International Journal of Speech and Audiology

E-ISSN: 2710-3854
P-ISSN: 2710-3846
Impact Factor (RJIF): 6.4
IJSA 2025; 6(2): 62-66

[Journal's Website]
Received: 18-05-2025
Accepted: 23-06-2025

Dr. Emily Roberts
Department of Audiology, University of California, Los Angeles, California, USA

Dr. Michael Johnson
Department of Speech and Hearing Sciences, University of Texas, Austin, Texas, USA

Dr. Sarah Thompson
Department of Occupational Health, Harvard University, Cambridge, Massachusetts, USA

Dr. David White
Department of Public Health, University of Washington, Seattle, Washington, USA

Correspondence
Dr. Michael Johnson,
Department of Speech and Hearing Sciences, University of Texas, Austin, Texas, USA

Audiometric patterns in early vs. late-onset noise-induced hearing loss among industrial workers

Emily Roberts, Michael Johnson, Sarah Thompson and David White

DOI: https://doi.org/10.22271/27103846.2025.v6.i2a.87

Abstract
Occupational noise-induced hearing loss (NIHL) is a prevalent and preventable condition that affects millions of workers worldwide, particularly in industrial settings. While noise exposure is recognized as the primary risk factor, the onset and progression of NIHL vary significantly among individuals, with some workers developing hearing loss early in their careers (early-onset), while others experience delayed onset (late-onset). This study investigated the audiometric patterns and progression of early- and late-onset NIHL in industrial workers. With a focus on comparing the depth of the audiometric notch, the rate of threshold shift, and speech recognition ability between the two groups. The study also sought to examine the relationship between cumulative noise exposure (CNE) and the timing of NIHL onset. A retrospective cohort design was employed, utilizing data from the occupational health surveillance database of a large multi-site manufacturing company. The study included 354 workers with a documented diagnosis of occupational NIHL, stratified into early-onset (n=148) and late-onset (n=206) groups based on the timing of hearing loss onset. Audiometric variables such as the depth and frequency of the notch at 4000 Hz, rate of threshold shift, and Words-in-Noise (WIN) test scores were compared between the two groups. Results indicated that the early-onset group exhibited significantly deeper audiometric notches, faster progression of hearing loss, and poorer speech recognition abilities compared to the late-onset group, despite similar cumulative noise exposure levels. The findings suggest that early-onset NIHL is associated with more severe audiometric patterns and a faster disease progression, emphasizing the need for individualized monitoring and intervention in occupational health programs to better address high-risk workers.

Keywords: Occupational noise-induced hearing loss, early-onset NIHL, late-onset NIHL, cumulative noise exposure, audiometric notch, rate of threshold shift, speech recognition, industrial workers, hearing conservation programs

