Preplanned Studies

# The Role of the Kurtosis Metric in Evaluating the Risk of Occupational Hearing Loss Associated with Complex Noise — Zhejiang Province, China, 2010–2019

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**Summary**

**What is already known about this topic?**

Occupational noise-induced hearing loss (NIHL) has been the second most common occupational disease in China. Noise energy is the main risk factor for occupational NIHL. Evidence shows the temporal structure of noise (as indicated by kurtosis metric) contribute to the development of NIHL. However, the role of the kurtosis metric in evaluating the risk of occupational NIHL associated with complex noise has been rarely reported.

**What is added by this report?**

Noise temporal structure (as indicated by kurtosis) is an important risk factor for occupational NIHL in addition to noise energy. Kurtosis can be used to quantify complex noise exposure. A combination of noise kurtosis and noise energy can effectively evaluate the risk of occupational hearing loss associated with complex noise.

**What are the implications for public health practice?**

Considering the effect of noise temporal structure on occupational NIHL, the existing international noise exposure standards (e.g. measurement method and noise exposure limit) for complex noise should be modified based on noise temporal structure. More effort is needed to reduce noise exposure, improve health screening, and monitor occupational NIHL.

Occupational noise-induced hearing loss (NIHL) is one of the most prevalent occupational diseases worldwide, and it ranks the second occupational disease in China (*1*). Complex noise, also known as non-Gaussian noise, is the main type of industrial noise in the workplaces, which is composed of transient high-energy impulsive/impact noise superimposed on Gaussian background noise (*2*). The previous animal experiments and epidemiological studies showed that in addition to noise energy, the temporal structure of noise was a necessary metric to assess the hearing loss caused by complex noise (*3*). These findings indicated that the existing international noise exposure standards (e.g. ISO 1999:2013) might not be adequate for complex noise, in which the noise energy (e.g. the A-weighted equivalent sound pressure level, $L_{Aeq}$) served as the only metric to assess NIHL based on the equal energy hypothesis (EEH) (*4*). The EEH assumes that the hearing loss caused by noise exposure is proportional to the exposure duration multiplied by the energy intensity, thus implying that the hearing loss is not related to the acoustic energy temporal distribution. In addition, due to the peak clipping effect of impulse noise, traditional noise measurement techniques are not suitable for measuring complex noise (*5*).

Recently, the evidence has shown that the kurtosis ($\beta$), as defined as the ratio of the fourth-order central moment to the squared second-order central moment of a distribution, can provide an “indirect” measure of sensitivity to the presence of impulse noise in complex noise exposure (*5*). There was little epidemiological data reporting whether the kurtosis metric could be used to quantify complex noise exposure and in combination with noise energy to assess the occupational hearing loss associated with complex noise (*3*).

In this study, a cross-sectional study was designed to investigate the role of kurtosis in evaluating the risk of occupational hearing loss associated with complex noise. A total of 2,898 manufacturing workers in the Zhejiang Province were recruited from 6 industries in 2010–2019. Findings of this study showed that the kurtosis metric could be used to quantify complex noise exposure, indicating the existing international noise exposure standards for complex noise should be modified based on noise temporal structure.

The inclusion criteria for these subjects were as follows: 1) a minimum of 1-year noise exposure with fixed work tasks; 2) no history of drug-related hearing loss, ear diseases, and military service; 3) either no use of hearing protection devices (HPDs) or use of them only within the last 1 year at the time of data collection; and 4) no exposure to organic solvents or heavy metals. A digital recorder (ASV5910-R, Aihua) was used to record the shift-long personal noise waveform for each participant. The noise waveform was analyzed using the MATLAB software (The MathWorks, R2017, Natick, USA) to obtain the A-weighted sound-pressure level ($L_{Aeq,8h}$) and kurtosis (β) value. Noise with a mean β≥10 was defined as complex noise, and that with a mean β<10 was defined as continuous steady-state noise. The cumulative noise exposure (CNE) was calculated using a combination of $L_{Aeq,8h,}$ and exposure duration for quantifying total noise energy of exposure, then the CNE was adjusted by kurtosis based on a model used in Xie et al. (*6*) The kurtosis-adjusted CNE is calculated as Adjusted-CNE=$L_{Aeq,8h}$+[(In β +1.9)÷log2×logT], where T is exposure time.

