

Original article

Coexposure to Noise and Ototoxicants as a Risk Factor for Hearing Loss in Healthcare Workers in a Tertiary Hospital

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Abstract

Background: Authorities have highlighted the need to study the threat posed by the combined effects of noise and other occupational hazards, including ototoxicants. Few studies focus on the combined effects among healthcare workers.

Objectives: This study aimed to investigate the prevalence of hearing loss among those who expose to noise alone and those with combined exposure to both noise and ototoxicants.

Methods: In this cross-sectional study among healthcare workers exposed to noise during their work, data were retrieved from annual check-up results, including audiometric findings and personal and work-related factors. Chemical exposure was determined through environmental and personal sampling data review. Hearing loss was diagnosed according to Cole's criteria. Logistic regression was performed to determine the association between noise-induced hearing loss (NIHL) and factors of interest, including ototoxicants exposure.

Results: Among 108 participants, a prevalence of NIHL of 29.6% was observed. None of the workplace chemical exposure monitoring exceeded 10.0% of the permissible exposure limit (PEL), and no biological exposure indices (BEI) were detected. Logistic regression analysis exhibited no significant association between NIHL and any risk factors, including exposure to ototoxicants.

Conclusion: Both noise and chemical exposure levels in this study were much lower than the recommended standards, which likely contributed to the non-significant results. The absence of widely accepted diagnostic criteria for hearing loss caused by noise, chemicals, or combined exposure necessitates discussion on proper diagnostic standards.

Keywords: Audiometry, noise-induced hearing loss, ototoxicants, occupational disease, work-related disease.

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Received: January 20, 2025

Revised: March 16, 2025

Accepted: May 16, 2025

Exposure to loud noise has long been recognized as a significant contributor to sensorineural hearing loss, a permanent medical condition that remains incurable.⁽¹⁾ Noise-induced hearing loss (NIHL) results from prolonged exposure to loud sounds, where the primary mechanism is the direct damage of auditory nerve cells within the cochlea, along with chemical changes in the auditory system. Hearing loss can lead to several negative outcomes, both in occupational and personal aspects such as challenges in communicating with colleagues and family, a higher risk of accidents due to being unable to hear alarms or machinery sounds at work, diminished ability to handle complex tasks, lower job performance, a decrease in overall quality of life, reduced income, and increased medical expenses.^(2, 3)

According to the 2017 report from the Bureau of Occupational Disease and Environment, Department of Disease Control, Thai Ministry of Public Health, there were 42,946 cases of hearing loss due to loud noise, with a rate of 71.3 per 100,000 people, which is a decrease from 2016 when 60,946 cases were reported (rate of 101.5 per 100,000 people). However, these figures stand in stark contrast to the actual cases of occupational diseases reported to the Compensation Fund of the Social Security Office (SSO) in Thailand from 2019 to 2023.⁽⁴⁾ During this period, hearing loss attributed to noise exposure ranked fifth among occupational diseases or work-related conditions. Hearing loss due to noise exposure affected a total of 57 employees, accounting for 0.01% of the overall cases per year. The incidence by year is shown in **Table 1**.

Several studies have shown varying prevalence of NIHL among healthcare workers. A study by Wongsuwan K, *et al.* found the prevalence of NIHL in workers of a medical center was 41.5%.⁽⁵⁾ Other studies conducted in hospital workers resulted in ranges of prevalence of 30.9% to 73.6%.⁽⁶⁻⁸⁾ These results underscore the significance of hearing loss as a critical occupational health issue among healthcare workers.

The definition of “noise exposure” is based on the Department of Labour Protection and Welfare’s notification on permissible noise levels for employees, which sets an average daily noise exposure (TWA) limit of 85 dB (A) for an 8-hour workday.⁽⁹⁾ This noise exposure limit is deemed sufficient to prevent most cases of work-related hearing loss and is the basis for establishing hearing conservation programs, which include regular hearing monitoring. European Union (EU) and international sources have highlighted the needs to study the threat from interactions between occupational risks.⁽¹⁰⁾ Exploring the combined effects, whether additive⁽¹¹⁾ or synergistic⁽¹²⁾, seems to be an emerging trend as the criteria for noise-induced hearing loss has already been established and solidified.

