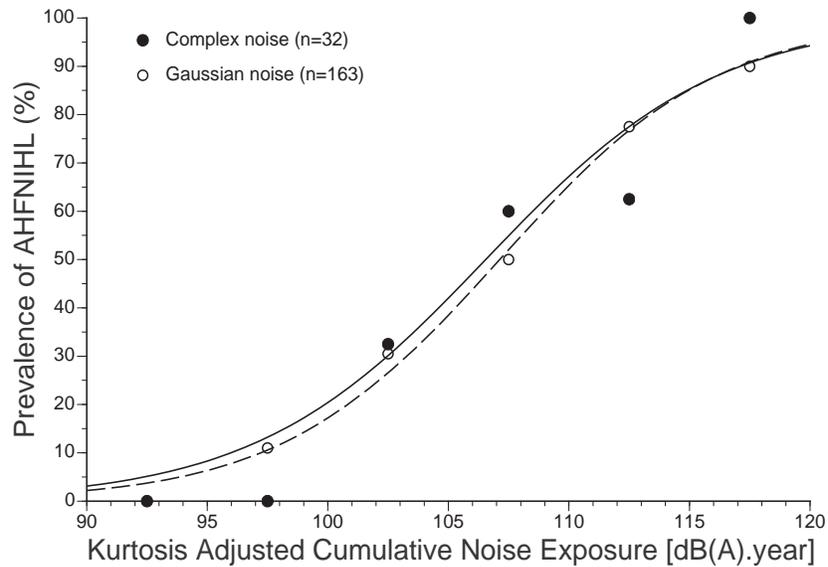


Figure 3. The dose-response relation for long-term complex and Gaussian noise exposure using the kurtosis adjustment.

Future Plans:

With the assistance of the Chinese CDC research team, we intend to complete audiometric and noise data collection on 1,250 subjects exposed to G and nonG noise in heavy industries and complete the analysis of the data sets as described in the original proposal by March 2013 at our campus expense. We will also analyze the noise data and organize the audiometric data on the subjects described above. Further, the data will be organized into a form similar to that in the international standard, ISO 1999, so that comparisons can be made to determine the predictive accuracy of current hearing risk assessment criteria (ISO-1999) using the epidemiological data obtained on the workers exposed to high-level industrial noise in China. These data will serve as the foundation for publications to address the following important issues in noise research: 1) the value of using the statistical metric, kurtosis [$\beta(t)$], along with an energy metric to determine the hazard to hearing from high level industrial noise environments, 2) the accuracy of the International Standard Organization (ISO-1999:1990) model for median noise-induced permanent threshold shift estimates, and 3) evaluation of the SVM model, with and without the kurtosis metric, to assess the effectiveness of the kurtosis metric as an indicator of the predictive accuracy of NIHL resulting from exposure to complex industrial noise.

The results above will allow us to better understand the role of the kurtosis metric and SVM model in NIHL which may lead to its incorporation into a new generation of more predictive hearing risk assessment for noise exposure.

C. Significant Results:

1. The kurtosis metric is a more sensitive indicator than energy alone (L_{eq}) in determining the hazard to hearing from high level complex noise. That is, an energy metric alone is not sufficient to characterize a complex noise and that the kurtosis, along with L_{eq} , is useful for the characterization of noise-induced hearing loss (NIHL) associated with complex noise.
2. The Support Vector Machine (SVM) model successfully predicted the NIHL resulting from the industrial noise exposures used in this study.
3. An innovative approach to characterize the hazardous effects of complex noise (non-G vs. G) was developed in which an energy based metric [cumulative noise exposure (CNE)] was combined with a temporal correction term (i.e., kurtosis) to evaluate human ($N = 195$) noise exposure data
4. Current hearing risk assessment criteria (International Standards Organization-ISO-1999) underestimates the NIHL by up to 10 dB for the higher kurtosis level group [$\beta(t) > 4$].

D. Publications:

Davis, R.I., Qiu, W., Heyer, N.J., Zhao, Y.M., Yang, Q.L., Nan, L., Tao, L.Y., Zhu, L.L., Zeng, L., Yao, D.H., (2012). The Use of the Kurtosis Metric in the Evaluation of Occupational Hearing Loss in Workers in China: Implications for Hearing Risk Assessment. *Noise and Health* Nov-Dec: 14.

Zhao Y.M, Qiu W., Zneg L., Chen S.S., Cheng X.R., Davis R.I., Hamernik, R.P., (2010). Application of the Kurtosis Statistic to the Evaluation of the Risk of Hearing Loss in Workers Exposed to High-Level Complex Noise. *Ear Hear.* 31:527-32.