

Combined Noise Exposure and Hearing Difficulty as Independent Correlates of Tinnitus-Related Trouble Falling Asleep: A Nationally Representative Analysis of U.S. Adults

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Abstract

Background: Noise exposure is an established risk factor for tinnitus, yet its association with tinnitus-related trouble falling asleep remains underexplored at the population level. This study examined associations between occupational and leisure noise exposure and tinnitus-related trouble falling asleep in U.S. adults, adjusting for hearing difficulty. **Methods:** Cross-sectional analysis of 36,697 adults aged ≥ 18 years from the 2014 National Health Interview Survey (NHIS), which included a hearing supplement. The primary outcome was tinnitus-related trouble falling asleep among adults with tinnitus ($n = 4,292$). Secondary outcomes included short sleep (>7 hours) in the full sample ($n = 33,507$). Noise exposure was categorized as: no exposure, occupational only, leisure only, or both. Survey-weighted logistic regression with design-based standard errors estimated adjusted odds ratios (aOR) controlling for age, sex, race/ethnicity, education, smoking, and hearing difficulty. **Results:** The weighted 12-month tinnitus prevalence was 11.5%. Among those with tinnitus, 41.8% reported trouble falling asleep. Combined occupational and leisure noise exposure was associated with the highest odds of tinnitus-related trouble falling asleep (aOR = 1.69, 95% confidence interval [CI]: 1.30–2.19, $P < 0.001$), followed by leisure noise only (aOR = 1.37, 95% CI: 1.03–1.84, $P = 0.033$); occupational noise alone was not independently significant (aOR = 1.13, 95% CI: 0.92–1.39, $P = 0.23$; P -for-trend < 0.001). Hearing difficulty was a strong independent predictor (aOR = 1.78, 95% CI: 1.47–2.15, $P < 0.001$). **Conclusions:** Combined noise exposure is associated with elevated odds of tinnitus-related trouble falling asleep after adjustment for hearing difficulty. Hearing difficulty is the strongest correlate, suggesting that hearing status should be routinely assessed in tinnitus patients with sleep complaints.

Keywords: cross-sectional studies, epidemiology, hearing loss, noise, occupational, sleep initiation and maintenance disorders, tinnitus

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KEY MESSAGES

- (1) Combined occupational and leisure noise exposure is associated with 69% increased odds of tinnitus-related trouble falling asleep in a nationally representative U.S. sample, with a highly significant exposure–response gradient (P -for-trend < 0.001).
- (2) Self-reported hearing difficulty is the strongest independent predictor of tinnitus-related trouble falling asleep (aOR = 1.78) and tinnitus problem

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severity (aOR = 2.65), and its inclusion as a covariate attenuates noise–sleep associations by up to 9.5%, demonstrating its critical role as a confounder.

- (3) Over 80% of noise-exposed adults report irregular or no hearing protection use, highlighting a substantial gap in preventive practice that warrants targeted public health intervention.
- (4) A decomposition analysis (Karlson–Holm–Breen [KHB] method) indicates that tinnitus accounts for 8%–18% of the noise–short sleep association, suggesting both tinnitus-mediated and tinnitus-independent pathways linking noise exposure to sleep impairment.

INTRODUCTION

Noise exposure represents one of the most prevalent environmental hazards globally, with well-documented effects on auditory health including noise-induced hearing loss (NIHL) and tinnitus.^[1,2] The World Health Organization estimates that over one billion young adults are at risk of hearing loss due to unsafe listening practices,^[3] while occupational noise exposure remains a leading cause of preventable hearing impairment in working-age adults.^[4,5] The National Institute for Occupational Safety and Health (NIOSH) has long recommended exposure limits to minimize NIHL,^[6] yet noise-exposed workers continue to experience disproportionate auditory and nonauditory health consequences.

Tinnitus, the perception of sound in the absence of an external source, affects approximately 10%–15% of adults in high-income countries.^[7,8] Using data from the 2014 National Health Interview Survey (NHIS), Batts *et al.* estimated the U.S. prevalence of bothersome tinnitus at 11.2%.^[9] A population-based analysis of the NHIS (published in 2010) similarly reported a prevalence of approximately 10% with substantial variability by age, sex, and noise exposure history.^[10] While many individuals experience mild or intermittent symptoms, a meaningful proportion report functional impairment in concentration, emotional regulation, hearing, and especially sleep.^[11]

Sleep disturbance is among the most commonly reported complaints among individuals with tinnitus. A recent meta-analysis estimated that 53.5% of tinnitus patients experience sleep impairment.^[12] Earlier clinical studies reported elevated sleep disturbance scores in 77% of chronic tinnitus patients with NIHL,^[13] and community-based surveys have found insomnia prevalence of approximately 52% among elderly individuals with tinnitus.^[14] The relationship between tinnitus severity and sleep impairment appears bidirectional: sleep disturbance exacerbates tinnitus perception and distress, while tinnitus-related intrusion impairs sleep onset and maintenance.^[15–17]

Independent of tinnitus, environmental and occupational noise exposure can directly disrupt sleep architecture through autonomic arousal, cortisol release, and

fragmented sleep patterns.^[18,19] Short sleep duration (< hours per night) is itself associated with an increased risk of cardiovascular disease,^[20,21] metabolic dysfunction,^[22] depression,^[23] and occupational injuries.^[24] The American Academy of Sleep Medicine (AASM) and Sleep Research Society (SRS) recommend that adults obtain at least 7 hours of sleep to promote optimal health.^[25] Understanding whether noise exposure contributes to short sleep through tinnitus-mediated and tinnitus-independent associations is, therefore, of considerable public health importance.