At least 16 hours after the last occupational noise exposure, the participants' pure-tone hearing threshold levels (HTL) at frequencies 0.5, 1.0, 2.0, 3.0, 4.0, 6.0, and 8.0 kHz for each ear were measured using an audiometer (Madsen OB40, Denmark). The HTLs were adjusted by subtracting the age- and sex-specific HTL according to Annex B, Table B.3, of the ISO 1999:2013. High-frequency noise-induced hearing loss (HFNIHL) was defined as adjusted HTL≥30 dB in either ear at 3.0, 4.0, and 6.0 kHz. The noise-induced permanent threshold shift ($NIPTS_{346}$) at 3.0, 4.0, and 6.0 kHz was calculated using the formulas in the ISO 1999:2013. Binary logistic regression analysis was used to analyze the odds ratios (ORs) of key factors affecting HFNIHL.

Table 1 showed that 72.3% of manufacturing workers were male. The average age and exposure duration were 35.81±9.36 and 9.00±7.60 years, respectively. The mean $L_{Aeq,8h}$ was 88.82±5.73 dB(A), of which 80.8% exceeded the occupational exposure limit (OEL) of 85 dB(A), and 21.0% exceeded 95 dB(A). Mean kurtosis values of steady-state noise in textile and paper-making industries were less or equal to 10, while mean kurtosis of complex noise in other industries was greater than 10. On average, 26.9% of manufacturing workers suffered from HFNIHL. The logistic regression analysis for key factors affecting HFNIHL% showed the OR of kurtosis was 1.37, which was similar to that for $L_{Aeq,8h}$ or exposure duration.

Figure 1A demonstrated the scatter plot between

TABLE 1. Prevalence of noise-induced hearing loss and its risk factors among manufacturing workers, Zhejiang province, China, 2010–2019.

| Noise type | Industry | General information on workers | | | $L_{Aeq,8h}$ [dB(A)] | | | | Kurtosis | HFNIHL (%) |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Sex (male %) | Age (y) | Exposure duration (y) | Mean | >85 (%) | >90 (%) | >95 (%) | Mean | |
| Steady-state | Textile | 346 (47.4) | 33.44 ± 8.00 | 8.00 ± 7.00 | 93.02 ± 6.57 | 85.5 | 76.3 | 57.2 | 9.98 ± 9.28 | 27.7 |
| | Paper making | 99 (64.7) | 47.74 ± 9.92 | 11.70 ± 8.63 | 88.54 ± 4.35 | 85.9 | 36.4 | 4.0 | 10.82 ± 9.74 | 26.3 |
| | Average | 445 (51.2) | 36.62 ±10.62 | 8.83 ± 6.76 | 92.02 ± 6.42 | 85.7 | 56.4 | 30.6 | 10.16 ± 9.38 | 27.4 |
| Complex | Furniture | 428(87.6) | 34.91 ± 10.24 | 5.35 ± 5.56 | 88.09 ± 4.86 | 77.6 | 36.0 | 5.4 | 165.85 ± 153.99 | 35.3 |
| | Automobile | 996 (81.1) | 35.07 ± 8.07 | 10.19 ± 8.35 | 88.43 ± 4.49 | 79.7 | 34.6 | 7.4 | 25.88 ± 37.38 | 24.4 |
| | Metal product | 351 (70.4) | 37.27 ± 9.69 | 7.71 ± 7.24 | 90.42 ± 5.98 | 80.9 | 61.3 | 23.9 | 33.80 ± 43.70 | 24.8 |
| | General equipment | 678 (64.7) | 36.18 ± 9.35 | 10.33 ± 7.39 | 86.91 ± 6.19 | 65.5 | 32.4 | 8.3 | 34.81 ± 43.77 | 26.0 |
| | Average | 2,453 (76.1) | 35.66 ± 9.11 | 9.03 ± 7.74 | 88.24 ± 5.40 | 75.9 | 41.1 | 11.3 | 53.90 ± 90.35 | 26.8 |
| Total | | 2,898 (72.3) | 35.81 ± 9.36 | 9.00 ± 7.60 | 88.82 ± 5.73 | 80.8 | 48.8 | 21.0 | 47.19 ± 84.69 | 26.9 |
| Binary logistic regression analysis of key factors influencing HFNIHL% | | | | | | | | | | |
| OR* (95% CI) | | 1.28† (1.04–1.57) | 1.22§ (1.10–1.36) | 1.14§ (1.06–1.22) | 1.41§ (1.30–1.53) | | | | 1.37§ (1.23–1.52) | – |