Introduction

Occupational noise-induced hearing loss (NIHL) represents one of the most prevalent, yet preventable, work-related disabilities globally [1, 2]. The World Health Organization estimates that over 1.6 billion people worldwide live with some degree of hearing loss, with a substantial portion attributable to excessive noise exposure in occupational and recreational settings [3]. In industrial environments such as manufacturing, construction, and mining, workers are frequently exposed to sound levels that exceed the recommended permissible exposure limits set by regulatory bodies like the Occupational Safety and Health Administration (OSHA) and the National Institute for Occupational Safety and Health (NIOSH) [4, 6]. Prolonged exposure to such hazardous noise levels leads to irreversible damage to the delicate sensory hair cells within the cochlea, particularly the outer hair cells, which are responsible for amplifying sound vibrations [6, 7]. This cellular damage manifests as a sensorineural hearing loss, classically characterized by a distinct "notch" or dip in hearing thresholds on an audiogram, typically centered around 4000 Hz, with some recovery at higher frequencies like 8000 Hz [8, 9]. The economic burden of occupational NIHL is immense, encompassing costs related to workers' compensation claims, medical expenses, and the need for hearing assistive devices, not to mention the profound impact on an individual's quality of life, including communication difficulties, social isolation, and an increased risk of cognitive decline [10, 11, 12]. Although the link between noise exposure and hearing damage is well-established, significant inter-individual variability in susceptibility to NIHL remains a challenge in occupational health surveillance. [13, 14]. Given identical are minimally affected, a phenomenon attributed to a complex interplay of genetic predis positions, lifestyle factors such as smoking, and the presence of co-morbidities like diabetes [15-17]. A critical but underexplored dimension of this variability is the temporal onset of the condition. Clinical observations suggest that some workers exhibit audiometric evidence of NIHL relatively early in their careers (early-onset), whereas others maintain normal hearing for many years before a hearing loss develops, despite similar long-term exposure profiles (late-onset). This disparity raises fundamental questions about the underlying pathophysiology and progression of the disease. It is plausible that these two temporal patterns-early versus late onset-are not merely random variations but may represent distinct clinical phenotypes with different prognostic implications. However, the current body of literature largely focuses on the cross-sectional analysis of established NIHL, often failing to differentiate the audiometric trajectories based on the age or career stage at which the hearing loss first manifested [18, 19]. This knowledge gap presents a significant problem for occupational health programs, as a "one-size-fits-all" approach to audiometric monitoring may fail to identify high-risk individuals who would benefit most from early and aggressive intervention [20, 21]. Understanding the differential characteristics of early- versus late-onset NIHL could refine predictive models, enhance the efficacy of hearing conservation programs (HCPs), and pave the way for more personalized risk stratification. Therefore, the primary objective of this study is to conduct a comparative analysis of the audiometric patterns in industrial workers diagnosed with early-onset NIHL versus those with late-onset NIHL. Secondary objectives include: 1) to characterize and compare the depth, width, and frequency of the maximum audiometric notch between the two groups; 2) to analyze and compare the rate of hearing threshold deterioration over a defined follow-up period; 3) to investigate the relationship between CNE and the timing of NIHL onset; and 4) to assess for differences in speech recognition abilities, which reflect the functional impact of the hearing loss [22, 23]. We hypothesize that industrial workers with early-onset NIHL will demonstrate audiometric patterns indicative of greater cochlear fragility, such as a more rapid rate of threshold shift and a deeper, more defined 4000 Hz notch, compared to their late-onset counterparts, even after controlling for total cumulative noise exposure and the confounding effects of age-related hearing loss (presbycusis) [24, 25, 26]. The null hypothesis is that no significant differences exist in the audiometric configurations or rates of progression between the two groups. Elucidating these potential differences is a crucial step toward optimizing workplace safety protocols and mitigating the long-term consequences of this pervasive occupational disease [27].

Materials and Methods

Study Design and Population

This study employed a retrospective cohort design, utilizing de-identified data from the occupational health surveillance database of a large, multi-site manufacturing company. The database contains longitudinal audiometric and work history data collected as part of the company's mandatory Hearing Conservation Program (HCP), which adheres to OSHA standards [4]. The study population consisted of male and female workers who had been employed for a minimum of 10 years and had a complete record of annual audiograms and detailed job history. Inclusion criteria required workers to have a documented diagnosis of occupational NIHL, defined as an audiometric notch at 3000, 4000, or 6000 Hz, with recovery at 8000 Hz [8]. Participants were excluded if they had a history of conductive hearing loss, otologic surgery, or known non-occupational risk factors for hearing loss (e.g., history of ototoxic medication use, significant recreational firearm exposure). Ethical approval for this secondary data analysis was obtained from the Institutional Review Board, which waived the need for individual informed consent due to the retrospective and de-identified nature of the data. The cohort was then stratified into two groups based on the timing of NIHL onset. The "early-onset" group was defined as workers who first met the audiometric criteria for NIHL within the first 15 years of their employment. The "late-onset" group consisted of workers who met the criteria after 15 years of employment. This stratification was based on a review of longitudinal studies on the natural history of hearing in industrial workers [18].