Despite the plausibility of these mechanisms, few studies have simultaneously examined how different sources of noise exposure, occupational versus leisure time, relate to tinnitus-specific trouble falling asleep at the population level, and fewer still have adjusted for hearing difficulty as a potential confounder.^[26,27] The 2014 NHIS provides a unique opportunity to address these gaps, as it included a comprehensive hearing supplement with detailed questions on noise exposure sources, tinnitus symptomatology, hearing status, and sleep duration. Using this nationally representative dataset, we aimed to: 1) examine associations between occupational and leisure-time noise exposure and tinnitus-related trouble falling asleep among U.S. adults with tinnitus, with explicit adjustment for self-reported hearing difficulty; and 2) assess whether these exposure patterns are also associated with short sleep duration in the general adult population. As a secondary exploratory analysis, we examined the prevalence of hearing protection use among noise-exposed adults.

METHODS

Study Design and Data Source

We analyzed data from the 2014 NHIS, a cross-sectional household interview survey conducted by the National Centre for Health Statistics (NCHS), Centres for Disease Control and Prevention.^[28] The NHIS employs a multistage probability sampling design to produce nationally representative estimates of the civilian, noninstitutionalized U.S. population. In 2014, the Sample Adult questionnaire included supplemental modules on hearing and tinnitus, providing detailed data not available in most other survey years.^[29] The final Sample Adult file contained 36,697 records with a conditional response rate of 80.5%.

Study Population

Inclusion criteria were: age 18 years or older; valid responses to noise exposure, tinnitus, and sleep items; nonzero survey weight; and complete data on education (from Person file) and hearing difficulty. Exclusion criteria were: age below 18 years; missing values on any key analytic variable.

Of 36,697 Sample Adult respondents, we excluded those with missing data on noise exposure variables, sleep outcomes, education (merged from the Person file), self-reported

hearing difficulty, or survey design variables, yielding 33,507 adults for the short sleep analysis. Among these, 4,292 reported bothersome tinnitus in the past 12 months and provided valid responses to the tinnitus-related trouble falling asleep item, forming the primary analytic sample.

Outcome Measures

The primary outcome was tinnitus-related trouble falling asleep, ascertained from the NHIS item asking whether the respondent was bothered by ringing, roaring, or buzzing in the ears or head when going to sleep during the past 12 months (HRTINSLP; coded yes/no). This item was administered only to respondents who endorsed bothersome tinnitus. The first secondary outcome was tinnitus problem severity (HRTINPRO), dichotomized as moderate-or-worse versus no/small problem. The second secondary outcome was short sleep duration, defined as fewer than 7 hours per 24-hour period based on self-reported usual sleep duration (ASISLEEP), consistent with the AASM/SRS recommendation.^[25]

Exposure Measures

Noise exposure was operationalized as a four-level categorical variable: 0) no major noise exposure; 1) occupational noise only, defined as ever having had a job with exposure to loud or very loud sounds/noise (HRWKVLNS or HRWKLNS); 2) leisure-time noise only, defined as exposure to very loud sounds 10 or more times per year outside of work (HRLSVLNS); and 3) combined occupational and leisure noise exposure. Hearing protection use at work was coded as regular (always/usually) versus irregular or none (about half the time/seldom/never) from items HRWKVLP1 and HRWKLP1, consistent with previous NHIS analyses.^[26]

Covariates

Models were adjusted for age (continuous), sex, race/ethnicity (non-Hispanic White, non-Hispanic Black, non-Hispanic Other, and Hispanic), education (bachelor's degree or higher, less than high school, high school graduate, and some college/associate degree), smoking status (never, former, and current), and self-reported hearing difficulty (any difficulty versus no difficulty, from AHEARST2). Education was obtained from the Person file and merged via household, family, and person identifiers. Hearing difficulty was included to control for confounding by hearing loss severity. Firearm exposure was included in supplementary models.

Missing Data

Of the 36,697 Sample Adult respondents, 3,190 (8.7%) were excluded due to missing data. Missing rates for individual variables were: tinnitus (HRTIN) 0.3%, tinnitus trouble falling asleep (HRTINSLP) 0.5%, sleep duration (ASISLEEP) 1.2%, noise exposure 3.8%, hearing difficulty

(AHEARST2) 0.4%, and education (EDUC1) 5.1%. Individuals excluded may differ systematically from the analytic sample. Complete-case analysis was used given the low missing rates for most variables.

