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Original Article

Longitudinal trajectories of noise-induced hearing loss in a municipal workforce: a pilot study of diagnostic migration (2023–2025)

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ABSTRACT

Introduction: Noise-Induced Hearing Loss (NIHL) remains a prevalent occupational health issue in industrial sectors. This study aimed to evaluate the longitudinal changes in hearing thresholds in municipal workers exposed to noise levels exceeding 85 dB(A) and to assess the impact of specific risk stratification on auditory health.

Methods: A Pilot Retrospective Longitudinal Cohort Study was conducted on 23 of 44 eligible male municipal workers who completed both surveillance cycles over a two-year period (2023–2025). The participants were stratified into Group A (Gardeners, n=5) and Group B (Drivers, n=18) categories based on job profiles. Pure-tone audiometry was analyzed according to Health and Safety Executive (HSE 2021) guidelines. Statistical analysis included the Wilcoxon signed-rank test for longitudinal within-subject comparisons and the Mann–Whitney U and Fisher's Exact tests for between-group analyses.

Results: The cohort exhibited a statistically significant deterioration in mean hearing thresholds over the study period. Wilcoxon signed-rank test comparing mean high-frequency thresholds (3–4–6 kHz) between 2023 and 2025 yielded $p < 0.001$. By 2025, 47.8% (n=11) of the workforce met the criteria for clinical referral (Category 3). All workers in Group A (5/5, 100%) progressed to Category 3, compared to 6/18 workers (33.3%) in Group B.

Conclusion: Group A demonstrated significantly accelerated hearing loss compared to drivers (B), validating the need for stratified risk management. The findings support the implementation of a shortened 6-month audiometric review cycle for high-risk occupational groups.

Keywords: Audiometry, hearing loss, municipal workers, noise.

Introduction

Occupational noise exposure remains a significant challenge for public health and occupational medicine globally.[1,2] In municipal work environments, employees are often subjected to fluctuating but persistent noise levels from heavy machinery, waste management vehicles, and maintenance equipment. Despite regulatory efforts, noise-induced hearing loss (NIHL) remains among the most common work-related illnesses.[3,4]

Chronic exposure to noise levels exceeding 85 dB(A) is the leading cause of sensorineural hearing loss, typically characterized by a distinctive "notch" in high-frequency auditory thresholds.[5,6] However, the impact of noise extends beyond the cochlea. Chronic noise acts as

a systemic stressor that correlates with reduced quality of life,[7] and occupational burnout.[8] Furthermore, a growing body of epidemiological evidence links long-term noise exposure to non-auditory health effects, including cardiovascular disease,[9] hypertension, and sleep disturbance.[10,11] The World Health Organization estimates that the burden of disease from occupational noise is substantial, necessitating rigorous surveillance protocols.[12]

For the effective management of these workers, the Health and Safety Executive (HSE) categorization system provides a standardized, age-corrected framework for auditory health surveillance.[13] Consistent with European Directive 2003/10/EC, this system classifies hearing health into levels of increasing severity, helping to differentiate between natural presbycusis and noise-induced trauma.[14,15] The strength of the HSE scheme lies in its ability to detect significant shifts over time, identifying workers at risk of rapid deterioration.[13,16]

This study utilized a retrospective longitudinal design to analyze routine occupational health surveillance data collected from a cohort of municipal workers between 2023 and 2025. By detailing these specific cases, this study aims to validate the use of HSE surveillance in municipal settings and advocate for integrated health monitoring to preserve the auditory integrity of the workforce.[17,18]

Methods

This pilot retrospective longitudinal cohort study analyzed routine occupational audiometric surveillance data from male municipal workers exposed to occupational noise levels exceeding 85 dB(A). Of an initial pool of 44 eligible workers, 23 completed audiometric testing during both the 2023 and 2025 surveillance cycles and were included in the final analysis.

