RMJ

Original Article

Comparing Diagnostic Criteria for Noise-Induced Hearing Loss in Hospital Personnel: Age Adjustments With ISO 7029-2017

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Abstract

Background: Noise-induced hearing loss (NIHL) is a prevalent occupational health concern, especially in high-noise industries. Despite various diagnostic methods, no universally accepted gold standard for diagnosing NIHL exists. Age adjustments, which are an unresolved issue, vary across proposed standards. Comparing diagnostic criteria is vital for improving early detection and prevention strategies.

Objective: To compare different NIHL diagnostic methods, assessing the impact of age adjustments on hearing threshold interpretations in hospital personnel.

Methods: A retrospective study was conducted, analyzing audiometric data from hospital personnel in a hearing conservation program (HCP) using multiple diagnostic criteria, including the National Institute for Occupational Safety and Health (NIOSH) and the Occupational Safety and Health Administration (OSHA) threshold shift criteria, the Coles, Lutman, and Buffin (CLB) method with OSHA age-adjustment table, and ISO 7029-2017 values. NIHL quantification was performed using various averages and age-associated hearing loss (AAHL) values.

Results: A total of 108 participants (71.30% male; mean age 43.92 years) were included. The mean duration of employment was 12.80 years. Based on OSHA Standard Threshold Shift (OSTS), 9.26% of participants had NIHL, while NIOSH Significant Threshold Shift (NSTS) identified 35.19%. Coles' bulge analysis revealed varied NIHL prevalence of 28.70% using OSHA Table F-1/F-2, and 46.30% with ISO 7029-2017. Mean hearing thresholds (average of 0.5 kHz, 1 kHz, 2 kHz, 3 kHz) were 23.02 dB (OSHA AAHL) and 20.90 dB (ISO 7029-2017), compared to 41.22 dB and 50.56 dB when 4 kHz was included.

Conclusions: NIHL diagnosis remains complex due to the lack of a definitive standard. Diagnostic criteria and age adjustment methods influence prevalence estimates, highlighting the need for further research to enhance NIHL assessment for more effective prevention strategies.

Keywords: Noise-induced hearing loss, Age-adjustment, Audiogram, ISO 7029-2017

Citation: Chevasutho P. Comparing diagnostic criteria for noise-induced hearing loss in hospital personnel: age adjustments with ISO 7029-2017. *Res Med J*. 20XX;XX(X):e273715. doi:10.33165/rmj.2026.e273715

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Received: 18 February 2025
Revised: 7 September 2025
Accepted: 27 October 2025
Published: 26 January 2026

Introduction

Current methods for diagnosing noise-induced hearing loss (NIHL) using pure-tone audiograms have been criticized for their inadequacy in diagnosing NIHL resulting from various types of noise exposure, particularly those beyond steady broadband noise or in cases of co-exposure. This limitation arises due to the absence of a universally accepted gold standard for diagnosing NIHL, as well as the fact that certain adverse effects of noise exposure may not be fully captured by the audiogram.[1-4] Various diagnostic methodologies

have been employed worldwide, including those proposed by Coles et al,[5] Niskar et al,[6] and Phillips et al.[7] Among these, the Coles, Lutman, and Buffin (CLB) method, developed over 2 decades ago, has remained the most widely accepted and commonly used approach by clinicians.[5] In specific cases where individuals are exposed to atypical noise, such as intense low-frequency noise, an alternative method proposed by Moore et al[8] has been suggested as a more suitable diagnostic tool. Most of these methods are based on the presence of a "noise notch" or a calculated bulge, which rely on the hearing threshold levels (HTLs) at 3, 4, or 6 kHz being elevated (indicating worse hearing) compared to HTLs at both lower frequencies (1 kHz) and higher frequencies (8 kHz). The specificity of the CLB method — defined as the percentage of individuals without NIHL who are correctly identified as not having NIHL — was estimated to be 87% when each ear was evaluated separately, as reported by Moore et al.[9]

