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# A Longitudinal Assessment of Hearing Loss in the World Trade Center General Responder Cohort



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**Data Availability:** The relevant data are available within the manuscript. De-identified datasets for analysis of the current study may be requested of the corresponding author made available upon submission of the World Trade Center Data Center Data Use Agreement and Data Request Form (including an attestation) and requisite IRB approval. AI was not utilized by any author in any stage or for any part of the hypothesis development or design, data collection, data evaluation or manuscript preparation.

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**Disclaimer:** The contents of this report are the sole responsibility of the authors and do not necessarily represent the official views of, nor an endorsement, by the National Institute for Occupational Safety and Health (NIOSH), the Centers for Disease Control and Prevention of the U.S. Department of Health and Human Services (CDC/HHS), or the U.S. Government.

## CLINICAL SIGNIFICANCE

This study augments current evidence, demonstrating that noise experienced while working on the World Trade Center (WTC) site by volunteer responders was associated with substantially increased risk of incident hearing loss above and beyond their other WTC exposures. Adjustment for previous occupation and confounding did not alter the results.

**Abstract**

**Objective**: In analyses without adjustment for World Trade Center (WTC) noise exposure, people with WTC and neighborhood exposures from the September 11th, 2001 attacks have experienced slightly elevated risks of hearing loss. We investigated incident hearing loss in the WTC General Responder Cohort by their levels of WTC exposure, their WTC noise exposure and previous occupation.

**Methods:** Adjusted multivariable log binomial regression models assessed persistent (≥10 months) hearing loss associated with WTC exposures using 22 years of the monitoring visit data (n = 45,537).

**Results:** Compared to the lowest exposure level without WTC noise exposure, WTC noise exposure increased hearing loss risk (adjusted relative risk range: 1.19 [95% confidence interval 1.08, 1.30] to 1.58 [1.43, 1.76]).

**Conclusions:** The results clarify the importance of WTC noise when evaluating the associations of WTC exposures on hearing loss.

**Keywords:** Hearing loss, tinnitus, ear pain, World Trade Center, General Responder Cohort

## LEARNING OUTCOMES

- Identify multiple causes of hearing loss other than age
- Specify the global prevalence of hearing loss
- Specify whether, in addition to responders' intensity and duration of WTC toxic exposures, occupations before the attack and on-site WTC noise are associated with hearing loss

## INTRODUCTION

Worldwide, more than 1.5 billion (one in five) people have hearing loss; 62% are more than 50 years old.[1,2] Approximately 25% of the hearing loss is moderate to severe. As such, hearing loss accounts for nearly two-thirds of standardized years lived with disability, which is concentrated in those with moderate or severe hearing loss.[1,3] The major causes of hearing loss are genetic susceptibility, premature birth, age-related degeneration, ototoxic medications, exposure to blasts, loud noise, and traumatic brain injury, brain tumors, radiation and cancer therapy,.[4-15] Hearing loss is also associated with exposure to heavy metals, solvents and air pollution, smoking, post-traumatic stress disorder (PTSD), high body mass index and chronic conditions including chronic ear infection/otitis media, high blood pressure, diabetes and cardiovascular disease, however these associations and their causal relationships are more tenuous.[4,7,8,13,16-21] Hearing loss impairs communication that can affect social interaction, economic status, and quality of life; it is associated with depression, frailty, dementia, hospitalization and death.[7]

People who responded to and/or lived in the areas affected by the September 11, 2001 attack on the World Trade Center (WTC) were exposed to noise and an amalgam of toxic substances,[22,23] physical and psychological trauma that produced and exacerbated a broad spectrum of short- and long-term adverse health conditions.[24-27] Those considered to have the greatest WTC exposures include: people exposed to the dust cloud and airplane-related physical and chemical debris produced by the destruction of the towers; people with the earliest and longest duration of WTC-exposures; and people working on the debris pile. Within three years of the attack, survivors of neighboring collapsed or damaged buildings who had been exposed to the dust and debris cloud were estimated to have a 70% increased risk of hearing problems including hearing loss.[28] Increased risk of self-reported hearing problems or loss was also identified in

disaster-affected area non-responders who reported they were able to hear during their WTC dust cloud exposure (adjusted odds ratio [AOR] 1.4, 95% confidence interval [CI] 1.1, 1.7); those who reported being unable to hear during their dust cloud exposure had even higher risk (AOR 3.0, 95% CI 2.2, 4.0).[29] Similar results were observed when comparing the highest to lowest quartile of an environmental exposure score in rescue and recovery workers in the WTC Health Registry.[30] Subsequent studies have found increased risks of self-reported ear congestion, pain or ringing (AOR 1.3, 95% CI 1.1, 1.6) and persistent hearing loss (AOR 1.2, 95% CI 0.9, 1.5) in surviving FDNY firefighters with high WTC exposures.[31] FDNY firefighters and emergency medical services (EMS) workers with the highest levels of WTC exposure had increased risk of low- and high- frequency hearing loss assessed via pure-tone threshold audiograms, compared to those with the lowest WTC exposure (AOR 1.3, 95% CI 1.1, 1.6; AOR 1.4, 95% CI 1.2, 1.5, respectively).[32]

We present an assessment of WTC-exposures and subsequent hearing loss, tinnitus and ear pain for the General Responder Cohort (GRC), a large and diverse group of volunteers who are non-FDNY responders.[33] The assessment yields novel evidence regarding the associations between incident GRC hearing loss and impairment after WTC exposure with the level and duration of on-site response work engaged in, exposures to on-site noise, and occupation immediately before September 11th, 2001.

