

# Comparison of Two Dose-response Relationship of Noise Exposure Evaluation Results with High Frequency Hearing Loss

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## Abstract

**Background:** Complex noise and its relation to hearing loss are difficult to measure and evaluate. In complex noise measurement, individual exposure results may not accurately represent lifetime noise exposure. Thus, the mean  $L_{Aeq,8h}$  values of individuals in the same workgroup were also used to represent  $L_{Aeq,8h}$  in our study. Our study aimed to explore whether the mean exposure levels of workers in the same workgroup represented real noise exposure better than individual exposure levels did.

**Methods:** A cross-sectional study was conducted to establish a model for cumulative noise exposure (CNE) and hearing loss in 205 occupational noise-exposed workers who were recruited from two large automobile manufacturers in China. We used a personal noise dosimeter and a questionnaire to determine the workers' occupational noise exposure levels and exposure times, respectively. A qualified audiologist used standardized audiometric procedures to assess hearing acuity after at least 16 h of noise avoidance.

**Results:** We observed that 88.3% of workers were exposed to more than 85 dB(A) of occupational noise (mean:  $89.3 \pm 4.2$  dB(A)). The personal CNE (CNEp) and workgroup CNE (CNEg) were  $100.5 \pm 4.7$  dB(A) and  $100.5 \pm 2.9$  dB(A), respectively. In the binary logistic regression analysis, we established a regression model with high-frequency hearing loss as the dependent variable and CNE as the independent variable. The Wald value was 5.014 with CNEp as the independent variable and 8.653 with CNEg as the independent variable. Furthermore, we found that the figure for CNEg was more similar to the stationary noise reference than CNEp was. The CNEg model was better than the CNEp model. In this circumstance, we can measure some subjects instead of the whole workgroup and save manpower.

**Conclusions:** In a complex noise environment, the measurements of average noise exposure level of the workgroup can improve the accuracy and save manpower.

**Key words:** Complex Noise; Cumulative Noise Exposure; Dose-response Relationship; Noise Exposure Evaluation; Workgroup

## INTRODUCTION

Hearing loss is among the most serious occupational hazards. Studies have estimated that in 2014, 360 million people worldwide had hearing disabilities, and hearing loss was the 13<sup>th</sup> greatest cause of disease burden measured as disability-adjusted life years (DALYS), with a DALYS value of approximately 4 million years.<sup>[1-3]</sup> Occupational noise exposure is an important factor leading to hearing loss. Noise-induced hearing loss (NIHL) is incurable, but is avoidable through primary prevention. The basis for prevention is an accurate evaluation of the noise hazard.

Studies have indicated that equivalent continuous A-weighted sound pressure level over 8 h ( $L_{Aeq,8h}$ ) and

exposure time are two important parameters that describe the relationship between the steady noise and hearing loss.<sup>[4-6]</sup> Earshan combined noise exposure, exposure time, and proposed cumulative noise exposure (CNE) to create a composite noise exposure index (Earshan, 1986). Zhao *et al.* successfully established a model that linked CNE to NIHL.<sup>[7]</sup> Some impulse noise parameters, such as the peak values of impulse noise and impulse number, have been successfully used to describe the relationship between typical military impulse noise and hearing loss.<sup>[5,8,9]</sup> Complex noise exists in most workplaces where impulse noises are embedded within steady-state background noise.<sup>[10]</sup> The measurement and evaluation of complex noise have always been difficult. Lagerholm and Toremalm proposed an  $L_{Aeq,8h}$  measurement that was obtained by measuring individual noise exposure throughout a workday using a dosimeter.<sup>[11]</sup> This measurement is believed to provide an accurate noise

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DOI:  
10.4103/0366-6999.152659

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exposure evaluation. We proposed that CNE can also be used to evaluate complex noise. Individual  $L_{Aeq,8h}$  values are not stable in a complex noise environment; thus, those values are not suitable for representing the real noise exposure of a group exposed to similar noise levels. The means of the workgroup's  $L_{Aeq,8h}$  might better represent the real noise exposure of an individual within that workgroup. Our paper carefully studied this hypothesis using regression models.

We conducted a large cross-sectional study from 2009 to 2010. We used dosimeters to measure individual noise exposure, and we used a questionnaire to obtain basic information and information about each participant's exposure to diseases and drugs that could cause hearing loss. The hearing loss data were obtained via an annual pure tone test. In this article, we established a model for hearing loss and CNE using individual noise exposure and workgroup noise exposure, respectively. The accuracy of the evaluation results for the two types of noise exposure measurements was in agreement.