The Health and Safety Executive (HSE) has emphasized the significance of a notch at 4 kHz as a well-established clinical indicator of NIHL, while also noting that a notch at 6 kHz is more variable and of limited diagnostic utility.[10] Additional diagnostic criteria have been introduced by the Occupational Safety and Health Administration (OSHA, 1981), the National Institute for Occupational Safety and Health (NIOSH, 1998), and the US Department of Defense (2019), all of which require serial audiogram comparisons over time. NIOSH defines NIHL based on a standard threshold shift (NSTS) — typically a permanent hearing threshold of 25 dB or greater at 3, 4, or 6 kHz in either ear, confirmed by repeat testing. OSHA uses a similar threshold but defines a standard threshold shift (OSTS) as a change of 10 dB or more at 2, 3, and 4 kHz in either ear, relative to the baseline audiogram. However, occupational audiograms often exhibit considerable variability over short intervals, sometimes differing markedly between tests conducted just 1 or 2 years apart due to multiple factors.[11]

In Thailand, hearing conservation programs adhere to the guidelines established by the Hearing Loss Prevention Program (HLPP) of NIOSH, which are not explicitly referenced in the national regulations.[12] Furthermore, age adjustment or age correction is not mandated in either the diagnosis or quantification of NIHL. Given the lack of a universally recognized gold standard for diagnosing NIHL, significant variability exists in its diagnosis. This inconsistency can be particularly challenging in clinical settings, where a 95% confidence level is required to minimize the likelihood of a diagnosis occurring by chance. In contrast, medico-legal contexts apply a lower threshold, diagnosing NIHL based on a probability exceeding 50%.[11]

Another challenge in NIHL assessment is its quantification. It is well established that aging significantly impacts hearing sensitivity.[2] However, OSHA and NIOSH do not impose strict requirements for routine age correction, which may lead to overestimation of both the prevalence and severity of NIHL among workers. However, OSHA provides age correction tables (F-1 and F-2) , which do not include the 8 kHz frequency, a key element in identifying the characteristic "bulge" in Coles' diagnostic method for NIHL.[13]

ISO 7029-2017 is a more recent and periodically revised standard for age correction, regarded by experts as the most appropriate for quantifying age-associated hearing loss (AAHL) at present.[11] ISO 7029-2017 is an international standard titled: Acoustics — Statistical distribution of hearing thresholds related to age and gender. It provides reference data for the distribution of hearing thresholds in otologically normal people. Previous versions of this standard were published in 1984 and 2000. The AAHL values used by Coles et al[5] were based on the now-outdated ISO 7029-1984. ISO 7029-2017 offers greater

sensitivity in detecting hearing abnormalities than previous versions (1984 and 2000), as it is based on populations carefully screened to exclude conductive hearing loss and noise exposure.[11] To date, no studies have applied ISO 7029-2017 in the context of NIHL assessment in Thailand, particularly within occupational settings, as far as the author is aware. This study is among the first to do so.

Methods

This retrospective study analyzed a set of data from an annual health examination in year 2024 from 108 hospital personnel aged 20-60 years, all of whom were enrolled in a hearing conservation program (HCP) due to their occupational exposure to noise. Although Thai regulations mandate an HCP for noise exposure levels of 85 dB or higher, workplace regulations in this study required implementation at a lower threshold of 80 dB. In compliance with legal requirements, these personnel underwent regular audiometric testing as part of their hearing monitoring regimen, alongside other HCP measures such as noise monitoring and the provision of personal protective equipment (PPE). Audiometric testing is mandatory for all personnel enrolled; so data were collected from the entire population. Audiograms were performed using an audiometer compliant with ANSI S3.6 – Specifications for Audiometers, within an audiometric booth certified according to the ANSI S3.1-1999 standard for ambient noise levels. The tests were administered by occupational health registered nurses who had completed a specialized training program in Occupational Health Nurse Practitioner Practice, accredited by the Ministry of Public Health (MOPH), Thailand. Data were obtained from medical records and supplemented with responses to annual questionnaires completed by participants during their routine physical examinations.

The diagnosis of NIHL among hospital personnel was conducted based on the CLB method. Given the absence of a universally accepted diagnostic standard, ISO 7029-2017 was incorporated as a reference to define HTL “bulges”, thereby mitigating the confounding effects of AAHL.[5]

After the diagnostic stage, the severity of NIHL was further evaluated by comparing individuals' hearing thresholds to the median reference values established using ISO 7029-2017 as a way of quantifying NIHL.[14] The median HTL (50th percentile) was chosen for this study, as it is the recommended default threshold unless there is strong evidence of exceptionally good or poor hearing ability, and despite differing opinions, it remains the best approach when occupational audiograms are unavailable or unreliable (Figure 1).[11, 15]

All data were anonymized, ensuring the removal of personally identifiable information such as names and hospital numbers. Data analysis was conducted using Stata version 14.0 (StataCorp. Version 14. College Station, TX: StataCorp LP; 2015). Ethical approval for this study was obtained from the hospital’s ethics committee.