Statistical Analysis

All analyses incorporated the NHIS complex survey design using the final annual Sample Adult weight (WTFA_SA), pseudo-stratum (STRAT_P), and pseudo-primary sampling unit pseudo-PSU (PSU_P).^[28,29] Survey-weighted logistic regression estimated odds ratios (ORs) and 95% confidence intervals (CIs). Three primary model sets were fitted: Model 1, tinnitus-related trouble falling asleep; Model 2, tinnitus problem severity; and Model 3, short sleep in the full sample. As an exploratory analysis, Model 4 examined the association of hearing protection use with tinnitus-related trouble falling asleep among occupational noise-exposed workers. A test for linear trend across the four ordered exposure groups was conducted by entering the exposure variable as a continuous ordinal predictor. To assess the extent to which tinnitus statistically attenuated the association between noise exposure and short sleep, we compared total effect estimates (Model 3b, without tinnitus) to direct effect estimates (Model 3c, with tinnitus), calculating the percentage statistically attenuated on the log-odds scale as

$$\left(\frac{\text{total} - \text{direct}}{\text{total}} \right) \times 100.$$

Population attributable fractions (PAFs) were estimated using the case-based formula:

$$\text{PAF} = \sum_{i=1}^k p_{d_i} \left(\frac{aOR_i - 1}{aOR_i} \right)$$

where p_{d_i} is the proportion of cases in each exposure category and aOR_i is the corresponding adjusted odds ratio (aOR) from the full model (Model 1, including all covariates). Sensitivity analyses restricted occupational exposure to very loud noise only and stratified by firearm use. Analyses were performed in Python 3.11 (Python Software Foundation, Wilmington, DE, USA) using statsmodels.^[30] The complete analysis code is available at <https://github.com/salisadegh/Tinnitus-Related-Sleep-Disturbance>.

Ethical Considerations

The study is based on the publicly available de-identified dataset provided by the NHIS database. This database has received ethical approval from the National Center for Health Statistics (NCHS) Research Ethics Review Board (ERB) (Protocol #2009-16). Informed consent has been obtained from all participants by NCHS as part of the NHIS data collection protocol. This study has obtained the appropriate data usage authorization through the NHIS public-use data release.

Table 1: Weighted Sample Characteristics by Noise Exposure Group (*n* = 33,507)

Characteristic	No Noise (63.3%)	Occupational only (14.9%)	Leisure only (10.9%)	Both (10.8%)
n (unweighted)	21,173	5,332	3,542	3,578
Female (%)	61.7	31.8	47.7	17.1
Mean age (years)	47.6	50.5	42.0	45.9
NH White (%)	64.6	65.8	74.9	77.4
NH Black (%)	11.7	13.4	8.6	8.5
Hispanic (%)	15.3	16.1	10.9	10.2
Current smoker (%)	13.7	22.2	19.1	28.4
Firearm use (%)	25.6	52.6	54.5	77.0
Tinnitus (%)	7.3	17.8	12.9	25.2
Short sleep (%)	28.8	35.5	30.3	40.9

Note: All percentages are survey-weighted. NH = non-Hispanic.

RESULTS

Sample Characteristics

Among 33,507 adults with complete data, the weighted exposure distribution was: no major exposure 63.3%, occupational noise only 14.9%, leisure noise only 10.9%, and combined exposure 10.8% (Table 1). Compared to the no-noise group, adults with combined exposure were predominantly male (82.9% versus 38.3%), more likely to report current smoking (28.4% versus 13.7%), and had higher rates of firearm use (77.0% versus 25.6%). The combined exposure group was slightly younger (mean 45.9 versus 47.6 years) and more likely to be non-Hispanic White (77.4% versus 64.6%).

Prevalence of Outcomes

The overall weighted 12-month tinnitus prevalence was 11.5%, with a clear gradient across exposure groups: 7.3% (no noise), 17.8% (occupational only), 12.9% (leisure only), and 25.2% (combined). Among the 4,292 adults with tinnitus and complete data, 41.8% reported tinnitus-related trouble falling asleep and 28.5% rated their tinnitus as a moderate or worse problem. Both outcomes showed an exposure-response pattern, with the combined group exhibiting the highest prevalence of trouble falling asleep (50.5%) and moderate-or-worse tinnitus problems (31.0%). Short sleep prevalence was 31.3% overall, ranging from 28.8% (no noise) to 40.9% (combined exposure) (Figure 2).