## METHODS

### Data source

The Centers for Disease Control and Prevention/National Institute for Occupational Safety and Health has supported multiple clinical centers to assess the health effects of the attack and provide medical monitoring and treatment for people directly affected by the September 11th, 2001 attacks.

These services, initiated on July 1, 2002, evolved into the WTC Health Program, established by law under the James Zadroga 9/11 Health and Compensation Act of 2010. Five WTC Health Program clinical centers of excellence provide periodic health monitoring, diagnosis and treatment for the GRC members located in the New York - New Jersey - Connecticut tristate area. Using program questionnaires, clinical center staff collect socio-demographic status and WTC response exposure information at the members' first health monitoring visit (V1), and, at all visits, self-reported physician diagnoses and medication use. The members also receive a physical examination at each visit.

**Ethics Review and Approval**

This research is approved by the GRC Clinical Centers of Excellence and Data Center Institutional Review Boards. The research was conducted in concurrence with the World Medical Association Declaration of Helsinki (1975, revised 2013) and with national and institutional committees' standards regarding the conduct of human studies. All members included in the study provided written, informed consent. This manuscript follows the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines for cohort studies.

**Inclusions/Exclusions**

Of 55,470 GRC members who attended Program monitoring visits from July 1, 2002 through June 30, 2024, written, informed consent for data aggregation and analysis was provided by 51,297 members. Of those, this analysis excluded members whose last monitoring visit was before 2006, when hearing loss information began to be collected (n = 2,028), and one person missing age information. Program members who reported incident hearing loss, ear ringing (tinnitus), or ear

pain during or after their WTC response were included in the analyses of those outcomes except when they did not report their earliest dates of experiencing those conditions (respectively n=48; n=49; n=106).





**Outcomes**

The primary outcome is persistent hearing loss; tinnitus and ear pain are secondary outcomes. All conditions were self-reported during monitoring visits that generally occur twelve or more months apart. Persistence of the hearing outcomes was classified as reported experience of the condition on at least two occasions that were ten or more months apart if the earliest date of the condition occurred after WTC exposure. Questions regarding hearing impairment during the responders' first monitoring visit ascertained the initial date as well as the current status of the condition. This enabled inference of hearing impairment persistence regardless of the number of monitoring visits.

**WTC Exposure Variables**

We assessed three WTC exposure measures: i) a four-level composite estimate of WTC exposure (Exp4); ii) having worked on the pile of the destroyed buildings (EverPile); and iii) the duration of working on the WTC effort (DaysWTC). Exp4 classified responders as having low, intermediate, high and very high WTC exposures (Table 1). This analysis used stratification categories to assess the combined effect of exposure to noise while working on the WTC effort and Exp4, EverPile and DaysWTC. Members who did not report information for Exp4 (n=2,778), EverPile (n=2,553) and DaysWTC (n=853) were excluded from analyses of those exposures. Each WTC exposure variable was stratified by whether the responder reported being exposed to noise while working on the WTC effort.

**Covariates and Potential Confounders**

Characteristics associated with higher and lower levels of hearing loss were assessed. They include (reference group; modal value used for imputation) age (20 – 29 years old; none), sex (male; none), race (white; white), ethnicity (non-Hispanic; non-Hispanic), highest level of education (<high school graduate; high school graduate), first visit body mass index (BMI <25; 25-29; BMI≥30), occupation on the day before the September 11$^{th}$ attack (protective services; protective services), and cigarette smoking status (non-smoker; non-smoker) prior to the earliest outcome date. Missing data for occupation (n=1,640) was retained as a category. Missing data for all other covariates were imputed as their mode values in the multivariate analyses (race n = 12,969; ethnicity n = 13,312; education n = 6,771; BMI n = 1,730; smoking n = 5,960).

**Comorbidities and Occupational Exposures**

While persistent headaches, post-traumatic stress disorder (PTSD) and rhinosinusitis and other chronic conditions (diabetes, high cholesterol, hypertension, cardiovascular disease, cancer) have been associated with hearing loss, the nature of their associations with hearing loss is equivocal.[2,7,10,13,17,18,34] To minimize potential error and model over-specification, the analyses did not adjust for non-WTC occupational exposures or comorbidities other than ideal (<25), overweight (25-29) and obese (≥30) BMI status.

**Statistical analysis**

To describe the sample, we conducted cross-tabulations of its characteristics by persistent hearing loss status, the primary outcome. Two-tailed, 95% Pearson's chi-square probability values are presented.

As the incidence of hearing impairment was greater than 10%, log binomial regression analyses were performed to independently investigate the associations of Exp4, EverPile and DaysWTC with hearing loss, tinnitus and ear pain.[35,36] The models adjusted for age, sex, race, Hispanic ethnicity, highest level of education, first visit BMI, occupation on September 10, 2001 and cigarette smoking status as potential confounders. To determine the extent to which follow-up, multiple visits and type of imputation of missing covariate values may have modified the results, we conducted respective sensitivity analyses of the primary outcome using Cox proportional hazards analysis, limiting analyses to members with more than one monitoring visit (n=42,379; excludes 6,889 responders), and deriving missing covariate data using fully conditional specification multiple imputation by logistic equations.[37] Results are presented as relative risks with two-tailed, Wald 95% confidence intervals (CI). With a maximum of eight exposure/noise strata, the cohort supported testing a relative risk of ≥1.25 with ≥90% statistical power. To compare our results with those published for other WTC responders and for disaster-affected area non-responders, we also present logistic regression odds ratios for hearing loss and Exp4 with and without WTC noise.[29-32,38]