In 2018, Thai legislation mandated the implementation of workplace hearing conservation programs (HCP). However, as in many other countries, the effects of combined exposures have not been taken into account, as the current noise exposure threshold does not consider the cumulative impact of multiple hazards.⁽¹³⁾ Research on the combined effects of noise and ototoxic chemicals is still limited. It was only in 1970s that the ototoxicity quality of several chemicals was recognized. Most of the studies focused on clinical drugs such as aminoglycoside antibiotics, cisplatin, quinines, and loop diuretics, and mainly focused on receivers who were the recipients of the aforementioned drugs instead of administrators of the medications.⁽¹⁴⁾ Existing studies mainly focused on the industrial sector, for example, Farfalla AA, *et al.*⁽¹⁵⁾ studied workers in agricultural fields, showing that those exposed to both noise and ototoxic chemicals had a sixfold increase in hearing loss (OR: 6.0; 95% CI, 4.7 - 7.8). Results reported among bus and truck drivers, military personnel and chemical plant environments also carries significant risks for auditory dysfunction.⁽¹⁶⁾ The number of studies among healthcare workers was still very limited.

Table 1. Incidence of occupational hearing loss in Thailand by year (SSO report 2019-2023).

Year	Number of cases	Number of employees registered	Incidence per 10,000 employees
2019	11	11,710,823	0.0094
2020	7	11,153,697	0.0063
2021	8	11,172,844	0.0072
2022	3	11,678,470	0.0026
2023	28	11,937,614	0.0234

There are some confusions around coining the term “ototoxicants”. Some experts remark that ototoxicants should be classified on the part of the ear they damage, such as neurotoxicants, cochleotoxicants, or vestibulotoxicants.^(10, 17, 18) Since 2019, American Conference of Governmental Industrial Hygienists (ACGIH) has adopted “OTO” notation to highlight a chemical’s ability to cause hearing impairment either alone or in combination with noise.⁽¹⁹⁾ ACGIH also reinstated that although there might not be sufficient evidence for some substances for its ototoxicity, they can still damage the auditory system through their neurotoxicity effects. Sometimes the terms “ototoxicants” and “ototoxic substances” are used interchangeably.⁽²⁰⁾ The author chose to adhere to this definition, still, some reinstatement might be needed in order to avoid misconceptions.

A significant number of workers are exposed to ototoxicants in the workplace. According to the Fourth European Working Conditions Survey of the European Foundation for the Improvement of Living and Working Conditions approximately 30.0% of the EU-27 workers in 2005 report exposure to noise at least a quarter of the time at the workplace, 11.2% the inhalation of vapors such as solvents and thinners, 19.1% the inhalation of smoke, fumes, powder or dust and 14.5% the handling of chemical substances.⁽²¹⁾

Present studies regarding ototoxic substances among healthcare workers are limited. Most of the time, the main focus would be towards chemicals in the pharmaceutical category.⁽²⁰⁾ Previous studies have demonstrated the importance of close monitoring for healthcare personnel exposing to these drugs, while very few have studied backline workers. The objective of this study was to investigate the co-exposure of noise and ototoxicants by comparing audiogram results among those who exposed to ototoxicants in workplace and those who do not. The study aimed to raise awareness for effects of the combine exposure between noise and ototoxicants.

Materials and methods

Instead of a mandatory threshold at 85 dB (A) for an 8-hour workday, a tertiary hospital mandates any healthcare workers exposing to at least 80 dB (A) for an 8-hour workday to undergo annual audiometric test, as there are no department with environmental noise level over 85 dB (A). All hospital workers exposed to noise during their work were recruited into the HCP. The author obtained the most

recent annual audiometric tests from the year 2024, along with other personal and work-related information. As this is a secondary data study, the available information is somewhat limited, particularly noise and chemical exposures outside the workplace.

All subjects in this study were exposed to noise; only some were categorized as part of the combined noise and ototoxicants exposure group. Workers were assigned to the combined-exposure group based on several criteria:

1. Department assignment: Workers were considered exposed to ototoxic substances if they were assigned to departments where ethylene oxide, toluene, or lead were officially listed as present. Those departments include central sterile supply unit, prosthesis and orthosis unit, medical device unit, and carpenters.