Logistic Regression Results

In adjusted models controlling for age, sex, race/ethnicity, education, smoking, and hearing difficulty (Table 2), combined noise exposure was significantly associated with tinnitus-related trouble falling asleep (aOR = 1.69, 95% CI: 1.30–2.19, $P < 0.001$), as was leisure noise only (aOR = 1.37, 95% CI: 1.03–1.84, $P = 0.033$). Occupational noise alone was not independently significant after hearing adjustment (aOR = 1.13, 95% CI: 0.92–1.39, $P = 0.23$). The P-for-trend across ordered exposure groups remained significant ($P < 0.001$). Hearing difficulty emerged as a strong independent predictor (aOR = 1.78, 95% CI: 1.47–2.15,

$P < 0.001$), confirming its role as a key confounder. Female sex (aOR = 1.33) and non-Hispanic Black race (aOR = 0.49) were also independently associated. Comparing models with and without hearing adjustment, the combined exposure OR attenuated from 1.87 to 1.69 (Figure 1) (−9.5%), indicating that part of the noise–sleep association was confounded by hearing loss severity.

For tinnitus problem severity, after hearing adjustment, none of the individual exposure categories remained statistically significant (combined aOR = 1.23, 95% CI: 0.92–1.65; leisure aOR = 1.31, 95% CI: 0.94–1.81; occupational aOR = 1.15, 95% CI: 0.91–1.46), while hearing difficulty was the strongest predictor (aOR = 2.65, 95% CI: 2.17–3.24).

Table 2: Adjusted Odds Ratios for Tinnitus-Related Trouble Falling Asleep (*n* = 4,292; Hearing-Adjusted, Design-Based standard error (SEs))

Variable	aOR	95% CI	P-value
Noise exposure (ref: No noise)			
Occupational only	1.13	0.92–1.39	0.230
Leisure only	1.37	1.03–1.84	0.033 *
Both	1.69	1.30–2.19	<0.001 ***
Age (per year)	1.00	1.00–1.01	0.559
Female (ref: Male)	1.33	1.09–1.61	0.004 **
NH Black (ref: NH White)	0.49	0.37–0.65	<0.001 ***
NH Other (ref: NH White)	0.90	0.66–1.22	0.484
Hispanic (ref: NH White)	0.86	0.70–1.06	0.167
Education (ref: Bachelor+)			
< High school	0.94	0.74–1.21	0.645
HS graduate	1.26	0.97–1.64	0.089
Some college/Associate	1.33	0.97–1.83	0.076
Former smoker (ref: Never)	0.96	0.78–1.18	0.713
Current smoker (ref: Never)	1.15	0.90–1.48	0.272
Hearing difficulty	1.78	1.47–2.15	<0.001 ***
P-for-trend (exposure)			<0.001 ***

Note: Survey-weighted logistic regression with Taylor series linearization for design-based SEs using NHIS 2014 pseudo-strata and pseudo-PSUs. Reference: Bachelor's degree or higher (education), Never smoker (smoking), NH White (race/ethnicity), No noise exposure (noise). * $P < 0.05$. ** $P < 0.01$. *** $P < 0.001$.