All statistical analyses except the multiple imputation of missing values and the log binomial regression analyses were conducted using SPSS for Windows version 28.0.1.1(15) (IBM Corp., Armonk, NY). The log binomial regression and multiple imputation analyses were respectively conducted using proc genmod and proc MI SAS 9.4 (SAS Institute, Cary, NC, USA). The Figure 1 Venn diagram and Figure 2 graph were produced in RStudio 4.4.0 (RStudio Team (2020). RStudio: Integrated Development for R. RStudio, PBC, Boston, MA URL http://www.rstudio.com/) using the eulerr and ellipse packages. The study report conforms with

the (Strengthening the Reporting of Observational Studies in Epidemiology) statement (Supplementary Digital Content 1, http://links.lww.com/JOM/B941).[39]



## RESULTS

The mean (± standard deviation) age of the cohort with any outcome data (n=49,266) on September 11, 2001 was 38.3±8.8 years. Incident ear pain occurred younger (ear pain mean age 48.5±9.2) than hearing loss (mean age 53.4±9.4) and tinnitus (52.1±9.1 years old) (Table 2). Those experiencing incident hearing loss were younger than those not experiencing hearing loss (mean age 55.2±9.6), although they were older than those without hearing loss on September 11, 2001 and at their last visit. The average observation time (last vs. first visit) was longer for cases than non-cases (hearing loss: 12.1 ± 6.1 vs. 7.9 ± 6.7 years; tinnitus: 10.6 ± 6.6 vs. 7.8 ± 6.7 years; and ear pain: 11.4 ± 6.4 vs. 7.8 ± 6.7 years, all $p \leq 0.001$). However, the average follow-up time from the first day worked on the WTC effort until the event (cases) or until last visit (non-cases) was 11.9 ± 4.6 years and 18.2 ± 5.3 years for members with and without persistent hearing loss, 14.8 ± 5.6 years and 17.9 ± 5.5 years with and without persistent tinnitus, and 14.6 ± 6.7 years and 18.4 ± 5.2 years with and without persistent ear pain (all $p \leq 0.001$). Forty-percent of the cohort experienced one of the three outcomes, with substantial intersection among the three (Figure 1). Of those studied, 12,479 (25.4%) reported persistent hearing loss, 12,379 (25.1%) reported persistent tinnitus and 7,490 (15.2%) reported persistent ear pain (Figure 3). Another 17.4% reported short term hearing loss (duration of <10 months) after their participation in the WTC work effort (data not shown).

Most of the socio-demographic and BMI characteristic distributions were statistically significantly different between those with and without persistent hearing loss, yet, except for

smoking cigarettes, the magnitude of the differences were generally small (Table 2). Members engaged in occupations other than protective services (including ~1% military) on September 10th, 2001 had higher risks of hearing loss, tinnitus and ear pain (Tables 3, 4, and 5).

Without considering other measures of WTC exposure, exposure to noise while working on the WTC effort increased the risk of incident hearing loss (ARR 1.23 [1.18, 1.27]), tinnitus (ARR 1.17 [1.13, 1.22]) and ear pain (ARR 1.33 [1.26, 1.41]). However, the combined effects of WTC noise and other measures of WTC exposure revealed dose-response relationships where members who experienced noise while working on the WTC effort consistently had higher risk of hearing loss (Table 3, Figure 2), tinnitus (Table 4) and ear pain (Table 5).

Compared to members with the lowest Exp4 level without WTC noise exposure, the risk of hearing loss increased with higher exposure among those who did not have WTC noise exposure, except in the group with very high Exp4, which had a small sample size (n=103) and unstable risk estimate (Table 3, Table 6). While significantly higher risk of hearing loss was associated with ever working on the WTC debris pile and with the number of days worked on the WTC effort, those risks were only similar to the range of Exp4 risk through intermediate exposure with WTC noise. Similar patterns, but lower risk of tinnitus than hearing loss, were associated with Exp4, EverPile and DaysWTC (Table 4). Similar patterns, but higher risk of ear pain, were observed with Exp4, ever working on the debris pile and number of days worked on the WTC site (Table 5). Cox proportional hazards sensitivity analyses accounting for time-to-event produced stronger results (Table 7), similar to the odds ratios from logistic analyses of WTC exposures and noise (Table 8). The log binomial regression analyses produced more conservative (lower) estimates than the logistic regression analyses (Table 8). The sensitivity analyses limited to members with two or more monitoring visits produced similar results to the analyses including

members with a single monitoring visit (data not shown). For example, the association of persistent hearing loss and intermediate Exp4 without WTC noise exposure was ARR 1.10 (1.01, 1.19 when limited to members with ≥2 visits; the full sample was ARR 1.11 [1.02, 1.21]). For very high Exp4 with WTC noise exposure, members with ≥2 visits had ARR 1.52 (1.38, 1.69; the full sample had ARR 1.58 [1.43, 1.76]). Sensitivity analyses using multiple imputation of missing values for covariates also produced almost identical results as the main analyses assigning the missing values to the mode value for the all outcomes (data not shown). For example, the adjusted risk ratio for the association of persistent hearing loss and intermediate (Exp4) without noise was ARR 1.12 (1.09, 1.15) and for very high Exp4 with WTC noise exposure was ARR 1.59 (1.54, 1.65).