Pure-tone air-conduction audiometry was performed in an acoustically controlled environment by trained personnel. To ensure data reliability and adherence to international standards, audiometers underwent biological checks and annual calibration in accordance with the ISO 8253-1 and ISO 389 reference standards. Bilateral thresholds were measured at 1, 2, 3, 4, 6, and 8 kHz. All audiograms were retrospectively reviewed by a qualified occupational physician to confirm HSE categorization and clinical referral status.

Hearing status was classified using the Health and Safety Executive (HSE 2021) age-adjusted categorization system: Category 1 (acceptable hearing), Category 2 (warning), and Category 3 (poor hearing requiring referral). For this study, Category 3 cases were further subclassified as 3A (rapid high-frequency loss), 3B (progressive loss involving speech frequencies), or 3C (asymmetric loss). Rapid hearing loss was defined as an aggregate threshold increase of ≥30 dB(A) across the 3, 4, and 6 kHz frequencies over the two-year surveillance interval. This threshold aligns with HSE criteria for accelerated deterioration. The HSE 2021 framework was selected as the primary risk stratification tool due to its structured age-adjusted thresholds and compatibility with UK occupational health surveillance. Its categorization is broadly comparable to international hearing conservation approaches, including ISO-based methodologies and NIOSH-referenced surveillance standards. This enhances the interpretability and applicability of our findings for occupational settings beyond the UK.

Additionally, it was determined that objective data regarding hearing protection device (HPD) compliance (e.g., fit-testing results or logged usage) and non-occupational noise exposure (e.g., recreational noise or secondary employment) were not consistently recorded. Consequently, these variables could not be included in the statistical models, and their potential role as confounders is acknowledged as a limitation on the study's ability to establish definitive causality.

Longitudinal changes were analyzed using the Wilcoxon signed-rank test given the non-normal

distribution of audiometric data. Between-group comparisons were performed using the Mann–Whitney U test for continuous variables and Fisher's Exact test for categorical variables. These non-parametric tests were specifically selected to ensure statistical robustness given the small sample size of Group A (n=5). Statistical significance was set at $p < 0.05$.

All procedures performed in this study involving human participants were conducted in accordance with the ethical standards of the responsible institutional committee and with the principles of the Declaration of Helsinki (1964), as revised in 2013.

The study utilized retrospective occupational health surveillance data collected as part of routine workplace health monitoring. All data were anonymized prior to analysis to ensure participant confidentiality.

This study was conducted and reported in accordance with the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines for cohort studies.

Results

An initial cohort of 44 noise-exposed municipal workers was identified through the surveillance program. However, inclusion required complete audiometric datasets for both the 2023 and 2025 surveillance cycles. Consequently, 21 individuals were excluded due to missed appointments, employment termination, or incomplete clinical records, resulting in a final study sample of N=23. This represents a retention rate of 52.3%. Basic demographic and clinical characteristics of excluded workers were not consistently available across records; therefore, a formal comparison with the final cohort could not be reliably performed. However, exclusions were primarily due to administrative reasons (missed appointments, employment termination, or incomplete documentation) rather than audiometric severity.

The median age of the cohort was 44.0 years (range: 22–62 years), reflecting a workforce with established occupational tenure.

Based on work categories, participants were divided into two groups:

-Group A (Gardeners): 21.7% (n=5) of the cohort.

-Group B (Drivers): 78.3% (n=18) of the cohort.

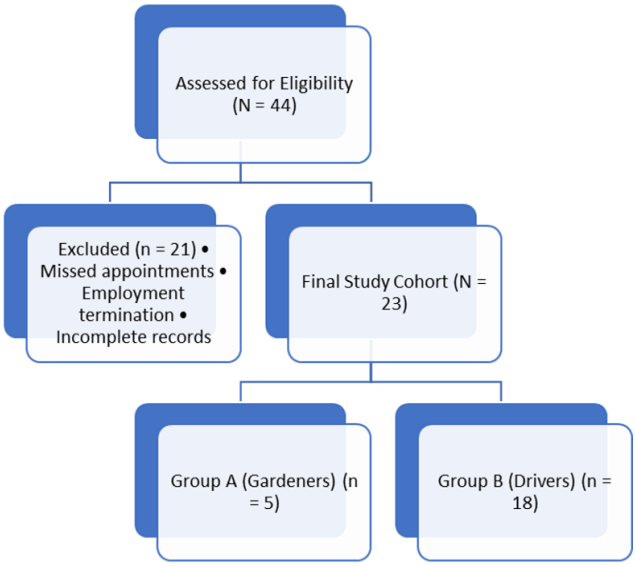

Figure 1. Flow diagram of participant selection. Of the initial 44 workers identified, 21 were excluded due to incomplete longitudinal data, resulting in a final analytical cohort of 23 workers stratified into occupational groups.