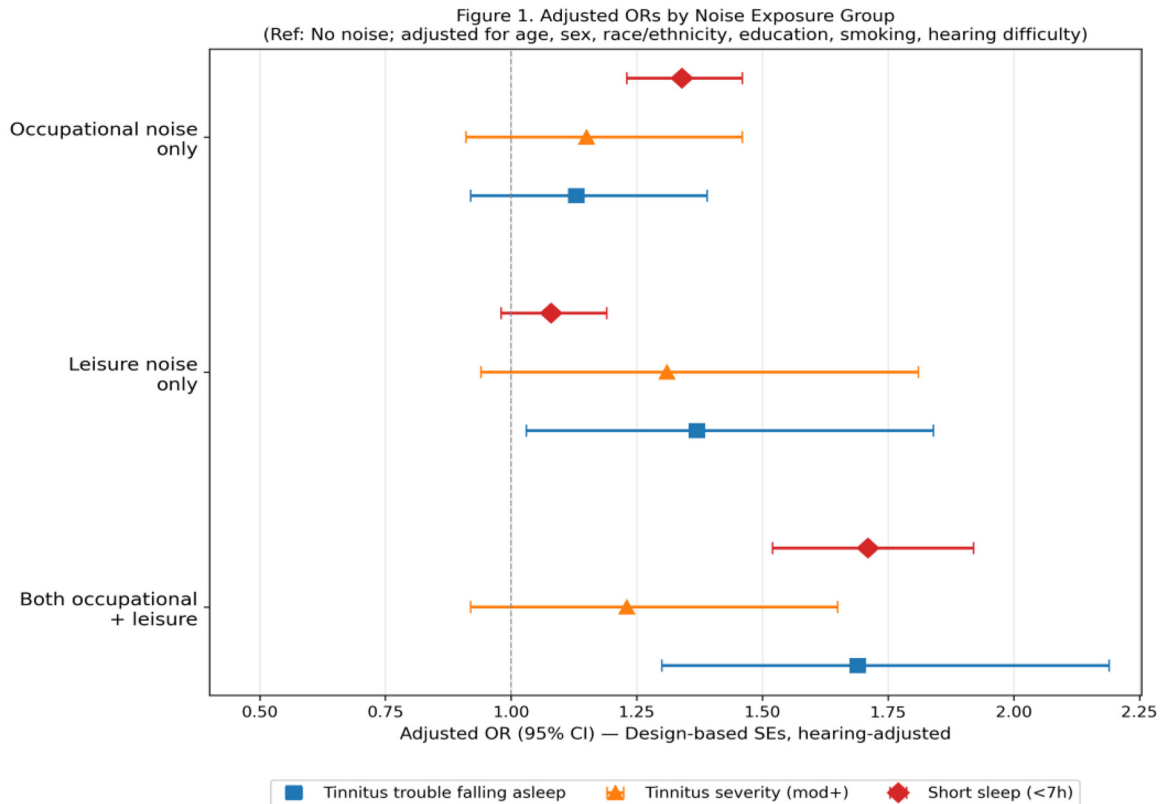


Figure 1: Adjusted Odds Ratios for Sleep Outcomes by Noise Exposure Group (Reference: No Noise Exposure)

Note: Blue squares = tinnitus-related trouble falling asleep (tinnitus subsample, $n = 4,292$); orange triangles = tinnitus severity moderate+ (tinnitus subsample); red diamonds = short sleep $<7h$ (full adult sample, $n = 33,507$). All models adjusted for age, sex, race/ethnicity, education, smoking, and hearing difficulty. Error bars = 95% CIs. Dashed line at OR = 1.0 indicates null.

In the full sample, combined exposure was associated with $aOR = 1.71$ (95% CI: 1.52–1.92) for short sleep (P -for-trend < 0.001). A decomposition analysis (KHB method) indicated that tinnitus was associated with a reduction of approximately 7.7% of the occupational, 18.4% of the leisure, and 8.0% of the combined exposure-short sleep association. These estimates decompose the association and do not imply causal mediation given the cross-sectional design.

Estimated Population Attributable Fraction

Under the assumption of causality, which cannot be confirmed from cross-sectional data, an estimated 18.0% of tinnitus-related trouble falling asleep cases would be attributable to noise exposure, with combined exposure contributing the largest share (11.8%). These estimates should be interpreted as a theoretical upper bound of the

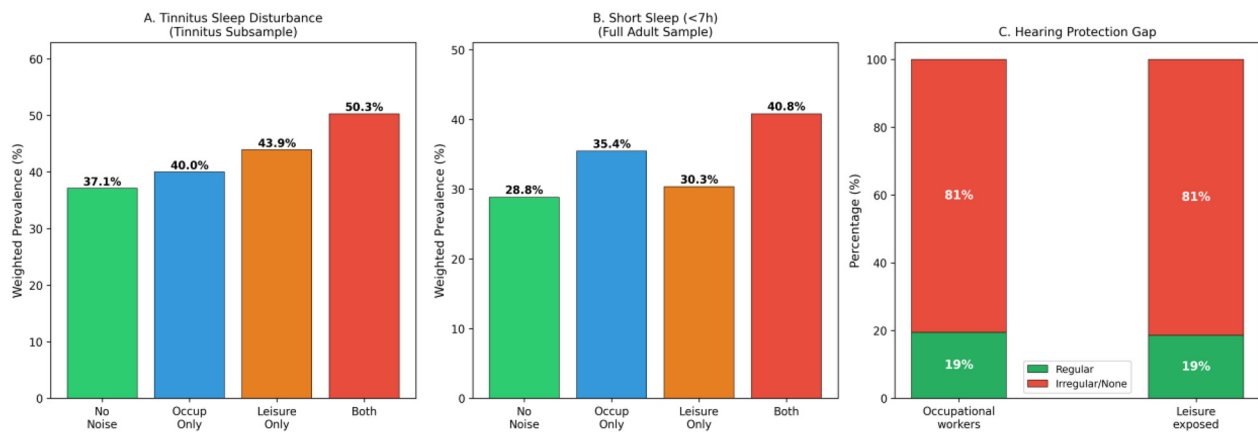


Figure 2: Weighted Prevalence of Sleep Outcomes and Hearing Protection Use Gap

Note: Panel A: Tinnitus-related trouble falling asleep among tinnitus subsample. Panel B: Short sleep (<7 hours) in the full adult sample. Panel C: Hearing protection use among noise-exposed adults, showing that over 80% report irregular or no protection use. All percentages are survey-weighted.

preventable fraction, contingent on causality, and the absence of residual confounding.

Exploratory Analysis: Hearing Protection

In an exploratory analysis, regular work hearing protection among occupational noise-exposed workers with tinnitus ($n=2,010$) was associated with a nonsignificant association (OR=0.80, 95% CI: 0.55–1.17, $P=0.254$). Descriptively, only 19.5% of noise-exposed workers and 18.6% of leisure noise-exposed adults reported regular hearing protection use.

Sensitivity Analyses

Sensitivity analysis results are presented in Table 3. Restricting occupational exposure to very loud noise only yielded consistent results (aOR = 1.19, 95% CI: 0.98–1.44 for very loud occupational; aOR = 1.43, 95% CI: 1.17–1.74 for leisure). Stratification by firearm use showed that the combined exposure effect was robust in both strata (aOR = 2.05 among nonfirearm users; aOR = 1.59 among firearm users).