Compared to members engaged in protective services the day before the attack, all members reporting other occupations, particularly those engaged in construction work or who reported being unemployed or retired, had higher risk of hearing loss (Table 2), tinnitus (Table 4) and ear pain (Table 5). The results of primary outcome sensitivity analyses excluding occupational status (data not shown) were almost identical (for hearing loss, intermediate Exp4 without WTC noise ARR 1.12 [1.03, 1.22], and very high Exp4 with WTC noise ARR 1.51 [1.36, 1.68]).

## DISCUSSION

This study found GRC members with more intense WTC exposures and WTC noise exposure had significantly elevated risk of persistent, post-September 11$^{th}$, 2001 incident hearing loss, tinnitus and ear pain. The results of our sensitivity analyses were similar. Our results in GRC members without WTC noise exposure are also consistent with the direction and magnitude of the associations observed in studies of people who had WTC exposures, including FDNY firefighters

and emergency medical service (EMS) workers, disaster-affected area non-responders, as well as WTC Health Registry rescue and recovery workers.[28-32] Among the GRC sample, the risk was greatest for those with high and very high WTC exposure who were also exposed to noise while working on the WTC effort. Similarly, for the WTC Health Registry studies, the highest rates of hearing impairment were found in those who had dust cloud exposure during which they reported being unable to hear.[29,30] The shorter observation time between first and last visits in members without hearing impairment does not reflect under-identification among them as their retrospective reporting period began from their date of birth (per the questions "have you ever had"). Case follow-up time-to-event was substantially shorter than the follow-up times of members without hearing impairment so follow-up duration was unlikely to meaningfully bias the results, as reflected in the proportional hazards results.

Evidence suggests noise exposure increases the risk of hearing impairment and exacerbates the effects of other environmental exposures.[8,14,15] Members employed in construction, telecommunications and other installation and repair, and in transportation and material moving before the attack may also have had past occupational exposure to noise and hand-arm vibration that contributed to their hearing impairment, however excluding occupation on September 10, 2001 from the log binomial analyses did not meaningfully change the associations.[15,40] These members had elevated risks of hearing loss compared to members occupied in protective services. While military service has been associated with increased risk of hearing loss, very few members were engaged in protective services were in jobs directly related to the military on September 10, 2001.[12] Some evidence suggests exposure to air pollution and solvents such as those present in the WTC collapse are also associated with hearing impairment.[8,16] Thus, the associations observed

between WTC exposures and hearing impairment are coherent with biologic mechanisms leading to hearing impairment.

The study strengths include a twenty-two year cohort of nearly 50,000 members. The data are captured by five clinical centers that serve WTC responders in the New York – New Jersey – Connecticut tristate area. The cohort sample size supported the assessment of the adjusted log binomial regression analyses producing reasonably tight confidence limits. The only WTC exposure ARRs to cross the null value for the associations of WTC exposure with hearing loss, tinnitus and ear pain was the sparse category of GRC members who had very high Exp4 but no WTC noise. The strength of the associations were similar for hearing loss and ear pain, with weaker associations observed for tinnitus. However consistent dose-response patterns of level and duration with WTC noise exposures were evident across all analyses. We believe our results are generalizable to the full GRC as 92% attending monitoring visits between July 1, 2002 and June 30, 2024 consented to their data being used for research, with 89% included in these analyses and results.

The study weaknesses include the use of self-reported outcomes, possible under-adjustment of potential confounders, and lack of direct evidence to explain the mechanisms of hearing impairment. Most of the evidence regarding the associations of WTC exposures and hearing problems is based upon self-reported outcomes.[28-31] While agreement between self-reported and audiometric assessment of hearing loss varies somewhat by age, sex and race, it is a more objective measure than self-reported status with an accuracy generally above 70%.[41] One study conducted in FDNY firefighters and EMS workers compared the results of examinations, conducted in sound booths within two years of WTC exposure and the last examination before September 11th, 2001, of pure-tone audiograms using supra-aural ear-phones.[32] That study found

smaller associations of short-term low and high frequency hearing loss than we observed with Exp4 and WTC noise, similar to those we observed with Exp4 in GRC without WTC noise exposure. The consistency of the associations of WTC exposures with both self-reported and examination-based hearing loss and the stronger joint associations of WTC- noise and other WTC exposures also supports the validity of our self-reported outcomes and results.

Our analyses adjusted for occupation on September 10, 2001 as a surrogate measure of occupational exposures. The analyses did not adjust for comorbidities other than having overweight or obese status at the members' first monitoring visit. The Exp4 WTC noise associations from our unadjusted models were somewhat suppressed by the adjusted analyses confounder variables. Nevertheless, our data were insufficiently sound to adjust for other occupational exposures and head injury, and we did not have information regarding risk factors such as genetic susceptibility or premature birth.

Noise can mechanically, ischemically and/or metabolically damage the inner ear sensory hair cells and cause permanent or temporary hearing impairment.[7] The fact that exposure to WTC noise systematically increased the risk of hearing impairment above and beyond that of level and duration of WTC exposures suggests some increased risk may be due to acceleration of sensorineural impairment. Our data cannot directly test the mechanisms leading to hearing loss in the GRC.

## CONCLUSIONS

Current evidence indicates that the level of GRC on-site WTC work and WTC-related noise exposures is associated with increased risk and incidence of hearing loss. Twenty-five percent of GRC reported persistent hearing loss and forty percent reported some hearing impairment. The

associations for WTC exposure and increased risk of hearing loss, with its broad health and social consequences, are consistent across the general responders, FDNY firefighters and EMS workers, and the WTC Health Registry members. This study clarifies the importance of WTC- noise exposure when evaluating the effects of WTC exposures on hearing loss.