## METHODS

### Study design and subject selection

This cross-sectional study was conducted in two large automobile manufacturers in the city of Shiyan in Hubei Province in central China. The Peking University Third Hospital's Institutional Review Boards for the protection of human subjects approved the protocol for this study. The manufacturers' processes and work environments had not changed for a number of years. Noise pollution was the main occupational hazard at both places. Aside from the noise, there were no other known occupational hazards that might affect hearing acuity. The workers were exposed to high-level, complex noise environments. Hearing protection devices were used by the workers since 2007.

The subjects of this study were selected from the plants according to the following inclusion criteria: (1) At least 1 year employment in their current task; (2) only exposed to one high noise task; (3) no history of genetic or drug-related hearing loss, head trauma, or ear diseases; (4) no military service, shooting activities, or other high-intensity nonindustrial noise exposure; (5) consent to participate in the study and complete the questionnaire.

There were 466 workers in the two plants. Of these, 205 workers met the inclusion criteria and participated in this study [Figure 1].

All of the workers included in this study voluntarily gave their verbal informed consent to participate. All of the subjects were required to complete a physical examination and health-related information questionnaire, which were followed by a face-to-face interview for quality control.

Collectively, the workers performed 8 types of jobs in two automobile plants [Table 1]. Their age was  $35.9 \pm 4.4$  years, and their noise exposure duration was  $14.8 \pm 5.6$  years.

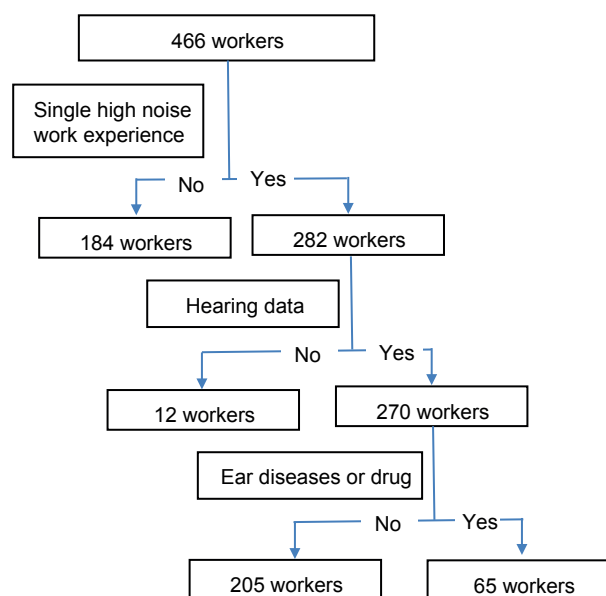


Figure 1: Screening process for subjects.

Table 1: Subject's work types

Plant	Work type	Code
Auto body plant	Stamping workers in number 1 stamping workshop	B1
	Spot welder in panel workshop	B2
	Spot welder in welding workshop	B3
	Assembly welder in welding workshop	B4
	Welder in medium-sized stamping plant	B5
Assembly plant	Assembly workers in number 1 assembly workshop	A1
	Assembly workers in number 2 assembly workshop	A2
	Assembly workers in number 3 assembly workshop	A3

### Questionnaire

At the plants, an occupational hygienist administered the questionnaire to each subject to collect the following information: General personal information (e.g., name, age, and sex), occupational history (e.g., plant, workshop, type of work, job description, length of employment, duration of daily noise exposure, military history, and history of hearing protection use), personal life habits (e.g., shooting, smoking, and alcohol use), and overall health (history of ear disease and use of ototoxic drugs).

### Physical and audiometric evaluation

We used the participants' most recent medical information as their hearing information. The workers underwent annual hearing examinations by professional otology doctors at an occupational disease prevention and control center. Each subject underwent a general physical examination and an otologic examination. Pure-tone audiometry was performed by an audiologist according to International Standard Organization's (ISO) 8253 standards in an isolated acoustic room with a calibrated pure-tone audiometer. Hearing thresholds were measured at 0.5, 1, 2, 3, 4 and 6 kHz in each ear at least 16 h after the subjects' last occupational noise exposure.