DISCUSSION

Using a nationally representative sample of U.S. adults, this study demonstrates two principal findings. First, combined occupational and leisure noise exposure is associated with a 69% increase in the odds of tinnitus-related trouble falling asleep after adjustment for hearing difficulty and other confounders (aOR = 1.69; P -for-trend < 0.001). Occupational noise alone was not independently significant after hearing adjustment, suggesting that the association is driven primarily by combined and leisure exposures. Second, self-reported hearing difficulty emerged as the strongest independent predictor of tinnitus-related trouble falling asleep (aOR = 1.78) and tinnitus problem severity (aOR = 2.65), confirming its role as a critical confounder that must be controlled in noise-tinnitus-sleep research. An exploratory analysis also documented low rates of hearing protection use among noise-exposed adults, though the protective effect did not reach statistical significance.

The overall 12-month tinnitus prevalence of 11.5% is consistent with prior U.S. estimates.^[9,10] Among those

with tinnitus, 41.8% reported trouble falling asleep, within the 25%–77% range across studies^[12–14] and close to the 53.5% pooled meta-analytic estimate.^[12] The 9.5% attenuation of exposure ORs after hearing adjustment (combined exposure: 1.87→1.69) demonstrates that prior analyses of this dataset that did not control for hearing difficulty^[9] may have overestimated the direct noise–sleep association.

A decomposition analysis using the KHB method indicated that tinnitus was associated with a reduction of 8%–18% of the noise–short sleep association. We emphasize that this decomposes the statistical association and does not establish causal mediation, given the cross-sectional design. The estimated PAF of 18.0% is similarly conditional on causal assumptions that cannot be verified here and should be interpreted as a theoretical upper bound.

The finding that occupational noise alone was not independently significant (aOR = 1.13, $P=0.23$) after controlling for hearing difficulty deserves attention. This may indicate that the occupational noise–sleep association operates primarily through hearing loss rather than through direct sleep-disruptive mechanisms. By contrast, leisure noise (aOR = 1.37, $P=0.033$) retained significance, possibly reflecting the impulsive, high-intensity nature of recreational exposures.^[8,30] Recent studies, including population-based analyses using validated sleep instruments such as the pittsburgh sleep quality index (PSQI), have provided richer characterization of these associations.^[12,31] Our contribution lies in the simultaneous examination of occupational and leisure sources, explicit hearing difficulty adjustment, which attenuated exposure estimates by up to 9.5%, and design-based variance estimation in a nationally representative sample.

Our exploratory analysis documented that only 19.5% of occupational and 18.6% of leisure noise-exposed adults reported regular hearing protection use, consistent with previous estimates.^[26,27] The nonsignificant association (OR = 0.80, $P=0.254$) likely reflects insufficient power in the tinnitus subsample ($n=2,010$). This descriptive finding warrants investigation in adequately powered prospective designs but cannot support causal claims in the present analysis.

Table 3: Sensitivity Analysis Results (Design-Based SEs, Hearing-Adjusted)

Analysis	Exposure	aOR	95% CI	<i>P</i>
Sensitivity 1	Very loud occupational	1.19	0.98–1.44	0.083
	Leisure noise	1.43	1.17–1.74	0.001
Sensitivity 2a No firearm ($n=1,816$)	Occupational only	1.06	0.79–1.42	0.687
	Leisure only	1.30	0.82–2.07	0.264
	Both	2.05	1.40–3.01	<0.001
Sensitivity 2b Firearm ($n=2,404$)	Occupational only	1.15	0.88–1.51	0.302
	Leisure only	1.40	0.98–2.00	0.064
	Both	1.59	1.17–2.15	0.003

Note: All models adjusted for age, sex, race/ethnicity, education, smoking, and hearing difficulty using Taylor series linearization.

Why Occupational Noise Alone May Appear Null

The nonsignificant association for occupational noise alone (aOR = 1.13) may reflect the healthy worker effect, whereby noise-exposed workers are systematically healthier. Additionally, occupational noise is typically continuous and chronic, potentially leading to habituation, while leisure noise is often impulsive and high-intensity. Self-reported occupational noise may also be subject to different recall biases than leisure noise.

Hearing Difficulty: Confounder or Mediator?

Classifying hearing difficulty as a confounder is an assumption. If hearing difficulty lies on the causal path from noise exposure to trouble falling asleep, our adjustment constitutes overadjustment. We present models with and without hearing difficulty (9.5% attenuation) to allow evaluation of both scenarios. Longitudinal studies are needed to resolve this ambiguity.

Mechanisms Linking Leisure Noise to Trouble Falling Asleep

Leisure noise exposures often occur during evening hours close to bedtime, potentially disrupting sleep onset more directly than daytime occupational noise. Individuals with high leisure noise exposure may also engage in sleep-disrupting behaviors such as evening alcohol consumption and irregular sleep schedules. Voluntary recreational noise may carry different emotional and arousal associations compared to habitual workplace noise.