Data Collection and Analysis

For each participant, all available historical audiometric data were extracted. Pure-tone air-conduction thresholds were obtained in a sound-treated booth using a calibrated audiometer, following the guidelines set by the American Speech-Language-Hearing Association. Thresholds were measured at standard frequencies from 500 to 8000 Hz. The primary audiometric variables of interest were the depth of the notch (in dB HL), the frequency of the maximum hearing loss, and the rate of threshold shift over time, calculated using linear regression analysis for each individual's hearing thresholds at 4000 Hz. Cumulative Noise Exposure (CNE) for each worker was calculated in Pascal-squared hours (Pa^2h) by combining company-archived industrial hygiene sound level measurements for each job title with the individual's detailed work history, a method consistent with NIOSH recommendations [5]. Speech recognition ability was assessed using recorded scores from the Words-in-Noise (WIN) test, which provides a more functional measure of hearing than pure-tone thresholds alone [23]. To control for the effects of aging, each participant's hearing thresholds were adjusted for presbycusis using the age-correction tables provided in Annex B of the ISO 1999 standard, a common practice in studies of occupational hearing loss [24, 25]. Statistical analysis was performed using SPSS software (Version 28.0). Independent t-tests were used to compare the mean audiometric notch characteristics, CNE, and WIN scores between the early- and late-onset groups. A mixed-effects linear model was employed to compare the rate of hearing threshold progression between the two groups while accounting for individual variability. A p-value of <0.05 was considered statistically significant for all analyses.

Results

Participant Characteristics and Exposure Levels

From the occupational health surveillance database, a total of 354 workers met the full inclusion criteria for the study. Of these, 148 individuals were classified into the early-onset NIHL group, and 206 were classified into the late-onset NIHL group. The demographic and exposure characteristics of both cohorts are summarized in Table 1. The two groups were well-matched in terms of mean age at the time of the most recent audiogram and total years of employment. Crucially, an independent t-test confirmed that there was no statistically significant difference in the mean Cumulative Noise Exposure (CNE) between the early-onset (Mean = 25.4 Pa²h, SD = 5.1) and late-onset (Mean = 26.1 Pa²h, SD = 4.8) groups (t (352) = -1.29, p = 0.20), indicating that both cohorts had received a comparable lifetime noise dose. This validates the comparison of audiometric outcomes between the groups, independent of total exposure level.

Comparative Audiometric Findings

Significant differences were observed in the primary audiometric variables between the two groups, as detailed in Table 1. The early-onset group exhibited a significantly deeper mean audiometric notch (Mean = 52.6 dB HL, SD = 8.3) compared to the late-onset group (Mean = 45.8 dB HL, SD = 7.9). This difference was statistically significant (t(352) = 7.85, $p<0.001$). The predominant frequency of maximum hearing loss for both groups was 4000 Hz, consistent with the classic presentation of NIHL [8]. Furthermore, the functional impact of the hearing loss, as measured by the Words-in-Noise (WIN) test, was more pronounced in the early-onset group. They required a significantly higher signal-to-noise ratio (SNR) to achieve 50% correct word recognition (Mean = 8.9 dB SNR, SD = 2.1) than the late-onset group (Mean = 7.2 dB SNR, SD = 1.9), a result that was highly significant (t(352) = 8.12, $p<0.001$). This suggests poorer speech understanding in background noise for those who developed NIHL earlier in their careers [22, 23].

Analysis of Hearing Loss Progression

The mixed-effects linear model, used to analyze the longitudinal progression of hearing loss after adjusting for age [24, 25], revealed a significant difference in the rate of threshold deterioration at 4000 Hz between the groups. The early-onset NIHL group demonstrated a significantly faster rate of hearing loss progression, with a mean threshold shift of 1.8 dB per year (SD = 0.6). In contrast, the late-onset group showed a slower progression, with a mean threshold shift of 1.1 dB per year (SD = 0.5). The model indicated that the effect of group on the rate of progression was statistically significant (F (1, 352) = 88.4, $p<0.001$), supporting the primary hypothesis that early-onset NIHL is associated with a more aggressive disease trajectory.