Abbreviation: HFNIHL=high-frequency noise-induced hearing loss.

* The selected variables including age, gender, exposure duration, $L_{Aeq,8h}$, and kurtosis, were fitted in the binary logistic regression model using the "enter" method; Age (years): <30, 40–, 50–, 60–, 70–, ≥70; Exposure duration (years): <5, 10–, 15–, 20–, >20; $L_{Aeq,8h}$ [(dB(A)]: <80, 85–, 90–, 95–, 100–, ≥100; Sex: male/female; Kurtosis: <10, 5–0, 100–, >100.

† *P*<0.05.

§ *P*<0.01.

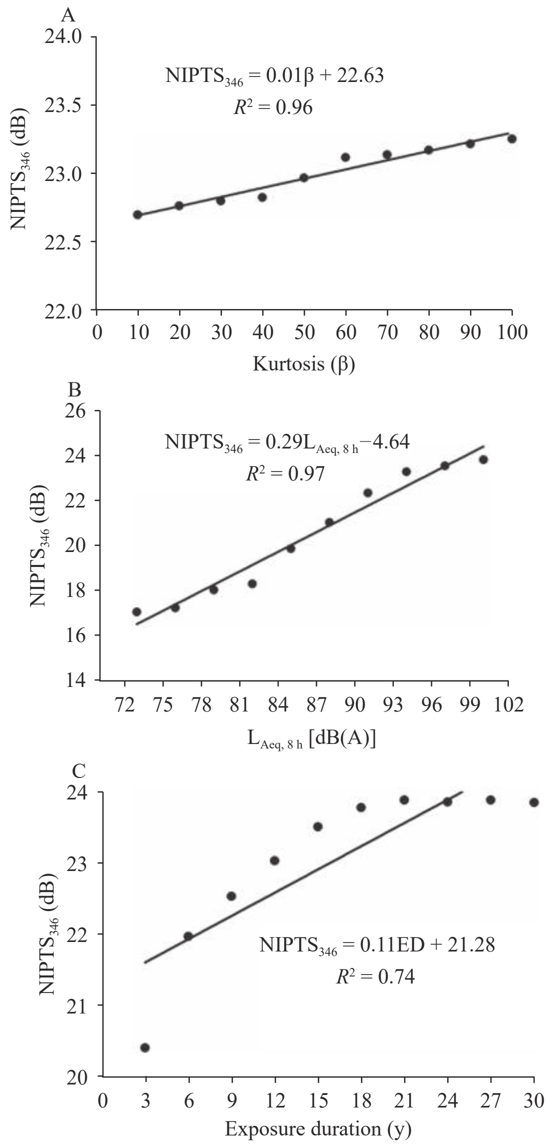


FIGURE 1. Linear regression equation between $NIPTS_{346}$ and kurtosis, $L_{Aeq,8h}$, or exposure duration in the scatter plot, Zhejiang province, China, 2010−2019. (A) The linear relationship between mean $NIPTS_{346}$ and mean kurtosis (β) in 10-β bin collapse; (B) The linear relationship between mean $NIPTS_{346}$ and mean $L_{Aeq,8h}$ in 3-dB(A) bin collapse; (C) The linear relationship between mean $NIPTS_{346}$ and mean exposure duration in 3- year bin collapse.
Abbreviation: NIPTS=noise-induced permanent threshold shift.