Clinical Implications: Therapeutic Window

The initial period after noise-induced tinnitus onset may represent a therapeutic window, during which CBT-I, sound enrichment therapy, and hearing rehabilitation may be most effective in preventing chronification of tinnitus-related sleep complaints.

Strengths include the large nationally representative sample, comprehensive noise and tinnitus variables, adjustment for hearing difficulty (a key confounder absent from most prior NHIS analyses), design-based variance estimation via Taylor series linearization, and multiple sensitivity analyses. Limitations include the cross-sectional design precluding causal inference, self-reported measures without objective audiometry or noise dosimetry, a single-item trouble-falling-asleep measure rather than a validated multi-item instrument such as the PSQI,^[31] and the fact that the hearing difficulty measure captures self-reported functional status rather than audiometric thresholds. Recent work has demonstrated that objective high-frequency audiometric data can classify tinnitus with over 94% accuracy using machine learning approaches,^[32] underscoring the potential value of incorporating such measures in future epidemiological studies of tinnitus-related outcomes. Residual confounding from unmeasured factors including depressive symptoms, shift work, and noise intensity levels cannot be excluded.

Additionally, recall bias may affect self-reported noise exposure. Social desirability bias may lead workers to underreport hearing protection nonuse. The single-item NHIS measure captures only trouble at sleep onset and cannot distinguish other sleep domains such as early morning awakening or sleep maintenance. As a binary measure, it may underestimate effect sizes compared to validated instruments such as the PSQI.

CONCLUSIONS

In this nationally representative analysis with design-based variance estimation, combined occupational and leisure noise exposure was independently associated with 69% increased odds of tinnitus-related trouble falling asleep after adjustment for hearing difficulty (P -for-trend < 0.001). Hearing difficulty itself was the strongest predictor across all tinnitus outcomes, demonstrating that hearing status is a critical variable that should be controlled in noise-tinnitus research and routinely assessed in clinical evaluation of tinnitus-related sleep complaints. Prospective studies incorporating objective audiometric assessment, which has shown promise for objective tinnitus assessment, and validated sleep instruments are needed to confirm statistical associations.

Availability of Data and Materials

The 2014 NHIS public-use data files are available from the CDC/NCHS at https://archive.cdc.gov/www_cdc_gov/nchs/nhis/nhis_2014_data_release.htm.

The complete analysis code, variable codebook, and reproducibility instructions are publicly available at <https://github.com/salisadegh/Tinnitus-Related-Sleep-Disturbance>.

Author Contributions

Seyed-Ali Sadegh-Zadeh: Conceptualization, methodology, formal analysis, software, writing—original draft, supervision.

Shayan Saadat: Clinical interpretation, critical revision, writing—review and editing.

Alireza Soleimani Mamalo: Data curation, validation.

Hamed Atashbar: Software, data processing.

Nooshin Borhani Rayeni: Literature review, writing—review and editing.

Zahra Mohammadinezhad: Literature review, writing—review and editing.

Yasaman Noshirvanbaboli: Data curation, visualization.

Ghazal Naghdibak: Data curation, validation.

Reza Hajizadeh: Clinical input on audiological and cardiovascular variables, critical revision.

Mohammadreza Pashaei: Clinical input on sleep and internal medicine variables, critical revision.

Ethics Approval and Consent to Participate

The study was based on the publicly available de-identified dataset provided by the National Health Interview Survey (NHIS) database. This database received ethical approval from the National Center for Health Statistics (NCHS) Research Ethics Review Board (ERB) (Protocol #2009-16). Informed consent was obtained from all participants by NCHS as part of the NHIS data collection protocol. This study obtained the appropriate data usage authorization through the NHIS public-use data release.

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Conflicts of Interest

The authors declare no conflicts of interest.