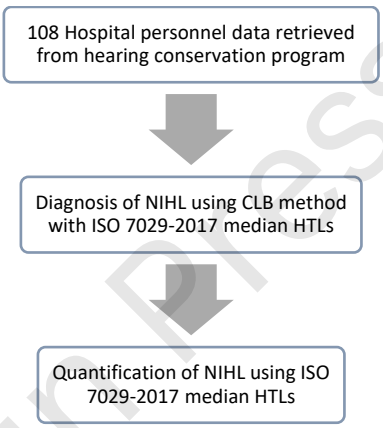
Results

A total of 108 participants were included in the study, with the majority being male (71.30%) and the remaining female (28.70%). The mean (SD) age of participants was 43.92 (10.27) years. Regarding medical history, 9.26% reported a history of past ear injuries or infections, while 88.89% had no such history. In terms of smoking habits, 11.11% were active smokers, 17.59% were past smokers, and 71.30% had never smoked. The mean (SD) duration of employment at the hospital was 12.80 (10.23) years.

The prevalence of NIHL depicted dissimilarity depending on the criteria used for assessment. Based on the OSTS criterion, 9.26% of participants were identified with NIHL (95% CI, 4.53-16.37). The NSTS criterion classified 35.19% of participants as having NIHL (95% CI, 26.24-44.96). The difference in prevalence between these criteria was statistically significant, as indicated by the Pearson chi-square test ($P < .001$) (Table 2).

When using Coles' bulge analysis, the prevalence differed based on the reference standard applied. Using OSHA Table F-1 and F-2, 28.70% of participants were identified with NIHL (95% CI, 20.41-38.20), whereas applying the ISO 7029-2017 standard, the prevalence increased to 46.30% (95% CI, 36.65-56.15); the highest proportion of affected workers identified.

Figure 1. Flow of Participant Selection



The requirements of the CLB method are (adapted from Moore[15]):

R1. A single measurement of the HTL at 3, 4 or 6 kHz should be at least 10 dB greater than the HTL at 1 or 2 kHz.

R2(a). This is the requirement for noise exposure at an equivalent daily 8-h continuous noise exposure (LEP,d) of not less than 85 dB(A) for a sufficient number of years to lead to a cumulative exposure of at least 100 dB(A) NIL.

R2(b). This is a less stringent requirement at 90 dB(A) NIL, although the lower limit on LEP,d remains at 85 dB(A)

R3(a). This requirement applies when R2(a) is met. There should be a downward notch or bulge in the audiogram in the range 3-6 kHz. A notch is defined as present when "the HTL at 3 and/or 4 and/or 6kHz is at least 10 dB greater than at 1 or 2 kHz and at 6 or 8 kHz". A bulge is defined as present when "the HTL at 3 and/or 4 and/or 6 kHz is at least 10 dB greater relative to the comparison values for age-related hearing loss at corresponding frequencies". To establish whether R3(a) is satisfied, a "bulge analysis" is conducted using the HTLs at 1 or 2 kHz and at 6 or 8 kHz as "anchor points". R3(a) is based on the assumption that NIHL will typically result in greater hearing loss at 4 kHz than at 1 or 2 and 6 or 8 kHz.

R3(b). This requirement applies when R2(a) is not met, but R2(b) is met. R3(b) is similar to R3(a), except that the notch or bulge in the audiogram must have a value of 20 dB or more, instead of 10 dB or more.

Abbreviations: CLB, Coles, Lutman, and Buffin method; HTL, hearing threshold level; NIL, noise immersion level.

Table 1. Demographic Data

Characteristic	No. (%)
Sex	
Male	77 (71.30)
Female	31 (28.70)
Age, mean (SD), y	43.92 (10.27)
History of past ear injuries/infections	
Yes	10 (9.26)
No	98 (90.74)
History of smoking	
Active smoker	12 (11.11)
Past smoker	19 (17.59)
Never smoke	77 (71.30)
Work at this hospital, mean (SD), y	12.80 (10.23)
Work department	
Laundry unit	24 (22.22)
Central sterile supply unit	20 (18.52)
Casting room technicians	2 (1.85)
Prosthesis and orthosis	6 (5.56)
Medical device unit	9 (8.33)
Electricians	6 (5.56)
Plumbers	5 (4.63)
Carpenters	8 (7.41)
Air conditioning technicians	10 (9.26)
Vehicles	17 (15.74)
Technician office	1 (0.93)