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## FIGURE LEGENDS

**Figure 1.** Distribution of Incident, Persistent Hearing Loss, Tinnitus and Ear Pain on or after September 11, 2001

**Figure 2.** Adjusted Relative Risk for Incident Hearing Loss on or after September 11th by Exp4 WTC Composite Exposure Levels and WTC Noise Exposure

**Figure 3.** Cumulative Incidence of Persistent Hearing Loss, Tinnitus and Ear Pain in the World Trade Center General Responder Cohort

**Figure 1**

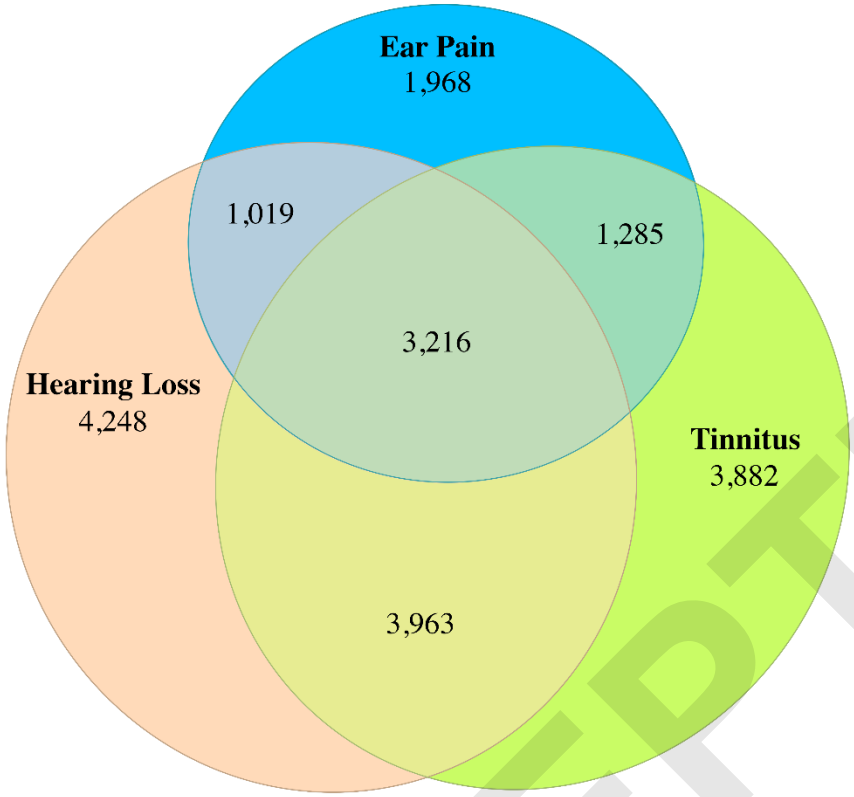


**Figure 2**

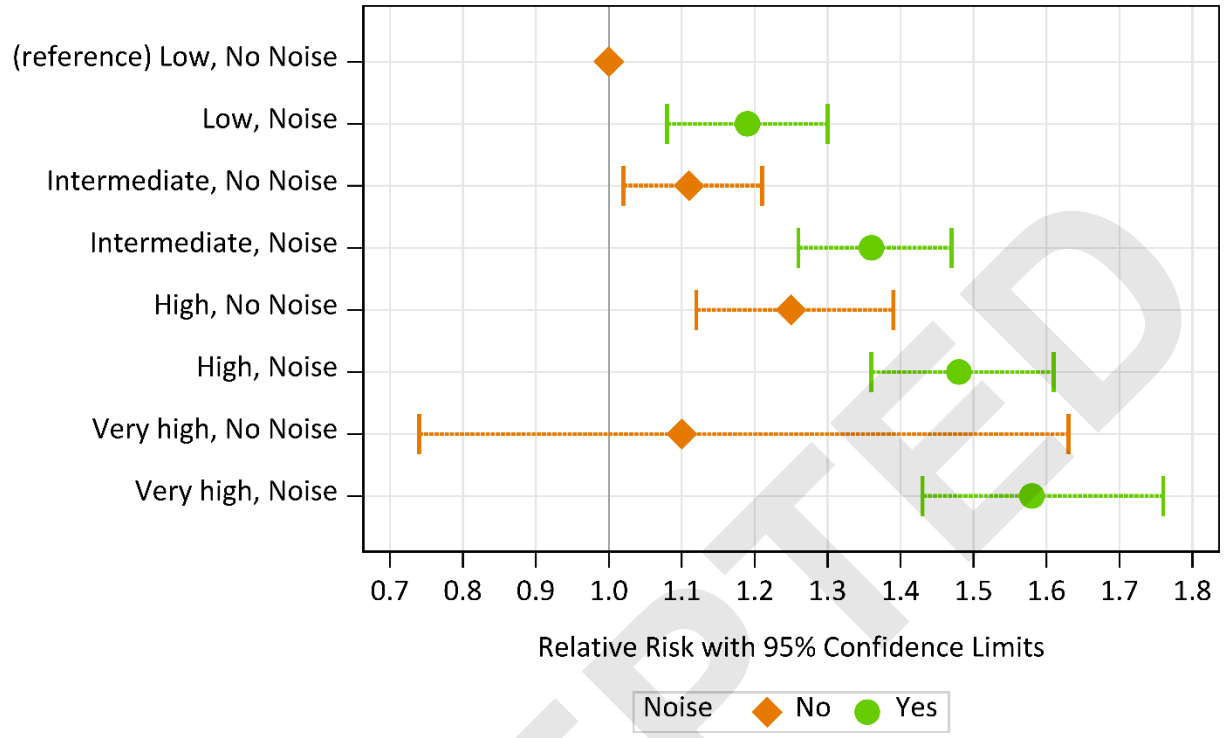
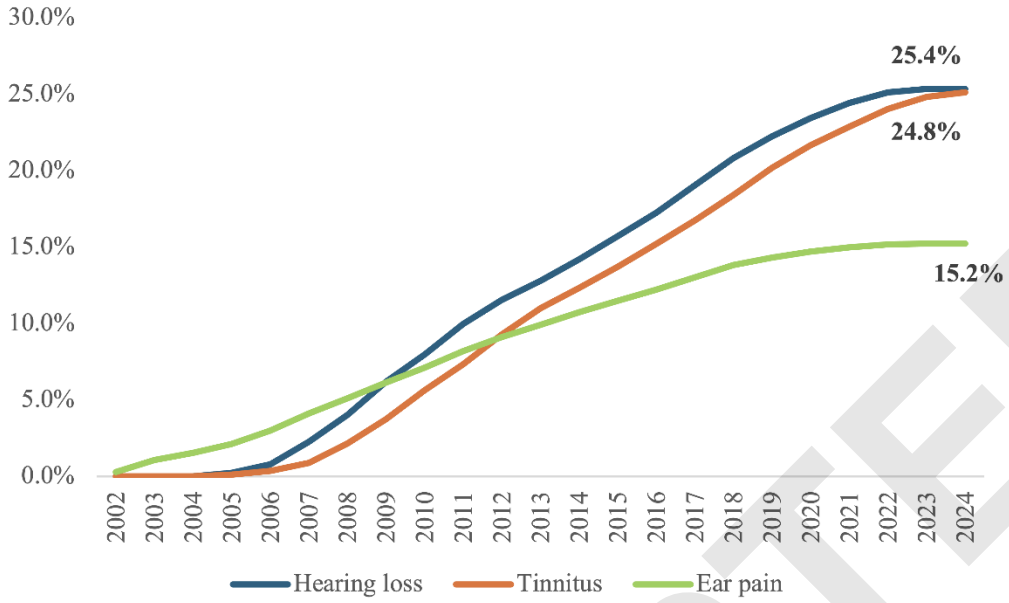