REFERENCES

- Lie A, Skogstad M, Johannessen HA, *et al.* Occupational noise exposure and hearing: A systematic review. *Int Arch Occup Environ Health* 2016;89:351–72.
- Masterson EA, Tak S, Themann CL, *et al.* Prevalence of hearing loss in the United States by industry. *Am J Ind Med* 2013;56:670–81.
- World Health Organization. Hearing loss due to recreational exposure to loud sounds: A review. Geneva: WHO; 2015.
- Nelson DI, Nelson RY, Concha-Barrientos M, Fingerhut M. The global burden of occupational noise-induced hearing loss. *Am J Ind Med* 2005;48:446–58.
- Themann CL, Masterson EA. Occupational noise exposure: A review of its effects, epidemiology, and impact with recommendations for reducing its burden. *J Acoust Soc Am* 2019;146:3879–905.
- National Institute for Occupational Safety and Health. Criteria for a recommended standard: occupational noise exposure, revised criteria 1998. DHHS (NIOSH) Publication No. 98–126. Cincinnati, OH: NIOSH; 1998.
- Baguley D, McFerran D, Hall D. Tinnitus. *Lancet* 2013;382:1600–7.
- Bhatt JM, Lin HW, Bhattacharyya N., Prevalence, severity, exposures, and treatment patterns of tinnitus in the United States. *JAMA Otolaryngol Head Neck Surg* 2016;142:959–65.
- Batts S, Stankovic KM. Tinnitus prevalence, associated characteristics, and related healthcare use in the United States: A population-level analysis. *Lancet Reg Health Am* 2024;29:100659.
- Shargorodsky J, Curhan GC, Farwell WR. Prevalence and characteristics of tinnitus among US adults. *Am J Med* 2010;123:711–8.
- Henry JA, Dennis KC, Schechter MA. General review of tinnitus. *J Speech Lang Hear Res* 2005;48:1204–35.
- Gu H, Kong W, Yin H, Zheng Y. Prevalence of sleep impairment in patients with tinnitus: A systematic review and single-arm meta-analysis. *Eur Arch Otorhinolaryngol* 2022;279:2211–21.
- Alster J, Shemesh Z, Ornan M, Attias J. Sleep disturbance associated with chronic tinnitus. *Biol Psychiatry* 1993;34:84–90.
- Lasisi AO, Gureje O. Prevalence of insomnia and impact on quality of life among community elderly subjects with tinnitus. *Ann Otol Rhinol Laryngol* 2011;120:226–30.
- Crönlein T, Langguth B, Geisler P, Hajak G. Tinnitus and insomnia. *Prog Brain Res* 2007;166:227–33.
- Schecklmann M, Pregler M, Kreuzer PM, *et al.* Psychophysiological associations between chronic tinnitus and sleep: A cross validation of tinnitus and insomnia questionnaires. *Biomed Res Int* 2015;2015:461090.
- Wallhäuser-Franke E, Schredl M, Delb W. Tinnitus and insomnia: Is hyperarousal the common denominator? *Sleep Med Rev* 2013;17:65–74.
- Basner M, Babisch W, Davis A, *et al.* Auditory and non-auditory effects of noise on health. *Lancet* 2014;383:1325–32.
- Halperin D. Environmental noise and sleep disturbances: A threat to health? *Sleep Sci* 2014;7:209–12.
- Covassin N, Singh P. Sleep duration and cardiovascular disease risk: Epidemiologic and experimental evidence. *Sleep Med Clin* 2016;11:81.
- Krittanawong C, Tunhasariwet A, Wang Z, *et al.* Association between short and long sleep durations and cardiovascular outcomes: A systematic review and meta-analysis. *Eur Heart J Acute Cardiovasc Care* 2019;8:762–70.
- Cappuccio FP, D'Elia L, Strazzullo P, Miller MA. Quantity and quality of sleep and incidence of type 2 diabetes: A systematic review and meta-analysis. *Diabetes Care* 2010;33:414–20.
- Baglioni C, Battagliese G, Feige B, *et al.* Insomnia as a predictor of depression: A meta-analytic evaluation of longitudinal epidemiological studies. *J Affect Disord* 2011;135:10–9.
- Uehli K, Mehta AJ, Miedinger D, *et al.* Sleep problems and work injuries: A systematic review and meta-analysis. *Sleep Med Rev* 2014;18:61–73.
- Watson NF, Badr MS, Belenky G, *et al.* Recommended amount of sleep for a healthy adult: A joint consensus statement of the American Academy of Sleep Medicine and Sleep Research Society. *J Clin Sleep Med* 2015;11:591–2.
- Green DR, Masterson EA, Themann CL. Prevalence of hearing protection device non-use among noise-exposed US workers in 2007 and 2014. *Am J Ind Med* 2021;64:1002–17.
- Tak S, Davis RR, Calvert GM. Exposure to hazardous workplace noise and use of hearing protection devices among US workers—NHANES, 1999–2004. *Am J Ind Med* 2009;52:358–71.
- National Center for Health Statistics. 2014 National Health Interview Survey (NHIS) public use data release: survey description. Hyattsville, MD: NCHS; 2015.
- Blackwell DL, Lucas JW, Clarke TC. Summary health statistics for US adults: National health interview survey, 2012. *Vital Health Stat* 10. 2014;1–161.
- Carroll YI, Eichwald J, Scinicariello F, *et al.* Vital signs: Noise-induced hearing loss among adults—United States 2011–2012. *MMWR Morb Mortal Wkly Rep* 2017;66:139–44.
- Buyse DJ, Reynolds CF III, Monk TH, Berman SR, Kupfer DJ. The Pittsburgh Sleep Quality Index: A new instrument for psychiatric practice and research. *Psychiatry Res* 1989;28:193–213.
- Sadegh-Zadeh SA, Soleimani Mamalo A, Kavianpour K, *et al.* Artificial intelligence approaches for tinnitus diagnosis: Leveraging high-frequency audiometry data for enhanced clinical predictions. *Front Artif Intell* 2024;7:1381455.