Table 2. Prevalence of NIHL by Different Criteria

NIHL by Criterion	No. (%)	95% CI
OSTS	10 (9.26)	4.53-16.37
NSTS	38 (35.19)	26.24-44.96
Coles' bulge analysis using OSHA Table F-1 and F-2	31 (28.70)	20.41-38.20
Coles' bulge analysis using ISO 7029-2017	50 (46.30)	36.65-56.15

Abbreviations: NIHL, noise-induced hearing loss; NSTS, NIOSH Significant Threshold Shift; OSHA, Occupational Safety and Health Administration; OSTS, OSHA Standard Threshold Shift.

An example of a bulge analysis using the CLB method, where 1 kHz and 8 kHz were selected as anchor points.[15] The AAHL values represent those for a 37-year-old man at the 50th percentile with no history of noise exposure. The measured HTL values were

then compared to the corresponding AAHL values, with any discrepancies at the anchor points referred to as "misfit values". These misfit values were subsequently interpolated across frequencies using a logarithmic scale (Table 3).

The AAHL values were then adjusted, ensuring that when an AAHL value exceeded (ie, was worse than) the measured HTL, it was set equal to the measured HTL, while any negative AAHL values were set to zero. The adjusted AAHL was then compared to the measured HTL to estimate NIHL, as shown in the bottom row of the table. According to the bulge criterion, any value exceeding 10 dB at 3 kHz, 4 kHz, or 6 kHz qualifies as a bulge. In this case, the most pronounced NIHL was observed at 6 kHz.

Further analysis of NIHL severity, illustrated the average HTL at specific frequencies according to different standards. Notably, HTL values at 1 kHz, 2 kHz, and 4 kHz and 0.5 kHz, 1 kHz, 2 kHz, 4 kHz, were significantly higher compared to those at 0.5 kHz, 1 kHz, 2 kHz, 3 kHz, and 1 kHz, 2 kHz, 3 kHz. Paired *t* test comparisons between each pair of standards revealed statistically significant differences in mean HTLs, with all comparisons yielding $P < .001$ (Table 4).

The 4 kHz frequency is not only essential in diagnosis the NIHL,[10] it is also particularly relevant for quantifying hearing difficulties, as it plays a crucial role in speech comprehension, especially in environments where background sounds are presented.[16] It is also one of the most reliable predictors of the Speech Reception Threshold (SRT), which determines the level at which an individual can understand 50% of sentences in background noise.[17] Earlier publications suggested using 2 kHz, 3 kHz, and 4 kHz to predict speech comprehension ability. However, more recent research emphasizes that 4 kHz should always be included, and that the average HTL across 1 kHz, 2 kHz, and 4 kHz provides a more accurate measure of the overall magnitude of NIHL.[11] Despite these advancements, current practice still primarily relies on averaging HTL across 0.5 kHz, 1 kHz, 2 kHz, and 3 kHz.

Table 3. Example of a Bulge Analysis Using the CLB Method With AAHL Values From ISO 7029-2017 for a Man Aged 37 Years at the 50th Percentile (Median)

Parameter	Frequency, Hz					
	1000	2000	3000	4000	6000	8000
HTL, dB HL	25	20	5	20	30	5
HTL at selected anchor points	25	NA	NA	NA	NA	5
Selected AAHL	1.09	1.85	2.57	3.20	4.13	4.80
Misfit values at anchor points, dB	23.91	NA	NA	NA	NA	0.20
Interpolated misfit values, dB	23.91	4.85	1.91	0.99	0.39	0.20
Adjusted AAHL	25	6.75	4.51	4.19	4.49	5
Set AAHL to 0 when AAHL< 0	25	6.75	4.51	4.19	4.49	5
Set AAHL to actual when AAHL > actual	25	6.75	4.51	4.19	4.49	5
NIHL, ie bulge (dB), rounded	0	13	0	16	26	0

Abbreviations: AAHL, age-associated hearing loss; CLB, Coles, Lutman, and Buffin method; HL, hearing loss; HTL, hearing threshold limit; NA, not applicable; NIHL, noise-induced hearing loss.