2. Environmental monitoring: Exposure was determined when the concentration of a chemical in workplace ambient monitoring exceeded 10.0% of the permissible exposure limit (PEL).

3. Biological monitoring: Workers were included in the combined-exposure group if any biological exposure index (BEI) for ototoxicants was detected.

The author applied the criteria by Coles RR, *et al.*⁽²²⁾ for diagnosis of NIHL. Cole’s criteria consist of three main requirements for the diagnosis of NIHL, which are high-frequency hearing impairment at 3–6 kHz range; potentially hazardous amount of noise exposure; high-frequency audiometric notch or bulge. A notch is defined where the hearing threshold level (HTL) at 3 and/or 4 and/or 6 kHz is at least 10 dB greater than at 1 or 2 kHz and at 6 or 8 kHz. Although the notching pattern generally appears in pure-tone audiometric test in NIHL, some studies also report this pattern in those with prolonged ototoxicants exposure as well.⁽²³⁾

Before statistical analysis, a normality test was performed, confirming the normal distribution of the data. Demographic data are presented in **Table 2**, displayed as frequencies and percentages, as well as means with corresponding standard deviations (SD) where applicable. To determine the required sample size for bivariate analysis, the author used the STATA version 14.0 statistical software with a significance level set at 0.05 and a power of 0.80. The total sample size needed is 52 participants divided into two groups, each consisting of 26 individuals. As this study is based on secondary data, the author chose to include all 108 subjects to avoid potential issues with missing data

Table 2. Demographic data of the sample (n = 108).

Characteristics	n (%)
Sex	
Male	77 (71.3)
Female	31 (28.7)
Age (years)*	43.9 ($\pm$ 10.9)
History of past ear injuries/infections	
Yes	12 (11.1)
No	98 (88.9)
History of smoking	
Active smoker	12 (11.1)
Past smoker	19 (17.6)
Never smoke	77 (71.3)
Work year(s) at this hospital*	12.8 (10.2)
History of exposing to noise at previous work(s)	
Yes	24 (22.2)
No	84 (77.8)
Work department	
Laundry unit	24 (22.2)
Central sterile supply unit	20 (18.5)
Casting room technicians	2 (1.9)
Prosthesis and orthosis	6 (5.6)
Medical device unit	9 (8.3)
Electricians	6 (5.6)
Plumbers	5 (4.6)
Carpenters	8 (7.4)
Air conditioning technicians	10 (9.3)
Vehicles	17 (15.7)
Technician office	1 (0.9)
PPE used during work	
All the time	7 (6.5)
Most of the time	18 (16.7)
Sometimes	43 (39.8)
Never use PPE	49 (37.0)
Ototoxic substance(s) exposed	
Ethylene oxide	21 (19.4)
Toluene	14 (13.0)
Lead	9 (8.3)
None	64 (59.3)

* Mean $\pm$ standard deviation

and to ensure that the dataset was sufficiently robust for meaningful analysis. The final sample consisted of 64 participants exposed to noise alone and 44 participants exposed to both noise and ototoxicants. Subsequently, logistic regression analysis was performed to evaluate the association between individual factors or work-related factors and NIHL.

Results

Demographic data are displayed on **Table 2**. Most of the workers are male, with an average age of 43.9 years, and an average of 12.8 years of work experience at this hospital. Most of them have never smoked (71.3%) and reported having no previous work

Table 3. Factors associated with abnormal audiogram (n = 108).