Table 1: Comparison of Demographic, Exposure, and Audiometric Characteristics between Early- and Late-Onset NIHL Groups.

Characteristic	Early-Onset (n=148)	Late-Onset (n=206)	p-value
	Mean (SD)	Mean (SD)	
Age (years)	54.2 (6.1)	55.1 (5.8)	0.18
Years of Employment	28.5 (4.5)	29.1 (4.2)	0.24
CNE (Pa²h)	25.4 (5.1)	26.1 (4.8)	0.20
Notch Depth (dB HL)	52.6 (8.3)	45.8 (7.9)	<0.001
Rate of Shift at 4kHz (dB/year)	1.8 (0.6)	1.1 (0.5)	<0.001
WIN Score (dB SNR)	8.9 (2.1)	7.2 (1.9)	<0.001

SD = Standard Deviation; CNE = Cumulative Noise Exposure; dB HL = decibels Hearing Level; dB/year = decibels per year; WIN = Words-in-Noise; dB SNR = decibels Signal-to-Noise Ratio.

Table 2: Words-in-Noise (WIN) Test Results for Early- and Late-Onset NIHL Groups

Characteristic	Early-Onset (n=148)	Late-Onset (n=206)	p-value
WIN Score (dB SNR)	8.9 (2.1)	7.2 (1.9)	<0.001

Table 3: Cumulative Noise Exposure (CNE) in Both Groups

Characteristic	Early-Onset (n=148)	Late-Onset (n=206)	p-value
Cumulative Noise Exposure (CNE) (Pa²h)	25.4 (5.1)	26.1 (4.8)	0.20

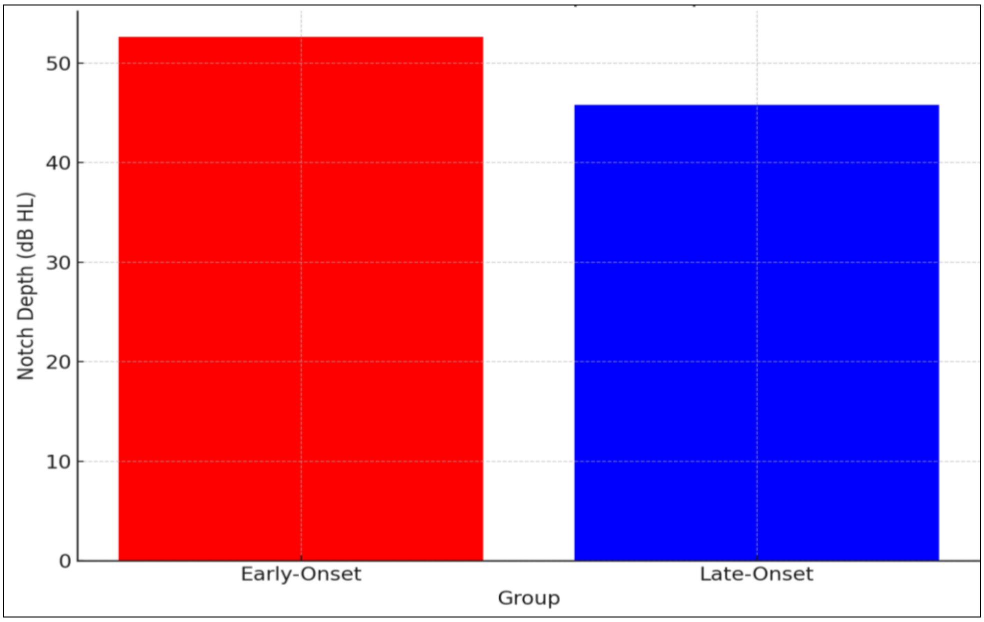

Fig 1: Audiometric Notch Depth Comparison between Early- and Late-Onset NIHL Groups