Regarding clinical co-factors, 47.8% (n=11) of the participants were smokers, and 34.8% (n=8) were classified as obese (BMI >30).

Longitudinal tracking of HSE categories revealed a clear diagnostic migration toward higher impairment levels over the two-year period.

Longitudinal analysis indicates that this category failed to act as a stable plateau for the high-risk subgroups. By the 2025 follow-up, 70% (n=7) of the workers originally classified in Category 2 had deteriorated further into Category 3 (Referral). Consequently, the prevalence of

Category 3 cases in the total cohort surged to 47.8% (n=11) by the end of the study ($p < 0.001$).

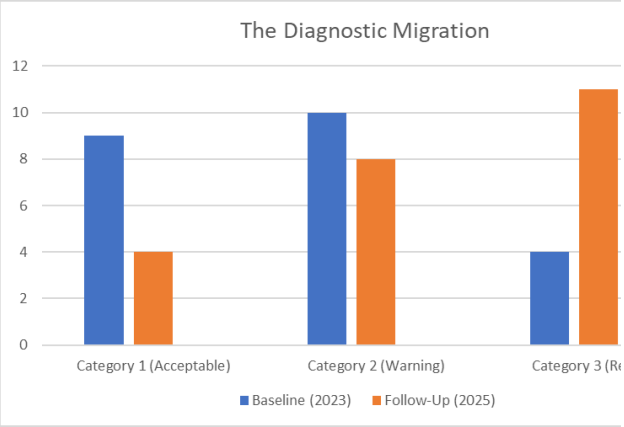

Figure 2. Longitudinal diagnostic migration of HSE Hearing Categories (2023–2025).

The graph illustrates a significant shift in the workforce distribution, with a marked reduction in Category 1 (Acceptable) cases and a corresponding surge in Category 3 (Referral) cases to 47.8% (n=11) by the end of the surveillance period.

Table 1: Individual Audiometric Progression and HSE Categorization

Worker	Exposure Group	HSE Category (2023)	HSE Category (2025)	High-Frequency Change (3–4–6 kHz)	Rapid Loss (≥30 dB(A))	Final Sub-category
1	B	1	2	Mild increase	No	–
2	B	1	1	Stable	No	–
3	B	1	1	Stable	No	–
4	B	1	2	Mild increase	No	–
5	B	2	2	Stable	No	–
6	B	2	**3**	Marked increase	Yes	**3A**
7	B	1	1	Stable	No	–
8	B	1	2	Mild increase	No	–
9	B	2	2	Stable	No	–
10	B	2	**3**	High-frequency worsening	Yes	**3A**
11	A	2	**3**	Pronounced increase	Yes	**3A**
12	B	2	2	Stable	No	–
13	B	1	1	Stable	No	–
14	B	1	2	Mild increase	No	–
15	B	3	**3**	Further worsening	No	**3B**
16	A	2	**3**	Pronounced increase	Yes	**3A**
17	B	2	**3**	High-frequency loss	Yes	**3A**
18	B	3	**3**	Stable severe loss	No	**3B**
19	B	1	2	Mild increase	No	–
20	A	2	**3**	Pronounced increase	Yes	**3A**
21	A	3	**3**	Progressive loss	No	**3B**
22	B	3	**3**	Stable	No	**3B**
23	A	2	**3**	Pronounced increase	Yes	**3A**

The analysis identified a polarization in auditory outcomes between the two occupational groups, establishing Group A as the higher-risk occupational group. It exhibited absolute

deterioration. No worker in this group remained in the Acceptable or Warning categories.