## Noise exposure measurement

Noise exposure information included noise exposure level and duration. We obtained the noise exposure duration from the worker's occupational history. Noise exposure levels were measured using personal noise dosimeters (Aihua, Model AWA5610B, Hangzhou, China) to collect  $L_{Aeq,8h}$  data. The dosimeters were calibrated after each use with a Model AWA6221A Sound Level Calibrator (Aihua Instruments, Hangzhou, China). The tolerance of the AWA6221A is  $<0.7$  dB, and the tolerance of the AWA5610B is  $<1.0$  dB. The AWA6221A complies with the International Electrotechnical Commission (IEC) standard IEC60942-2004 Class 1. The AWA5610B meets the IEC 61252:2002 and Chinese National Standards (GB) GB/T15952-1995.

The participants'  $L_{Aeq,8h}$  values were determined using personal noise dosimeters. The researchers attached the dosimeters to the participants, who were asked to wear them for 1 day from 8:00 to 16:30. Microphones covered with windscreens were placed on the workers' chests. The logging period was 2 s, which allowed the collection of 14,400 2-s A-weighted equivalent continuous sound levels ( $L_{Aeq,2s}$ ) during an 8-h shift. After measurement, the data were transferred to a computer with MATLAB 7.1 (Mathworks, USA). We reviewed the integrity of the data and intercepted the data during working time to calculate  $L_{Aeq,8h}$ . We used the mean  $L_{Aeq,8h}$  of all of the workers in a workgroup as the workgroup's noise exposure level.

Cumulative noise exposure was used to quantify each subject's personal noise exposure. Because none of the subjects in this study changed their work environment, CNE was defined as:  $CNE = L_{Aeq,8h} + 10 \log T$  (1)

Where  $L_{Aeq,8h}$  is the equivalent continuous A-weighted noise exposure level normalized to an 8-h working day, and  $T$  is exposure time. The personal CNE was labeled CNEp; the personal noise exposure level was used as the  $L_{Aeq,8h}$ , and the length of time employed was used as the exposure time. The group CNE was labeled CNEg; workgroup noise exposure level was used as  $L_{Aeq,8h}$ , and the length of time employed was used as the exposure time. The workgroup noise exposure level was the mean of the personal noise exposure levels of all of the workers in one workgroup.

## Definition of an adjusted high-frequency hearing loss

The hearing threshold levels at each frequency were adjusted for age and gender using the 50<sup>th</sup> percentile values in the ISO (ISO-1999 1990) Annex B. The workers' adjusted high-frequency hearing loss (HFHL), and prevalence was defined as one or more hearing levels at 3, 4, or 6 kHz in either ear equal to or higher than 25 dB.

## Reference data for steady noise

Zhao *et al.*, of this paper, conducted a study on steady noise in 2009.<sup>[7]</sup> Zhao collected noise exposure level and hearing loss data for 163 workers in a textile factory. The study discussed the dose-response relationship between hearing loss and CNE. Steady noise data were cited as a reference in our study, and the relationships between steady noise and CNE were compared with the relationships between complex noise and CNE.

## Data processing and statistical analysis

The data were analyzed using SPSS for Windows software, version 18.0 (SPSS, Chicago, IL, USA). The quantitative parameters were expressed as the mean  $\pm$  standard deviation and median (minimum, maximum). The Pearson  $\chi^2$  test was applied to examine the categorical parameter differences between the study groups. The association between hearing loss and CNE was examined using binary logistic regression. The workers were grouped by every 5 dB or 3 dB of CNE, and the rate of HFHL was calculated for each group. We drew dose-response relationship curves for CNE and HFHL. All reported  $P$  values were two-tailed, and  $P < 0.05$  was considered as statistically significant.

## RESULTS

### Field investigation

The two automobile plants were founded in the 1970s. At the fabrication plant, steel plates were cut and welded into car bodies. At the assembly plant, the automobile parts manufactured at other plants were assembled to the car. The occupational hazard factors at the plants included noise, dust and electro-optical hazards. One of the most serious of these factors was noise, particularly complex noise [Figure 2]. The background noises were mainly mechanical noise and aerodynamic noise, which were generally higher than 80 dB(A). The background noise level was unstable, and

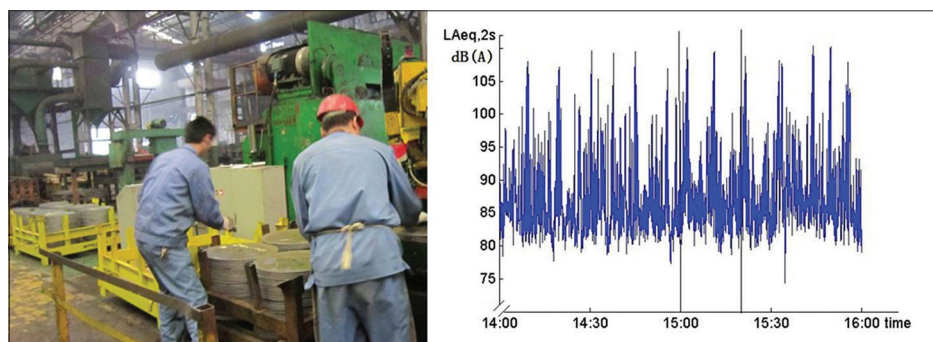


Figure 2: Work environment (left) and personal noise exposure in a specific workspace (right).