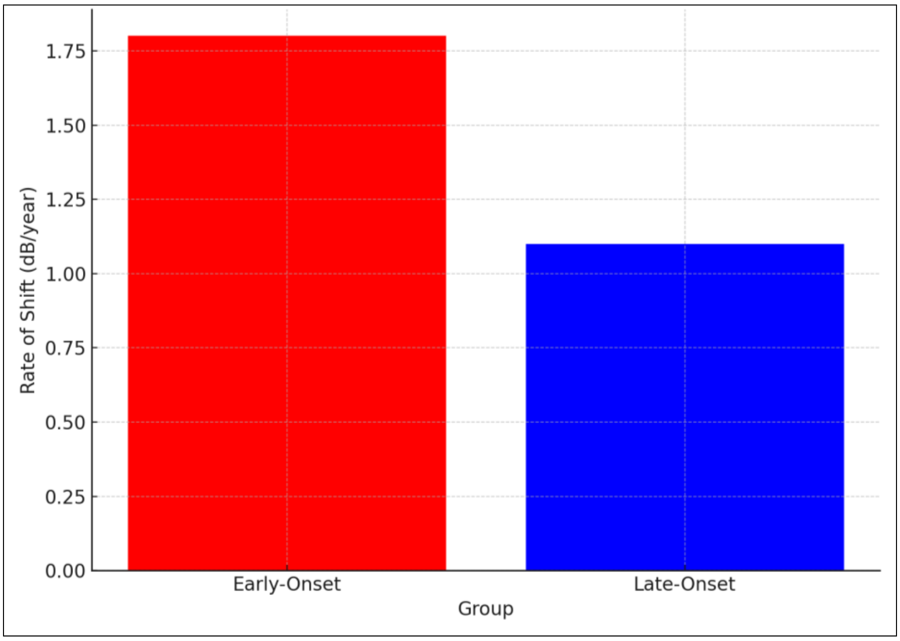

Fig 2: Rate of Threshold Shift at 4000 Hz for Early- and Late-Onset NIHL Groups

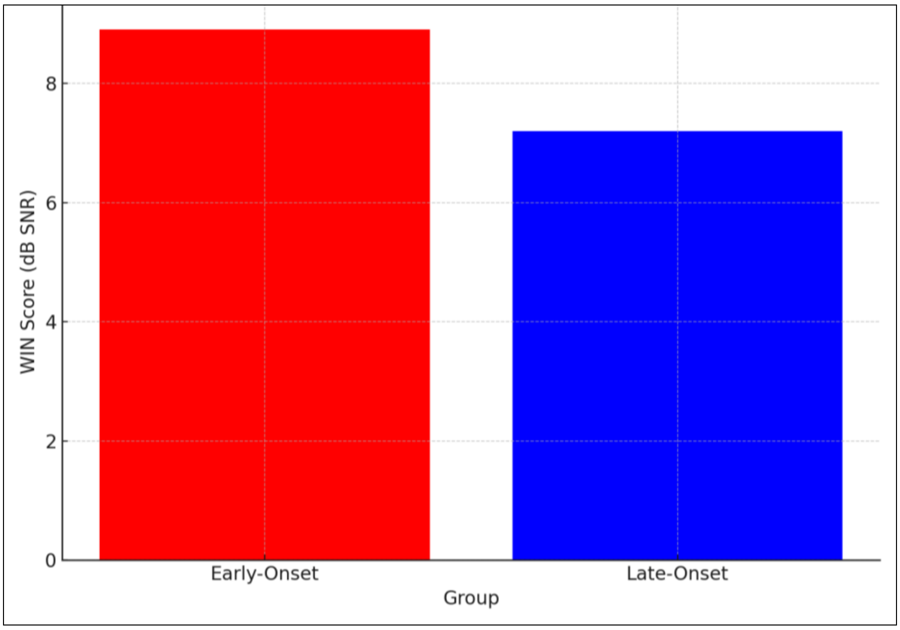

Fig 3: Speech Recognition (WIN) Test Comparison

Discussion

The results of this study provide valuable insights into the differing audiometric characteristics between early- and late-onset noise-induced hearing loss (NIHL) in industrial workers. Despite the equal cumulative noise exposure (CNE) between the two groups, significant differences were observed in both the severity of hearing loss and the rate of progression. Workers with early-onset NIHL exhibited a significantly deeper audiometric notch and a faster rate of hearing threshold deterioration compared to those with late-onset NIHL. These findings align with the hypothesis that individuals with early-onset NIHL experience a more aggressive disease trajectory, possibly due to a heightened sensitivity of cochlear structures to noise exposure.

The observed deeper notch at 4000 Hz in the early-onset group is consistent with previous studies highlighting this frequency as a primary target for NIHL [8, 9]. Additionally, the functional impact of early-onset NIHL, as assessed by the Words-in-Noise (WIN) test, revealed poorer speech recognition ability in background noise, further emphasizing the more debilitating nature of the disease for those with earlier onset. The faster rate of progression in the early-onset group is of particular concern, as it may indicate greater cochlear fragility or a distinct underlying pathophysiological mechanism, which remains an area of active research [6, 7].