**Figure 3**



T**ABLE 1.** Classification of Levels for Composite Measure of World Trade Center (WTC) Exposures (Exp4)

| Exp4 Level | Was in the dust cloud | Worked on the debris pile | Total days worked on the WTC effort |
|---|---|---|---|
| Very high | Yes | Yes | >90 days |
| High | Yes | No | >90 days |
| High | Yes | Yes | ≤90 days |
| Intermediate | No | Yes | <40 days |
| Intermediate | No | No | ≥40 days |
| Low | No | No | <40 days |

**TABLE 2.** Sample Characteristics by Incident, Persistent Hearing Loss on or after September 11, 2001 (n=49,220)

| Characteristics | No (n =36, 741) n (%) [mean±sd] | Yes (n =12,479) n (%)[mean±sd] | Total (n =49,054) n (%) [mean±sd] |
|---|---|---|---|
| Age September 11, 2001 [mean±sd] (p≤0.001) | [37.4±8.5] | [41.0±8.9] | [38.3±8.7] |
| Age (years) at Visit 1 (p≤0.001) | | | |
| 20-29 | 969 (2.6) | 193 (1.5) | 1,162 (2.4) |
| 30-39 | 7,622 (20.7) | 1,951 (15.6) | 9,573 (19.4) |
| 40-49 | 13,340 (36.3) | 4,525 (36.3) | 17,865 (36.3) |
| 50-59 | 9,716 (26.4) | 3,805 (30.5) | 13,521 (27.5) |
| ≥60 | 5,094 (13.9) | 2,005 (16.1) | 7,099 (14.4) |
| Age (years) at hearing loss [mean±sd] | | [53.4±9.4] | |
| Age (years) at tinnitus [mean±sd]† | | [52.1±9.1] | |
| Age (years) at ear pain [mean±sd]†† | | [48.5±9.2] | |
| Observation time (years) at hearing loss [mean±sd] (p≤0.001) * | [7.9±6.7] | [12.1±6.1] | [9.0±6.8] |
| Observation (years) at tinnitus [mean±sd] (p≤0.001) *, † | [7.8±6.7] | [10.6±6.6] | [9.0±6.8] |
| Observation (years) at ear pain [mean±sd] (p≤0.001)*, †† | [7.8±6.7] | [11.4±6.4] | [9.0±6.8] |
| Follow-up time (years) at hearing loss [mean±sd] (p≤0.001) | [18.2±5.3] | [11.9±4.6] | [16.6±5.8] |
| Follow-up time (years) at tinnitus [mean±sd] (p≤0.001) **, † | [17.9±5.5] | [14.8±5.6] | [16.6±5.8] |
| Follow-up time (years) at ear pain [mean±sd] (p≤0.001) **, †† | [18.4±5.2] | [14.6±6.7] | [17.1±6.0] |
| Gender (p≤0.001) | | | |
| Male | 31,647 (86.1) | 11,026 (88.4) | 42,673 (86.7) |
| Female | 5,094 (13.9) | 1,453 (11.6) | 6,547 (13.3) |
| Race *** (p≤0.001) | | | |
| White | 18,708 (71.9) | 7,851 (76.6) | 26,559 (73.2) |
| Black | 3,391 (13.0) | 803 (7.8) | 4,194 (11.6) |
| Asian | 464 (1.8) | 121 (1.2) | 585 (1.6) |
| Other | 3,467 (13.3) | 1,470 (14.3) | 4,937 (13.6) |
| Hispanic ethnicity ***(p≤0.001) | | | |
| Non-Hispanic | 19,885 (76.5) | 7,882 (79.2) | 27,767 (77.3) |
| Hispanic | 6,099 (23.5) | 2,068 (20.8) | 8,167 (22.7) |
| Education *** (p≤0.001) | | | |
| <High school graduate | 2,004 (6.5) | 961 (8.4) | 2,965 (7.0) |
| High school graduate | 6,099 (19.6) | 2,677 (23.5) | 8,776 (20.7) |
| <Bachelor of art or science degree | 13,081 (42.1) | 4,651 (40.8) | 17,732 (41.8) |
| Bachelor of art or science graduate | 9,877 (31.8) | 3,116 (27.3) | 12,993 (30.6) |
| Body Mass Index at visit 1 *** (p≤0.001) | | | |