some machines were switched on irregularly. The impulse noises were mainly mechanical noises derived from cutting and impacting activities. The workers worked in specific areas, and the noise exposure levels changed constantly. Figure 2 shows one worker's noise exposure level ( $L_{Aeq, 2s}$ ) over a single workday.

In the field investigation, we found that protection with earplugs had been promoted since 2007. The plants provided ordinary earplugs for workers who were exposed to high-noise environments, but did not check for compliance. The workers usually did not wear the earplugs for a variety of reasons, such as communication difficulties and a lack of awareness of hearing safety. One of the 205 workers did not report whether he wore the earplugs. Twenty-six (12.7%) of the remaining 204 workers wore earplugs. For the group of workers that wore earplugs, the prevalence of NIHL was 65.4%; for the group that did not wear earplugs, the NIHL prevalence was 75.3%. There was no statistically significant difference between the two groups for the prevalence of HFHL ( $\chi^2 = 1.155, P = 0.282$ ).

### Personal noise exposure

The personal noise exposure level was  $89.3 \pm 4.2$  dB(A), ranging from 76.1 dB(A) to 100.2 dB(A). The proportion that exceeded 85 dB(A) was 88.3% [Table 2].

The means of the personal noise exposure levels of all of the workers in one workgroup were used as the workgroup noise exposure level. For example, the workgroup noise exposure level of B1 was 91.1 dB(A).

### Cumulative noise exposure

The personal CNE (CNEp) was  $100.5 \pm 4.7$  dB(A), ranging from 86.4 to 112.5 dB(A). The workgroup CNE (CNEg) was  $100.5 \pm 2.9$  dB(A), ranging from 90.5 to 104.7 dB (A) [Table 3].

### Relationship between cumulative noise exposure and high-frequency hearing loss

Personal cumulative noise exposure and CNEg were grouped by 5 dB and 3 dB differences respectively, and the HFHL rate was calculated for each group [Table 4].

Binary logistic regression models were established using HFHL as the dependent variable and CNE as the independent variable [Table 5]. The Hosmer and Lemeshow

**Table 2: Workgroups and personal noise exposure level**

Workgroup	n	Mean $\pm$ SD	Median (minimum, maximum)
B1	8	91.1 $\pm$ 4.9	93.0 (79.3, 93.7)
B2	10	82.9 $\pm$ 5.1	84.2 (76.1, 89.8)
B3	7	85.8 $\pm$ 2.9	85.6 (83.3, 91.8)
B4	4	85.6 $\pm$ 1.2	85.8 (84.0, 86.9)
B5	8	88.1 $\pm$ 1.0	88.1 (86.2, 89.5)
A1	85	90.1 $\pm$ 3.7	90.4 (81.6, 99.5)
A2	33	90.7 $\pm$ 4.7	91.4 (77.4, 100.2)
A3	50	89.1 $\pm$ 3.5	89.0 (82.4, 99.5)
Total	205	89.3 $\pm$ 4.2	89.4 (76.1, 100.2)

SD: Standard deviation.

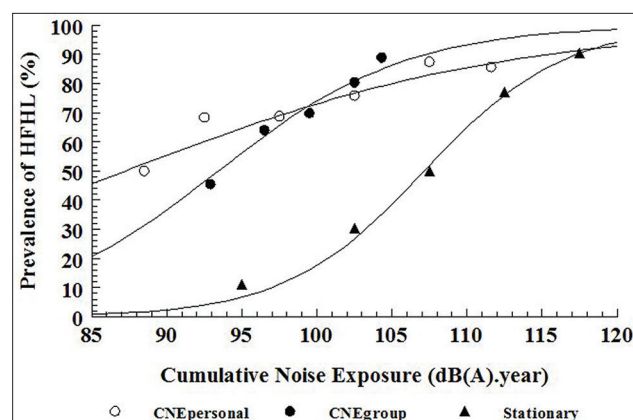
test for CNEp and HFHL was not statistically significant ( $\chi^2 = 6.734, P = 0.566$ ). The Hosmer and Lemeshow test for CNEg and HFHL was statistically significant ( $\chi^2 = 17.089, P = 0.029$ ). The Wald value was 8.653 in CNEg model and 5.014 in the CNEp model; therefore, the CNEg model offered the better fit.