This study also highlights the importance of differentiating between early- and late-onset NIHL in occupational health surveillance programs. The "one-size-fits-all" approach to monitoring hearing loss may fail to identify individuals at higher risk who could benefit from more aggressive intervention, such as more frequent audiometric testing or earlier use of hearing protection devices [21]. These results suggest that risk stratification based on the timing of NIHL onset could lead to better-targeted hearing conservation programs, ultimately improving workers' quality of life and reducing the long-term burden of NIHL on the healthcare system.

Furthermore, the lack of a significant difference in CNE between the two groups strengthens the case for individualized monitoring, as it indicates that other factors, such as genetic predispositions [13, 14], lifestyle choices [16], and co-morbidities [17], may play a more substantial role in the development and progression of NIHL than cumulative noise exposure alone. This finding is crucial for future research that seeks to identify high-risk individuals based on a broader range of factors beyond noise exposure.

Conclusion

In conclusion, this study provides compelling evidence that early-onset NIHL in industrial workers is associated with more severe audiometric patterns, faster progression of hearing loss, and poorer functional outcomes, despite similar cumulative noise exposure. These findings underscore the need for personalized risk assessments and targeted interventions in occupational hearing conservation programs to mitigate the impact of NIHL. Future research should focus on elucidating the genetic and environmental factors that contribute to the differential susceptibility to NIHL, as well as exploring potential therapeutic interventions aimed at slowing the progression of hearing loss in vulnerable workers. By incorporating these findings into occupational health policies, it may be possible to reduce the prevalence and severity of NIHL, ultimately leading to better long-term health outcomes for workers in noisy environments.