| | | | |
|---|---|---|---|
| <25 | 5,133 (14.5) | 1,540 (12.8) | 6,673 (14.1) |
| 25-<30 | 14,643 (41.3) | 5,007 (41.5) | 19,650 (41.4) |
| ≥30 | 15,661 (44.2) | 5,509 (45.7) | 21,170 (44.6) |
| Cigarette smoking status before hearing loss (cases) or at last visit (non-cases) *** (p≤0.001) | | | |
| Never smoker | 21,948 (64.3) | 5,057 (55.4) | 27,005 (62.5) |
| Former smoker | 9,405 (27.6) | 2,902 (31.8) | 12,307 (28.5) |
| Current smoker | 2,756 (8.1) | 1,162 (12.7) | 3,918 (9.1) |
| Occupation on September 10, 2001 (p≤0.001) | | | |
| Protective services | 20,269 (55.2) | 5,377 (43.1) | 25,646 (52.1) |
| Construction | 5,302 (14.4) | 2,768 (22.2) | 8,070 (16.4) |
| Telecommunications & other installation & repair | 2,337 (6.4) | 1,033 (8.3) | 3,370 (6.8) |
| Transportation & material moving | 2,022 (5.5) | 832 (6.7) | 2,854 (5.8) |
| Other jobs | 5,083 (13.8) | 1,919 (15.4) | 7,002 (14.2) |
| Unemployed, retired | 414 (1.1) | 226 (1.8) | 640 (1.3) |
| Not reported | 1,314 (3.6) | 324 (2.6) | 1,638 (3.3) |
| Composite Exposure 4 Level (Exp4) † (p≤0.001) | | | |
| Low | 5,164 (15.2) | 1,432 (12.3) | 6,596 (14.5) |
| Intermediate | 22,032 (64.9) | 7,675 (66.2) | 29,707 (65.2) |
| High | 5,463 (16.1) | 1,984 (17.1) | 7,447 (16.4) |
| Very High | 1,278 (3.8) | 509 (4.4) | 1,787 (3.9) |
| Ever worked on the WTC debris pile (EverPile) (p≤0.001) | | | |
| No | 18,533 (53.2) | 5,882 (49.6) | 24,415 (52.3) |
| Yes | 16,272 (46.8) | 5,983 (50.4) | 22,255 (47.7) |
| Number of days worked on WTC effort (DaysWTC) (p≤0.001) | | | |
| <8 days | 6,781 (18.8) | 2,148 (17.5) | 8,929 (18.5) |
| 8 – 31 days | 8,043 (22.3) | 2,610 (21.2) | 10,653 (22.0) |
| 31 – 91 dayss | 10,928 (30.3) | 3,583 (29.1) | 14,511 (30.0) |
| >91 days | 10,320 (28.6) | 3,954 (32.2) | 14,274 (29.5) |
| Exposed to noise while working on WTC effort (p≤0.001) | | | |
| No | 10,509 (28.6) | 3,029 (24.3) | 13,538 (27.5) |
| Yes | 26,232 (71.4) | 9,450 (75.7) | 35,682 (72.5) |

DaysWTC: total days worked on WTC effort; EverPile: Ever worked on the WTC debris pile; Exp4 composite measure of WTC exposure; sd: standard deviation; WTC: World Trade Center

*Observation time: number of years between first and last monitoring visits

**Follow-up time: number of years from (cases) the first day worked until the outcome event or (non-cases) until the last visit

***Missing values for race (n = 12,969), ethnicity (n = 13,312), education (n = 6,771), BMI (n = 1,730) and smoking (n = 5,960) were excluded from column percents.

† n cases =12,379

†† n cases = n=7,490

†††Low Exp4= no dust cloud or debris pile exposure, worked <40 days on WTC effort

Intermediate Exp4 = no dust cloud, either had debris pile work and worked <40 days on the WTC effort or did not work on the debris pile and worked ≥40 days on WTC effort

High Exp4 = had dust cloud exposure, and either worked on the debris pile or worked on WTC effort >90 days

Very high Exp4 = had dust cloud exposure, worked on the debris pile and worked on WTC effort >90 days