mean $NIPTS_{346}$ and mean kurtosis (β) in 10-β bin collapse, and their linear regression equation was: $NIPTS_{346}$=0.01β+22.63, $R^2$=0.96. Figure 1B showed the linear regression equation between mean $NIPTS_{346}$ and mean $L_{Aeq,8h}$ in 3-dB(A) bin collapse (i.e. $NIPTS_{346}$=0.29$L_{Aeq,8h}$−4.64, $R^2$=0.97). Figure 1C also demonstrated a linear relationship between $NIPTS_{346}$ and exposure duration, in which the $R^2$ value of exposure duration was relatively lower than that of kurtosis or $L_{Aeq,8h}$.

Figure 2A illustrated dose-response relationship between HFNIHL% and CNE for complex noise or steady-state noise. The average HFNIHL% (22.4%) for complex noise was significantly higher than that (15.04%) for steady-state noise ($P$<0.05). Figure 2B demonstrated that after CNE was adjusted by kurtosis, the 2 regression lines were nearly overlapped, and the difference of HFNIHL% between complex noise and steady-state noise was significantly reduced from 7.40% to 1.28%.

## DISCUSSIONS

Table 1 illustrated an epidemiological feature of occupational NIHL in China. The high prevalence of occupational NIHL in young male workers was associated with the wide distribution of noise in manufacturing industries, high noise levels, and long-term exposure duration. Relevant data showed that at least 10 million workers in China were assumed to be exposed to harmful noise levels, and the prevalence of occupational NIHL was estimated to be more than 20% (*1*). Approximately 600 million workers were estimated to be exposed to harmful levels of noise globally, and the prevalence of occupational NIHL in developed countries and developing countries were >10% and 18%–67%, respectively (*1*).

Binary logistic regression analysis in Table 1 showed that the order of ORs for risk factors of occupational NIHL was $OR_{LAeq,8h}>OR_{kurtosis}>OR_{sex}>OR_{age}>OR_{duration}$, which suggests that $L_{Aeq,8h}$ has the greatest contribution to NIHL, and kurtosis is an important factor affecting NIHL, as is exposure duration, age, and sex. Figure 1 demonstrated that the relationships between $NIPTS_{346}$ and these factors of kurtosis, $L_{Aeq,8h}$, and exposure duration were linear, indicating there was a clear dose-response relationship between each of these factors and occupational NIHL.

Figure 2A further illustrates the role of kurtosis is a risk factor. The HFNIHL% among manufacturing workers exposed to complex noise with mean kurtosis ≥10 was significantly higher than that in those exposed to steady-state noise with mean kurtosis <10, which suggested that workers exposed to complex noises had worse hearing loss than those exposed to steady-state noise. These results also indicated that the kurtosis metric could quantify complex noise exposure. These findings emphasize that, in addition to noise energy (as indicated by CNE, noise intensity, or exposure