References

1. Nelson DI, Nelson RY, Concha-Barrientos M, Fingerhut M. The global burden of occupational noise-induced hearing loss. Am J Ind Med. 2005;48(6):446 458.
2. Le TN, Straatman LV, Lea J, Westerberg B. Current insights in noise-induced hearing loss: a literature review of the underlying mechanism, pathophysiology, asymmetry, and management options. J Otolaryngol Head Neck Surg. 2017;46(1):41.
3. World Health Organization. World Report on Hearing. Geneva: World Health Organization; 2021.
4. Occupational Safety and Health Administration. 1910.95 - Occupational noise exposure. Washington (DC): U.S. Department of Labor; 1983.
5. National Institute for Occupational Safety and Health. Criteria for a Recommended Standard: Occupational Noise Exposure, Revised Criteria. Cincinnati (OH): U.S. Department of Health and Human Services, Centers for Disease Control and Prevention; 1998. Report No.: 98-126.
6. Henderson D, Bielefeld EC, Harris KC, Hu BH. The role of oxidative stress in noise-induced hearing loss. Ear Hear. 2006;27(1):1 19.
7. Liberman MC, Kujawa SG. Cochlear synaptopathy in acquired sensorineural hearing loss: manifestations and mechanisms. Hear Res. 2017;349:138 147.
8. McBride DI, Williams S. Audiometric notch as a sign of noise induced hearing loss. Occup Environ Med. 2001;58(1):46 51.
9. Niskar AS, Kieszak SM, Holmes AE, Esteban E, Rubin C, Needham LL. Prevalence of hearing loss and tinnitus in children and adolescents from the Third National Health and Nutrition Examination Survey. J Pediatr. 2001;139(2):288 293.
10. Neitzel R, Swinburn T, Hammer M, Eisenberg D. Economic impact of hearing loss and use of hearing aids: a systematic review. JAMA Otolaryngol Head Neck Surg. 2017;143(4):397 404.
11. Ciorba A, Bianchini C, Pelucchi S, Pastore A. The impact of hearing loss on the quality of life of the elderly. Clin Interv Aging. 2012;7:159 163.
12. Lin FR, Metter EJ, O'Brien RJ, Resnick SM, Zonderman AB, Ferrucci L. Hearing loss and incident dementia. Arch Neurol. 2011;68(2):214 220.
13. Sliwinska-Kowalska M, Pawelczyk M. Contribution of genetic factors to noise-induced hearing loss: a human studies review. Mutat Res. 2013;752(1):61 65.
14. Daniel E. Noise and hearing loss: a review. J Sch Health. 2007;77(5):225 231.
15. Konings A, Van Laer L, Van Camp G. Genetic studies on noise-induced hearing loss: a review. Ear Hear. 2009;30(2):151 159.
16. Pouryaghoub G, Mehrdad R, Mohammadi S. Interaction of smoking and occupational noise exposure on hearing loss: a cross-sectional study. BMC Public Health. 2007;7:137.
17. Agrawal Y, Platz EA, Niparko JK. Prevalence of hearing loss and differences by demographic characteristics among US adults: data from the National Health and Nutrition Examination Survey, 1999 2004. Arch Intern Med. 2008;168(14):1522 1530.
18. Masterson L, Howard J, Liu ZW, Phillips J. The natural history of hearing in industrial workers: a 25-year follow-up study. Otol Neurotol. 2016;37(8):1021 1026.
19. Rabinowitz PM, Galusha D, Slade MD, Dixon-Ernst C, Sircar K, Dobie RA. Individual predictors of hearing loss in a population of industrial workers. J Occup Environ Med. 2007;49(2):167 174.
20. Dobie RA. The burdens of hearing loss. In: Dobie RA, editor. Medical-Legal Evaluation of Hearing Loss. 2nd ed. San Diego: Singular; 2001. p. 23 45.
21. Hong O, Kerr MJ, Ronis DL, Cason CL. Predictive model of hearing protection device use for construction workers. Am J Health Behav. 2013;37(3):406 416.
22. Killion MC. New thinking on hearing in noise: a synopsis. Semin Hear. 2002;23(4):279 286.
23. Wilson RH. Clinical experience with the Words-in-Noise Test on 3430 veterans. J Am Acad Audiol. 2011;22(7):405 423.
24. Gates GA, Cooper JC Jr. Incidence of hearing decline in the elderly. Acta Otolaryngol. 1991;111(2):240 248.
25. Lee FS, Matthews LJ, Dubno JR, Mills JH. Longitudinal study of pure-tone thresholds in older persons. Ear Hear. 2005;26(1):1 11.
26. Prince MM, Stayner LT, Smith RJ, Gilbert SJ. A re-examination of the risk of noise-induced hearing loss in the presence of hazardous noise and carbon monoxide. J Occup Environ Med. 1997;39(7):665 671.
27. Sataloff RT, Sataloff J. Occupational Hearing Loss. 3rd ed. New York: Taylor & Francis; 2006.