Table 4. NIHL Quantification Using Different AAHL Values

Average	OSHA (F-1/F-2), dB	ISO 7029-2017, dB
Mean of 0.5 kHz, 1 kHz, 2 kHz, 3 kHz*	23.02	20.90
Mean of 0.5 kHz, 1 kHz, 2 kHz, 4 kHz	41.22	50.56
Mean of 1 kHz, 2 kHz, 3 kHz**	23.81	21.37
Mean of 1 kHz, 2 kHz, 4 kHz***	51.82	41.59

Abbreviations: AAHL, age-associated hearing loss; NIHL, noise-induced hearing loss; OSHA (F-1/F-2), Occupational Safety and Health Administration Table F-1 and F-2.

* Current practice in USA (American Medical Association) and Thailand (Social Security Office; Workmen's Compensation Fund).

** UK standard.

*** Ireland and Australia standard.

Discussion

As emphasized multiple times throughout this article, there has been no universally accepted gold standard for diagnosing NIHL. The most reliable approach to determine the gold standard is the method proposed by Moore et al[9] which compares the specificity of each diagnostic technique between individuals with noise exposure and a nonexposed control population. Among these methods, the highest overall sensitivity (72.5%) was observed in the Phillips et al[7] method, whereas the Niskar et al[6] method exhibited a significantly lower sensitivity of 27%. The CLB method (2000) demonstrated a sensitivity of 70%.[9]

A study conducted in a population similar to that of the present study found that the prevalence of NIHL, as determined using the NSTS, was 41.5% (95% CI, 37.49-45.54). When assessed using the OSTS, the prevalence was lower at 25.3% (95% CI, 21.81-28.93).[18] Similarly, research conducted among auto parts workers in Thailand reported an NIHL prevalence of 30.72% based on NIOSH criteria and 14.37% based on OSHA criteria, with a substantial discrepancy of 53.22%.[19] Findings from research on workers in the chemical industry revealed that the prevalence of NSTS and OSTS and OSTS with age correction ranged from 22.15% to 31.91%, 4.83% to 14.85%, and 2.34% to 5.29%, respectively.[20]

A large-scale study by Masterson et al[21] further demonstrated a considerable variation in NIHL prevalence depending on the hearing shift criteria used (NSTS, OSTS, and OSTS with age correction). In that study, the prevalence of workers identified with OSTS was 31.64% lower than that of workers diagnosed using NSTS. Comparatively, the present study found an even greater difference of 73.68%.

Healthcare workers have been identified as one of the occupational groups with the highest prevalence of NIHL. In the same study, the Healthcare and Social Assistance sector exhibited a prevalence of 23.9% based on NSTS criteria.[21] In contrast, the prevalence decreased to 16.67% when OSHA criteria were applied. Following age correction, the prevalence was further reduced to 8.02%. Regardless of the diagnostic method used, this occupational sector showed a consistently higher prevalence of NIHL compared to the overall worker population, which exhibited prevalence rates of 20.26%, 13.85%, and 6.41%, by using NSTS, OSTS, and OSTS with age correction, respectively.

One possible explanation for the notably high prevalence of NIHL reported using the ISO 7029-2017 method in this study was the arbitrary selection of the median (50th percentile) as the comparison percentile. Since the choice of percentile significantly impacts NIHL

estimation, Moore et al[11] recommend using the 50th percentile as the default reference for age-related corrections. However, Cole opposes this approach, cautioning against applying a fixed percentile across all frequencies when assessing the severity of NIHL.[5] Instead, he advocates for an alternative calculation method, particularly in medicolegal contexts.

Nevertheless, as there is no definitive method for selecting the most appropriate percentile, a retrospective analysis of past audiograms from some participants could help identify individuals with unusually high or low hearing thresholds. If a participant's hearing thresholds are poorer than expected, a lower (worse) percentile should be applied, and vice versa.

Data collected from 60 dental professionals revealed that 15% to 25% of male and 13% to 18% of female participants had hearing thresholds exceeding the 95th percentile limits when compared to the ISO 7029-2017 normative age- and sex-distributions.[22] Furthermore, clinical hearing loss was observed in 61% of male and 25% of female ears, based on a diagnostic criterion using a 4-frequency air conduction threshold pure-tone average (4F-PTA) of 500, 1000, 2000, and 4000 Hz exceeding 20 dB. The present study did not include dental professionals, as noise exposure in dental settings did not exceed the standard threshold.