Factors	Audiometric results		P-value	Odds ratio
	NIHL (n = 32)	noNIHL (n = 76)		
Age (years)*	45.7 ± 10.0	42.5 ± 10.6	0.23	1.0 (1.0 - 1.1)
Work year(s) at this hospital *	15.1 10.7	11.5 9.7	0.13	1.0 (1.0 - 1.1)
History of past ear injuries/infections			0.27	
Yes	2 (6.2)	10 (13.2)		0.4 (0.1 - 2.1)
No	30 (93.8)	66 (86.8)		Ref
History of smoking			0.91	
Active smoker	4 (12.5)	8 (10.5)		0.8 (0.3 - 2.6)
Past smoker	5 (15.6)	14 (18.4)		1.2 (0.3 - 4.3)
Never smoke	23 (71.9)	54 (71.1)		Ref
History of exposing to noise at previous work(s)			0.65	
Yes	8 (25.0)	16 (21.1)		1.3 (0.5 - 3.3)
No	24 (75.0)	60 (79.0)		Ref
Work department			0.52	
Laundry unit	6 (18.8)	18 (23.7)		Ref
Central sterile supply unit	3 (9.4)	17 (22.4)		0.5 (0.1 - 2.5)
Casting room technicians	0 (0.0)	2 (2.6)		-
Prosthesis and orthosis	2 (6.2)	4 (5.3)		1.5 (0.1 - 6.2)
Medical device unit	1 (3.1)	5 (6.6)		0.6 (0.1 - 6.2)
Electricians	4 (12.6)	5 (6.6)		2.4 (0.5 - 12.0)
Plumbers	2 (6.2)	6 (7.9)		2.0 (0.3 - 15.0)
Carpenters	2 (6.2)	6 (7.9)		1.0 (0.2 - 6.4)
Air conditioning technicians	5 (15.6)	5 (6.6)		3.0 (0.6 - 14.1)
Vehicles	7 (21.9)	10 (13.7)		2.1 (0.6 - 8.0)
Technician office	0 (0.00)	1 (1.3)		-
PPE used during work			0.56	
All the time	2 (6.3)	5 (6.6)		0.5 (0.2 - 1.3)
Most of the time	5 (15.6)	13 (17.1)		0.6 (0.1 - 2.2)
Sometimes	10 (31.2)	33 (43.4)		0.7 (0.1 - 3.9)
Never use PPE	15 (46.9)	25 (32.9)		Ref

* Mean ± standard deviation.

experience with noise (77.8%). More than half of the workers self-reported rarely using ear plugs or earmuffs while working with noise, with 39.8% used “sometimes” and 37.0% said they “never” use PPE at all.

Using Cole’s criteria, 32 workers (29.6%) were diagnosed with NIHL. Logistic regression analysis results performed to evaluate the association between factors and NIHL are presented on **Table 3**.

The analysis showed no significant association between noise-induced hearing loss and any of the risk factors, including exposure to ototoxic substances. More than half of the workers in the program (59.3%) did not have any contact with ototoxic chemicals at all. Among combined-exposure group, each worker exposed to chemicals was exposed to only one type of chemical. According to criteria mentioned earlier, neither workplace nor biological monitoring yielded positive results. Therefore, the author relied solely on

the Safety Data Sheets (SDS) available at each worker’s workplace to determine whether a sample belonged to the combined exposure group or the noise-only exposure group. As shown in Table 4, workers exposed to ethylene oxide, toluene, or lead did not exhibit a significantly higher risk compared to those exposed to noise alone. Also, when comparing the combined-exposure group (n = 44) to the noise-only group (n = 64), no significant difference was observed (**Table 4**).

Considering non-occupational exposure, smoking is also suggested by European Agency for Safety and Health at Work (EU-OSHA)⁽¹⁰⁾ as one of the ototoxic substances. In this study, however, there is no significant difference between ever-smoking group (n = 31) and non-smoking group (n = 77), and odds ratio of 0.7 (95% CI: 0.4 - 2.4).

Table 4. Abnormal audiogram associated with noise and ototoxicants exposure (n = 108).

Factors	Audiometric results		P-value	Odds ratio
	NIHL (n = 32)	noNIHL (n = 76)		
Ototoxicants listed at work			0.27	
Ethylene oxide	3 (9.4)	18 (23.7)		0.3 (0.1 - 1.3)
Toluene	4 (12.5)	10 (13.2)		0.8 (0.2 - 2.9)
Lead	4 (12.5)	5 (6.6)		1.6 (0.4 - 6.7)
None	21 (65.6)	43 (56.5)		Ref
Ototoxicants listed at work				
Any ototoxicants (n = 44)	11 (34.5)	33 (43.4)	0.38	0.7 (0.3 - 1.7)
None (n = 64)	21 (65.5)	43 (56.6)		Ref
Ototoxicants found in work environment sampling			—	
Ethylene oxide	0	0		
Toluene	0	0		
Lead	0	0		
None	0	0		
Ototoxicants found in personal sampling (BEI)		—		
Ethylene oxide (N/A)	—	—		
Toluene (Blood toluene level, mg/L)	0	0		
Lead (Blood lead level, mcg/L)	0	0		
None	0	0		