Zhao *et al.* conducted a study of the relationship between CNE and HFHL.<sup>[7]</sup> The CNE was calculated based on steady noise, and we have used the results in Figure 3 as a reference [Figure 3].

## DISCUSSION

Complex noise is common in industrial noise environment. These environments often contain mixtures of multiply reflected impact noises and a relatively Gaussian broadband noise.<sup>[12]</sup> However, few studies have examined the effects of complex noise, possibly because complex noise is difficult to accurately measure and the evaluation index is hard to standardize. In addition, it is difficult to find a plant in which the noise pollution consists of complex noise and the work environment has not changed for a number of years. The use of noise dosimeter provides a basis for accurate measurements. The dosimeter can record a noise level every 2 s and allows the collection of 14,400 2-s A-weighted equivalent continuous sound levels ( $L_{Aeq, 2s}$ ) during an 8-h shift. Aside from full-time measurement, each individual needs to measure more than 3 times, which requires significant manpower and increases the difficulty of accurate measurements.

In our study, we selected two automobile plants that satisfied these criteria. We adopted strict inclusion and exclusion criteria to select subjects from a stable working population. None of the subjects had transferred from a previous high-noise work environment, and all were employed in a high-level noise environment that included a wide range of energy ( $L_{Aeq, 8h} = 76.1\text{--}100.2$  dB(A)) and exposure durations (1.2–29.3 years). All of the subjects were required to complete personal noise exposure measurements and a strict physical examination.



**Figure 3:** Dose-response relationship curves for cumulative noise exposure and high-frequency hearing loss. The data are from a study in which Zhao collected information about noise exposure levels and hearing loss for 163 workers in a textile factory.

**Table 3: Personal cumulative noise exposure**

Workgroup	n	CNEp*		CNEg†	
		Mean ± SD	Median (minimum, maximum)	Mean ± SD	Median (minimum, maximum)
B1	8	102.0 ± 5.2	104.7 (91.7, 106.5)	102.0 ± 2.8	103.0 (95.6, 104.0)
B2	10	95.4 ± 5.0	96.1 (88.8, 104.2)	95.4 ± 1.3	95.3 (93.1, 97.2)
B3	7	97.9 ± 3.2	98.1 (94.7, 103.0)	97.9 ± 1.2	97.3 (97.0, 100.5)
B4	4	96.1 ± 4.8	98.3 (88.9, 99.0)	96.1 ± 3.7	97.7 (90.5, 98.5)
B5	8	98.7 ± 1.3	98.9 (96.1, 100.4)	98.7 ± 1.3	98.7 (96.1, 100.5)
A1	85	101.3 ± 4.6	101.2 (86.4, 112.1)	101.3 ± 2.7	102.2 (90.9, 104.6)
A2	33	101.6 ± 5.5	102.0 (91.1, 112.5)	101.6 ± 2.8	102.5 (92.1, 104.7)
A3	50	100.4 ± 3.9	100.6 (92.4, 112.1)	100.4 ± 1.8	100.9 (92.8, 102.6)
Total	205	100.5 ± 4.7	100.5 (86.4, 112.5)	100.5 ± 2.9	101.3 (90.5, 104.7)

\*CNEp: Personal cumulative noise exposure; †CNEg: Workgroup cumulative noise exposure; SD: Standard deviation.

Noise-induced hearing loss first appeared at 4000 Hz and gradually spread to lower frequencies. Voice-frequency hearing loss appeared after several years.<sup>[13]</sup> Thus, the early stage of NIHL is characterized by HFHL, and our study used HFHL as the endpoint.

Hearing protection is an important factor that affects the likelihood of hearing loss. Thus, we investigated the participants' hearing protection status. The plants' hearing conservation program had been implemented for <3 years. Considering the low ratio of the work population that wore earplugs and their improper use, we supposed that the effect of earplug use in our study was small.