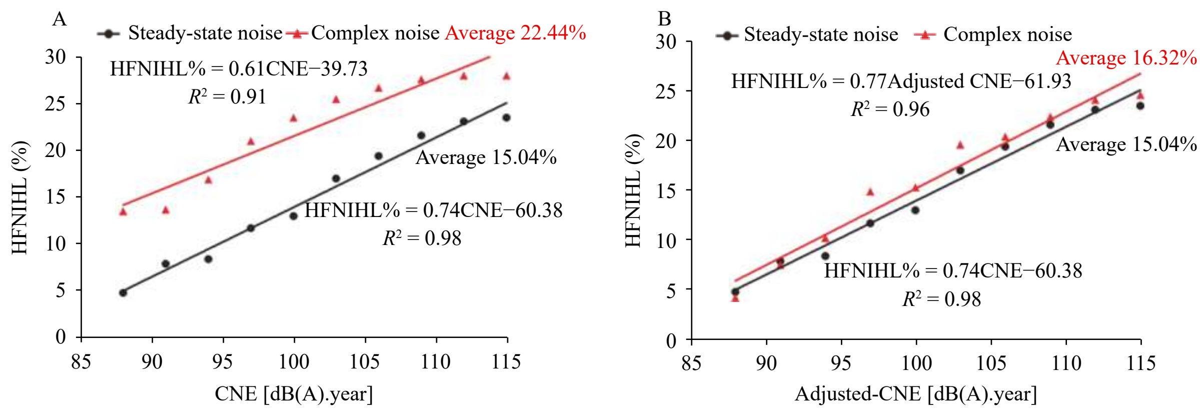


FIGURE 2. Dose-response relationship between HFNIHL% and CNE or kurtosis-adjusted CNE, Zhejiang province, China, 2010−2019. (A) A significant difference in average HFNIHL% between complex noise and Gaussian noise; (B) The two linear regression equations of complex noise and Gaussian noise were almost overlapped after CNE was adjusted by kurtosis.

Abbreviations: HFNIHL=high-frequency noise-induced hearing loss; CNE=cumulative noise exposure.

duration), the temporal structure of noise (as indicated by kurtosis) is also an important risk factor for occupational NIHL (*7*). This result was supported by studies that have reported that hearing loss caused by complex noise was underestimated using current international noise exposure standards. Noise energy is a necessary metric, but the structural characteristics of noise were also an important risk factor for the hearing loss induced by complex noise (*8*–*9*).

Figure 2B demonstrated the role of kurtosis combined with noise energy (i.e., CNE) in the evaluation of NIHL. After CNE was adjusted by kurtosis, the regression line between HFNIHL% and kurtosis-adjusted CNE for complex noise almost overlapped the line between HFNIHL% and CNE for steady-state noise. This demonstrates the ability of kurtosis to adjust CNE based on the equal energy hypothesis to provide a consistent estimate of hearing loss across varied noise environments using a single metric. This result is in agreement with related human investigations that reported kurtosis combined with noise energy could be used as a single metric to evaluate the risk of NIHL in different noise environments (*6*,*10*).

Considering the effect of noise temporal structure on NIHL, it is necessary to re-evaluate the appropriateness of the current international noise exposure standards (e.g. measurement method and OEL) for complex noise. Traditional noise measurement methods using dosimeters or sound level meters should be improved by a kurtosis metric to compensate for the lack of ability to capture the peak clipping effect of impulse noise. The role of kurtosis as the additional risk factor for the occupational NIHL suggests that the noise OEL of 85 dB(A) may be unsafe for the hearing of workers exposed to noise exposure with a complex temporal structure. The American College of Occupational and Environmental Medicine (ACOEM) also concludes that although the Occupational Safety and Health Administration (OSHA) action level for noise exposure is 85 dB(A), there is evidence that the NIHL risk increases with long-term exposure to noise above 80 dB(A) and that the risk increases significantly as the exposure rises above 85 dB(A) (*11*). Therefore, the OEL for noise should be modified based on the noise temporal structure.

This study was subject to at least two limitations. First is that the sample size for some types of work was insufficient. Second was that the kurtosis measure was a proxy measure for quantifying noise complexity and may be limited to quantifying certain aspects of a complex signal.

Based on these findings above, conclusions could be drawn as follows: 1) noise temporal structure was an important risk factor for occupational NIHL in addition to noise energy; 2) the kurtosis metric could be used to quantify complex noise exposure; and 3) as a combination of noise temporal structure and noise energy, the kurtosis-adjusted CNE could be used to evaluate the risk of occupational hearing loss associated with complex noise.

**Conflicts of interest**: No conflicts of interest.

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