Discussion

NIHL in this study was 29.6%, which is comparatively lower than findings from similar research conducted in Thailand.^(5, 7) The statistical analysis revealed no significant association between any risk factors, including exposure to ototoxic substances, and the prevalence of NIHL. In contrast, Wongsuwan K's study found that NIHL was associated with smoking, presenting an odds ratio of 5.6 (95% CI = 1.7 - 18.9), and with being over 40 years old, which yielded an odds ratio of 10.4 (95% CI = 2.8 - 38.2).⁽⁵⁾ A recent study identified statistically significant risk factors for NIHL, including a history of smoking (adjusted OR = 4.1, 95% CI 1.1 - 16.0), prior noise exposure (adjusted OR = 23.6, 95% CI 2.1 - 267.9), and the frequency of using personal protective equipment (adjusted OR = 0.7, 95% CI 0.0 - 0.6).⁽²⁴⁾ Similarly, Dement *et al.* found that work duration was a strong predictor, with a risk ratio of 3.8 (95% CI = 2.1 - 7.0).⁽²⁵⁾

The author found that the result is concordant with a number of other studies. Statistical differences between exposed and unexposed groups in pure-tone thresholds were reported only in fewer than half of the studies in which it was used (12 of 25 studies).⁽²⁶⁾ The author decided to report the study results regardless of their non-statistically significant nature. The reasons may be attributed to several factors, which will be discussed as follows.

The first reason might be the low level of exposure, for both noise and ototoxicants. This hospital initiated HCP at a threshold as low as 80 dB (A). The ototoxicants exposed in this study were ethylene oxide, toluene, and lead, which is particularly similar to Beaver's study stating that most sample collected were lead, and then toluene.⁽²⁰⁾ However, the exposure monitoring results in this study were all negative. The environmental report showed chemical levels lower than 10.0% PEL, which according to OSHA are below the action level, hence will not require specific risk-mitigating actions, such as exposure monitoring and medical surveillance.⁽²⁷⁾ Even when applying more stringent standards, such as the ACGIH Threshold Limit Values (TLVs) for ototoxicants—which are typically five to ten times lower than the respective OSHA's PELs—the exposure levels monitored in this study were still below those thresholds. Schäper M, *et al.* proposed that exposure to ototoxicants at concentrations below a certain threshold, referred to as the “ototoxic threshold,” may not be likely to cause hearing loss.⁽²⁷⁾ A study also proposed that as noise exposures increase, noise could become the more predominant cause of hearing loss, even in the presence of ototoxicants, making the effects of ototoxicants more obscure.⁽²⁸⁾ In this study, however, the noise exposure levels were well below widely established thresholds, which may explain the lack of statistically significant findings between both groups.

Another possible reason is the absence of widely accepted diagnostic criteria for hearing loss caused by noise, chemicals, or combined exposure. The diagnostic standards established by OSHA are primarily designed for long-term studies to identify conditions such as Standard Threshold Shift (STS).⁽²⁰⁾ However, National Institute for Occupational Safety and Health (NIOSH) and others have recognized the OSHA definition of a standard threshold shift may undercount hearing loss by up to 28.0% – 36.0%.^(3,29) A study among healthcare workers by Wongkeereepiboon N, *et al.* demonstrated a wide discrepancy in prevalence —41.5% using NIOSH criteria and 23.5% using OSHA standards.⁽³⁰⁾ Some experts also highlighted that OSHA's definition of a STS may inadequately capture hearing loss related to ototoxicant exposure.⁽³¹⁾ Given these reasons, the author chose Cole's criteria over OSHA or NIOSH, as research suggests it can detect hearing loss from co-exposure to noise and ototoxicants even below PEL or TLV. The absence of longitudinal audiometric data further limited the use of other methods.^(20,32)

In addition to the lack of established criteria for diagnosing hearing loss from combined noise and ototoxicant exposure, there is no consensus on the most appropriate audiometric tests for such cases. Experts have suggested using a battery of assessments—such as extended high-frequency pure-tone audiometry (EHF-PTA), transient evoked otoacoustic emissions (TEOAE), distortion product otoacoustic emissions (DPOAE), acoustic reflex threshold (ART), and auditory brainstem response (ABR)—to evaluate chemical-related auditory effects.^(23,26) While these tests are common in clinical and research settings, they are rarely used in occupational environments due to their time, staffing, and cost demands.