In contrast, Group B demonstrated significantly higher auditory resilience. Only 6/18 workers (33.3%) progressed to Category 3.

Fisher's Exact Test confirmed that membership in Group A was significantly associated with progression to clinical referral status ($p = 0.042$). Additionally, the Mann-Whitney U test confirmed that the magnitude of threshold shifts was significantly higher in Group A compared to B ($p = 0.038$).

Table 2. Group Comparison: Exposure Group A vs. B

Variable	Group A (Gardeners) (n=5)	Group B (Drivers) (n=18)	p-value
Referral Rate (Category 3)	5/5 (100%)	6/18 (33.3%)	**0.042**
Rapid Loss sub-category (3A)	4/5 (80%)	3/18 (16.7%)	–
Median Threshold Shift	Higher Magnitude	Lower Magnitude	**0.038**

Beyond noise exposure, the study evaluated the prevalence of synergistic risk factors—specifically Smoking, Obesity (BMI >30), and Hypertension—across the cohort.

Despite the visible trend indicating a "heavier" clinical profile for Group A, these differences did not reach statistical significance (Smoking: $p = 0.62$; Hypertension: $p = 0.54$; Obesity: $p > 0.99$). This lack of statistical confirmation is attributable to the limited sample size (n=23), which restricts the power to detect secondary associations. However, the qualitative clustering of these factors within the rapid-progression group (A) warrants clinical attention.

Table 3. Comparative Table of Clinical and Demographic Factors

Variable	Group A (Gardeners) (n=5)	Group B (Drivers) (n=18)	Total Cohort (N=23)
Median Age (Years)	46.0	43.5	44.0
Smoking Status			
Smokers (*n*)	3 (60.0%)	8 (44.4%)	11 (47.8%)
Non-Smokers (*n*)	2 (40.0%)	10 (55.6%)	12 (52.2%)
BMI Status:			
Obese (>30)	2 (40.0%)	6 (33.3%)	8 (34.8%)
Non-Obese (< 30)	3 (60.0%)	12 (66.7%)	15 (65.2%)
Hypertension:			
Present (*n*)	2 (40.0%)	4 (22.2%)	6 (26.1%)
Absent (*n*)	3 (60.0%)	14 (77.8%)	17 (73.9%)
Final HSE Outcome (2025)			
Category 3 (Referral)	**5 (100%)**	**6 (33.3%)**	**11 (47.8%)**

Discussion

This study demonstrates a rapid deterioration in auditory health within the municipal workforce from 2023 to 2025. Similar findings have been reported in occupational health studies published in the International Journal of Occupational Safety and Health. Patel and Ghosh documented significantly high-frequency hearing threshold shifts among weaving factory workers exposed to elevated noise levels, particularly in the 4–6 kHz frequency range, which is a characteristic audiometric pattern of noise-induced hearing loss.[19] The high proportion of workers meeting HSE 2021 Category 3 referral criteria (47.8%, n=11) exceeds rates typically cited in general manufacturing.[4,20]

The significant longitudinal threshold shift ($p < 0.001$) confirms that current mitigation strategies are insufficient for this demographic.

A critical finding is the instability of the "Warning" classification (HSE Category 2). Rather than serving as a stable plateau, it was a transitional phase toward severe impairment; 70% (n=7) of workers in this category migrated to Category 3 by 2025. This "diagnostic migration" indicates that the standard two-year surveillance interval is inadequate for detecting damage before clinical referral is required. [16]

The disparity between groups was absolute, with Group A (Gardeners) showing progression to the referral category in all workers (5/5, 100%). The dominance of Sub-category 3A (Rapid High-Frequency Loss) in Group A suggests exposure to high-intensity impulsive sound from landscaping machinery. Such noise carries a higher risk than continuous noise of equivalent energy,[21,22] leading to acute acoustic trauma rather than gradual decline.[15]