The results of our study show that 177 workers (86.3% of the total) were exposed to significantly high noise level environments (those with noise levels exceeding 85 dB(A)). The high noise sources in the workshop switched irregularly. The workers and their locations relative to noise sources were not fixed in some workspaces, and there were unsteady continuous and impulse noises in these workplaces. The workers' personal noise exposure levels changed irregularly over time. The average CNEp and CNEg were 100.5 ± 4.7 dB(A) and 100.5 ± 2.9 dB(A), respectively. Tables 3 and 5 show that the mean CNEg was the same as the mean CNEp, but the standard deviation was obviously reduced in every group; specifically, the CNEg was more stable. As the CNE formula shows, CNE consists of  $L_{Aeq,8h}$  and  $10\log T$ . The CNEp variation in each group comprises two parts.  $L_{Aeq,8h}$  is constant for CNEg in each group. The variation in CNEg comes from  $10\log T$  (length of service), so the CNEg variation is small.

The results of the binary logistic regression analysis are shown in Figure 3. Steady noise<sup>[7]</sup> was used as a reference, and CNEg was more similar to the steady noise reference than CNEp was. The reason could be that the change in complex noise was greater within individuals than within the group.<sup>[5]</sup> The average noise exposure level of the workgroup could better represent the workers' actual noise exposure than the personal exposure level does. The curve of nonstationary noise is in the left of Figure 3. It suggests that HFHL induced by nonstationary noise was more serious than that of stationary noise that is consistent with

**Table 4: CNE and HFHL**

Group	CNEp* (205)		Group	CNEg† (205)	
	n	HFHL‡ (%)		n	HFHL (%)
85.0–89.9	4	50.0	90.0–94.9	11	45.5
90.0–94.9	19	68.4	95.0–97.9	25	64.0
95.0–99.9	64	68.8	98.0–100.9	53	69.8
100.0–104.9	87	75.9	101.0–103.9	107	80.4
105.0–109.9	24	87.5	104.0–106.9	9	88.9
110.0–114.9	7	85.7	-	-	-

\*CNEp: Personal cumulative noise exposure; †CNEg: Workgroup cumulative noise exposure; ‡HFHL: High-frequency hearing loss; CNE: Cumulative noise exposure.

**Table 5: Binary logistic regression models of CNE and HFHL**

CNE	B	SE	Wald	P	OR
CNEp*	0.078	0.035	5.014	0.025	1.08
CNEg†	0.159	0.054	8.653	0.003	1.17

\*CNEp: Personal cumulative noise exposure; †CNEg: Workgroup cumulative noise exposure; SE: Standard of error; OR: Odds ratio; CNE: Cumulative noise exposure; HFHL: High-frequency hearing loss.

conclusions of many previous researches.<sup>[5,14,15]</sup> However, due to time constraints, we did not study whether the mean of workers' noise exposure levels of the workgroup was same to the mean of a worker's noise exposure levels of multiple measurements.

The personal noise measurement had high accuracy for personal noise exposure measurement, but each person was required to complete a full time measurement, which required significant manpower. During the field measurements, we found that the workload of managing 10 dosimeters was significant. At least 3 weeks were needed for all workers to complete a full time measurement in a 150-person plant if all conditions were normal. Because the average workgroup noise exposure level can accurately represent the workers' actual noise exposure, we can employ the workgroup measurement strategy instead of the personal noise measurement. Given that the noise exposure of workers in the same workgroup was similar, we could sample some workers to represent the entire workgroup, which could

reduce the amount of measurement work required to achieve an accurate noise exposure reading.

A workgroup is a group of workers in which each person performs the same work, and each worker's task is the same.<sup>[16]</sup> Thus, the noise exposure for each worker is similar, which is consistent with our results because the standard deviation of noise in each workgroup was low. In our study, we selected eight workgroups in two plants and calculated the CNEg for each using personal noise exposure data and workgroup noise exposure data. We found that the CNEg was more stable, and it was more closely related to hearing loss. Because of limited time, some problems regarding CNEg remain unresolved, such as how to sample workers and how to determine an optimal sample size. Solving these problems would be conducive to promoting the workgroup noise measurement method.

In a complex noise environment, the average noise exposure level of the workgroup can accurately represent the workers' actual noise exposure than the personal exposure level does. The measurements of average noise exposure level of the workgroup can improve the accuracy and save manpower.

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**Received:** 28-11-2014 **Edited by:** Li-Shao Guo

**How to cite this article:** Zhang H, Li N, Yang QL, Qiu W, Zhu LL, Tao LY, Davis RI, Heyer N, Zhao YM. Comparison of Two Dose-response Relationship of Noise Exposure Evaluation Results with High Frequency Hearing Loss. *Chin Med J* 2015;128:816-21.

**Source of Support:** Nil. **Conflict of Interest:** None declared.