Zhang et al[22] reported that male participants in their study had a mean (SD) of 4F-PTA of 25.5 (21.5) dB, while female participants had a mean (SD) of 4F-PTA of 14.2 (10.8) dB. Compared to the present study, where the total population exhibited an average of 4-frequency HTL of 50.56 dB, Zhang's study reported significantly lower thresholds. Notably, Zhang's research did not specify noise exposure levels in their sampling environment, whereas the present study exclusively included individuals exposed to noise levels of 80 dB or higher in their workplace.

Another important aspect of audiogram interpretation is longitudinal analysis. As regulatory requirements increasingly mandate long-term retention of audiometric test results — sometimes extending until an employee's retirement — longitudinal interpretation is becoming increasingly important. Serial audiometric monitoring is essential for detecting changes in HTL that may indicate irreversible conditions such as NIHL. However, a major challenge for interpreters is accounting for the effects of aging. Whether age adjustment should be performed routinely remains a subject of debate. Overestimating the impact of aging could compromise the effectiveness of hearing conservation programs by leading program managers to misattribute NIHL to age-related hearing loss. Conversely, neglecting age correction could result in an underestimation of age-related effects, leading to misallocated resources that target age-related hearing loss rather than NIHL.

Age adjustments are permitted under certain regulations, such as those established by the US Federal Railroad Administration (FRA) (2006), the US Occupational Safety and Health Administration (OSHA) (1983), and the US Mine Safety and Health Administration (MSHA) (1999). However, the US NIOSH (1998) does not mandate or recommend age adjustment.[23] Although NIOSH age adjustment tables are incorporated into OSHA's hearing conservation amendment, NIOSH itself argues that these "corrections" do not accurately reflect true age-related hearing changes.[13] Similarly, the US Department of Defense (2018) does not permit age adjustments when assessing changes in audiometric thresholds. In contrast, Thailand's regulations do not explicitly mention age adjustment. Some organizations may opt to apply age corrections according to OSHA's recommendations to avoid overestimating NIHL prevalence due to age-related hearing loss.

Instead of the standard from ISO 7029-2017, Flamme et al[24] proposed the use of population-based tables derived from the US National Health and Nutrition Examination Survey (NHANES) (2005-2012) to estimate age-related hearing changes. These tables account for work histories spanning up to 30 years and beyond. However, it is important to note that using ISO 7029-2017 for age adjustment may yield distinct results compared to NHANES tables.[25] The population used to develop ISO 7029-2017 was carefully screened to exclude individuals with conductive hearing loss or noise exposure, which may lead to an overestimation of age-related hearing loss compared to NHANES-derived estimates which reflect real-world occupational exposure. A study by Stenklev et al[1] also raised concerns about ISO 7029's reliability, particularly in female subjects, as it appeared to underestimate HTL in even otologically normal samples. Additionally, the study noted that ISO 7029-2017 criteria might be unreliable for individuals over 60 years of age. Further research on this issue would be beneficial for practical applications.

This study had certain limitations. First, the requirements for the CLB method could not be fully met, as occupational noise exposure in this setting did not exceed the 90 dB(A) noise immersion level (NIL). Second, the author deliberately selected the median (50th percentile) as the "anchor point" for all bulge analyses, following experts' recommendations.[11] The choice of percentile may significantly influence NIHL estimations. Future research should explore alternative percentiles tailored to individual participants, such as selecting the percentile based on the HTLs for the frequencies with the best thresholds in the better-hearing ear. Further investigations could also examine the integration of age adjustment methods in longitudinal audiometric analyses.

Conclusions

This study highlights the challenges of diagnosing NIHL with different methods yielding varying prevalence. The choice of diagnostic criteria significantly impacts NIHL prevalence and quantification. ISO 7029-2017 standard gives a statistically different result when compared to the Table F1-F2 currently recommended by OSHA, highlighting the complexities of age adjustment in audiometric assessments as both overestimation and underestimation can affect the accuracy of NIHL diagnosis.

Additional Information

Ethics Approval: This study was approved by the Ethical Committee of Chonburi Hospital (No. 54/67/S/h3 on 6 August 2024).

Clinical Trial Consideration: This study does not report on a clinical trial.

Financial Support: No financial support was provided for this study.

Conflict of Interest: The author declares no conflict of interest.

Author Contributions:
Conceptualization: Pitchaya Chevasutho
Formal Analysis: Pitchaya Chevasutho
Methodology: Pitchaya Chevasutho
Visualization: Pitchaya Chevasutho
Writing – Original Draft: Pitchaya Chevasutho
Writing – Review & Editing: Pitchaya Chevasutho

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