While noise is the primary driver,[18] individual factors likely play a synergistic role. Although the sample size limited statistical power, the clustering of smoking (60% in Group A) and hypertension (40% in Group A) suggests a potential "triad of risk" involving noise exposure, smoking-induced hypoxia, and metabolic stress. Smoking-induced hypoxia and vascular constriction may increase cochlear vulnerability and impair recovery from acoustic trauma. [9,11,23,24] Additionally, chemical contaminants in fuel exhaust may play a potentiating role.[25]

Finally, the effectiveness of Personal Protective Equipment (PPE) is called into question. Similar observations have been reported in other occupational settings, where inconsistent use of hearing protection devices has been associated with increased prevalence of hearing threshold impairment among noise-exposed workers.[26]

Real-world attenuation of earplugs is often lower than laboratory ratings due to poor fitting or inconsistent use.[27,28] The 100% referral rate in Group A may suggest potential limitations in PPE effectiveness or compliance; however, PPE use was not directly measured in this study.[28] These findings highlight the need for larger, prospective municipal surveillance studies.

Therefore, several limitations should be considered when interpreting the findings. First, the final analytical sample was relatively small (n = 23), limiting statistical power and the ability to perform multivariable analyses. Second, participant attrition was substantial, with approximately half of the initially identified cohort (44 workers) lacking complete paired audiometric data. Although attrition was largely administrative, selection bias cannot be fully excluded.

Third, potential confounding factors may have contributed to the observed differences in progression, including variability in baseline hearing status, non-occupational noise exposure, and consistency of hearing protection use. Finally, the observational design prevented causal inference. Larger prospective studies with improved retention and standardized exposure assessment are warranted.

Conclusion

This pilot longitudinal cohort study provides compelling evidence that municipal workers classified in Group A (gardeners) experience accelerated noise-induced hearing loss (NIHL) compared with their counterparts in Group B (drivers). The observation that 100% of Group A workers required clinical referral by 2025 highlights a critical limitation of the current preventive framework for this occupational subgroup and suggests a pattern of rapid progression associated with repeated exposure to high-intensity impulsive noise.[20]

Furthermore, the findings indicate that, for high-risk occupational groups, the "warning" classification (HSE Category 2) may represent a transitional stage rather than a stable condition, frequently progressing to more severe auditory impairment within the standard two-year surveillance interval.[16,27] The clustering of

synergistic risk factors—particularly smoking and hypertension—among the most affected workers further suggests that metabolic and vascular conditions may exacerbate cochlear susceptibility to acoustic trauma and accelerate the progression of hearing damage.[9,22]

These observations highlight the need for targeted preventive interventions structured according to the hierarchy of controls. First, priority should be given to reducing noise exposure at the source through engineering interventions. The implementation of a "Buy Quiet" procurement strategy is strongly recommended, whereby gasoline-powered gardening equipment is progressively replaced with professional-grade electric alternatives as existing machinery reaches the end of its operational lifespan. Such a substitution could substantially reduce exposure to impulsive noise and mechanical vibration associated with landscaping equipment.[20]

Second, administrative controls should be implemented to limit cumulative daily noise exposure. Job rotation strategies may reduce the prolonged operation of high-noise machinery by the same workers, allowing alternating assignments between noisy tasks (such as leaf blowing or mechanical trimming) and quieter activities, including manual planting or general maintenance.

In addition, improvements in hearing protection practices are warranted. Although personal protective equipment represents the final line of defense within the hierarchy of controls, it remains essential in high-noise environments. Mandatory individual fit testing should therefore be introduced to ensure proper acoustic sealing of earplugs and to verify effective attenuation under real-world working conditions. For tasks exceeding 95 dB(A), the implementation of dual hearing protection (earplugs combined with earmuffs) should be recommended until engineering controls successfully reduce exposure levels.[26,29]

Finally, enhanced health surveillance is necessary to evaluate the effectiveness of these preventive interventions. Given the rapid deterioration observed in this cohort, shortening the audiometric surveillance interval from the current 24 months to six months for high-risk workers could facilitate earlier detection of temporary threshold shifts and enable timely preventive intervention before permanent hearing impairment occurs.[13,30]

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