Lastly, an explanation for non-significant analytical results might be because of statistical power. Choi YH, *et al.* reviewed audiometric reports and chemical exposure data for 30,000 Korean workers and only discovered effect sizes of hearing threshold increment with occupational noise at 1.6-fold and 2.2-fold higher in individuals exposed to heavy metals and organic solvents.⁽³³⁾ Given that their sample size was approximately 300 times larger than the one used in this study, it can be inferred that the statistical power in the current analysis was insufficient for robust statistical calculation.

Globally, organizations like the World Health Organization (WHO), the International Labour Organization (ILO), and the American College of Occupational and Environmental Medicine (ACOEM) acknowledge the risks of combined noise and chemical exposure in the workplace.^(10,34) While the WHO and EU-OSHA call for stricter standards, current regulations—including ILO and European legislation—do not yet address combined exposures. France's INRS (Institut National de Recherche et de Sécurité) has proposed stricter styrene limits and mandatory hearing protection, while the US Army recommends annual audiograms for chemically exposed workers. NIOSH and Germany's DGUV support better risk assessment and scientific guidelines.⁽³⁵⁾ As no specific thresholds exist for ototoxicants or their combined effects with noise, the ALARP principle should guide workplace controls. ACGIH also recommends including co-exposed workers in hearing conservation programs. Further research is needed to define exposure limits and identify appropriate audiometric tests and diagnostic criteria.

With only 0.0094 cases per 10,000 workers reported in Thailand in 2019 compared to 1.4 per 10,000 in the US, or about 12,000 workers suffered work-related hearing loss yearly, work-related hearing loss in Thailand is likely underreported.^(36,37) While NIHL is already underreported, hearing loss from ototoxicants is even more so. Clerc F and Pouyatos B were unable to develop a predictive model partly due to this underreporting and the common attribution of work-related hearing loss solely to noise exposure.⁽³⁸⁾ This further underscores the need for future research to focus on diagnosing hearing loss related to ototoxicants and combined exposures.

This study had some limitations. Some workers at the study center were exposed to noise levels well below the threshold and thus were not included in the HCP. However, a subset of these workers was also exposed to ototoxicants. Since they were not part of the HCP, audiometric testing was not performed, mainly due to cost and time constraints. This may have led to an underestimation of hearing loss prevalence from both noise and combined exposures. Additionally, as a secondary data study, the information—particularly regarding noise and chemical exposure outside the workplace—was limited. This highlights the need for future research with larger sample sizes and more comprehensive data collection—ideally through prospective study designs.

Conclusion

The hospital in this study is currently practicing in accordance with the EU-OSHA recommendation that there should be a lowered threshold for noise exposure in workers subjecting to ototoxicants in their work.⁽¹⁰⁾ The recommended combined exposure threshold is based loosely around 80 dB (A) for an average 8-hour work shift, as opposed to the current 85 dB (A) threshold TWA according to Thai law and several other international regulations.^(9, 37, 39) The prevalence of NIHL in this study was comparatively lower than those from similar studies. The statistical analysis revealed no significant association between ototoxic substances and NIHL. Further studies, recommendations and standards would be helpful in implementing a strong evidence-based noise threshold for a better, safer working environment.

Acknowledgements

The authors would like to express their gratitude to all participants who were involved in this study.

Conflict of interest statement

All authors have completed and submitted the International Committee of Medical Journal Editors Uniform Disclosure Form for Potential Conflicts of Interest. All authors declare that they have no conflicts of interest.

Data sharing statement

All data generated or analyzed in the present study are included in the published article. Further details are available for non commercial purposes from the corresponding author upon reasonable request.

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