**TABLE 3.** Adjusted* Risk Ratios (95% CI) for Incident Persistent Hearing Loss on or after September 11, 2001 associated with Occupation on September 10, 2001 and WTC exposure

| Occupation on September 10, 2001 and WTC exposure | Exp4† (n=45,537) ARR (95% CI) | EverPile (n=46,670) ARR (95% CI) | DaysWTC (n=48,367) ARR (95% CI) |
|---|---|---|---|
| Occupation on September 10, 2001 | | | |
| Protective services, military | 1.0 (Ref) | 1.0 (Ref) | 1.0 (Ref) |
| Construction | 1.60 (1.53, 1.67) | 1.60 (1.53, 1.66) | 1.57 (1.51, 1.64) |
| Telecommunications & other installation & repair | 1.41 (1.33, 1.50) | 1.44 (1.36, 1.53) | 1.40 (1.32, 1.49) |
| Transportation & material moving | 1.32 (1.23, 1.41) | 1.33 (1.25, 1.42) | 1.31 (1.23, 1.40) |
| Other jobs | 1.34 (1.27, 1.40) | 1.34 (1.28, 1.41) | 1.32 (1.26, 1.38) |
| Unemployed, retired | 1.71 (1.53, 1.91) | 1.70 (1.53, 1.90) | 1.72 (1.54, 1.91) |
| Not reported | 0.88 (0.76, 1.02) | 0.87 (0.75, 1.01) | 0.89 (0.78, 1.03) |
| Exp4† & WTC Noise Interaction | | | |
| Low exposure, no WTC Noise | 1.0 (Ref) | | |
| Intermediate, no WTC Noise | 1.11 (1.02, 1.21) | | |
| High exposure, no WTC Noise | 1.25 (1.12, 1.39) | | |
| Very high exposure, no WTC Noise | 1.10 (0.74, 1.63) | | |
| Low exposure, had WTC Noise | 1.19 (1.08, 1.30) | | |
| Intermediate exposure, had WTC Noise | 1.36 (1.26, 1.47) | | |
| High exposure, had WTC Noise | 1.48 (1.36, 1.61) | | |
| Very high exposure, had WTC Noise | 1.58 (1.43, 1.76) | | |
| Ever worked on WTC Pile & WTC Noise Interaction | | | |
| Never Pile, no WTC Noise | | 1.0 (Ref) | |
| Ever Pile, no WTC Noise | | 1.12 (1.05, 1.19) | |
| Never Pile, had WTC Noise | | 1.21 (1.15, 1.28) | |
| Ever Pile, had WTC Noise | | 1.38 (1.31, 1.46) | |
| Days on WTC effort & WTC Noise Interaction | | | |
| <8 Days, no WTC Noise | | | 1.0 (Ref) |
| 8-31 Days, no WTC Noise | | | 1.10 (1.02, 1.19) |

| | | |
|---|---|---|
| 32-91 Days, no WTC Noise | | 1.07 (0.97, 1.18) |
| >91 Days, no WTC Noise | | 1.15 (1.04, 1.27) |
| <8 Days, had WTC Noise | | 1.35 (1.26, 1.46) |
| 8-31 Days, had WTC Noise | | 1.28 (1.20, 1.36) |
| 32-91 Days, had WTC Noise | | 1.28 (1.21, 1.36) |
| >91 Days, had WTC Noise | | 1.35 (1.27, 1.43) |

AOR: Adjusted odds ratio; ARR: Adjusted relative risk; CI: Confidence interval; DaysWTC: total days worked on WTC effort; EverPile: Ever worked on the WTC debris pile; Exp4 composite measure of WTC exposure; WTC: World Trade Center*Adjusted for age, body mass index highest and level of education at first monitoring visit, sex, race, Hispanic ethnicity and cigarette smoking status before persistent hearing loss

†Low Exp4 = no dust cloud or debris pile exposure, worked <40 days on WTC effort
Intermediate Exp4 = no dust cloud, either had debris pile work and worked <40 days on the WTC effort or did not work on the debris pile and worked ≥40 days on WTC effort
High Exp4 = had dust cloud exposure, and either worked on the debris pile or worked on WTC effort >90 days
Very high Exp4 = had dust cloud exposure, worked on the debris pile and worked on WTC effort >90 days

**TABLE 4**. Adjusted* Risk Ratios (95% CI) for Incident Persistent Tinnitus on or after September 11, 2001 associated with Occupation on September 10, 2001 and WTC exposure

| Occupation on September 10, 2001 and WTC exposure | Exp4† (n=45,536) ARR (95% CI) | EverPile (n=46,669) ARR (95% CI) | DaysWTC (n=48,368) ARR (95% CI) |
|---|---|---|---|
| Occupation on September 10, 2001 | | | |
| Protective services, military | 1.0 (Ref) | 1.0 (Ref) | 1.0 (Ref) |
| Construction | 1.38 (1.32, 1.45) | 1.37 (1.31, 1.43) | 1.37 (1.31, 1.43) |
| Telecommunications & other installation & repair | 1.32 (1.24, 1.40) | 1.36 (1.28, 1.44) | 1.33 (1.25, 1.41) |
| Transportation & material moving | 1.20 (1.12, 1.29) | 1.22 (1.14, 1.30) | 1.21 (1.13, 1.29) |
| Other jobs | 1.28 (1.22, 1.34) | 1.28 (1.22, 1.34) | 1.27 (1.21, 1.33) |
| Unemployed, retired | 1.52 (1.35, 1.70) | 1.52 (1.35, 1.70) | 1.51 (1.35, 1.69) |
| Not reported | 0.88 (0.75, 1.02) | 0.86 (0.73, 1.00) | 0.90 (0.78, 1.04) |
| Exp4† & WTC Noise Interaction | | | |
| Low exposure, no WTC Noise | 1.0 (Ref) | | |
| Intermediate, no WTC Noise | 1.10 (1.01, 1.19) | | |
| High exposure, no WTC Noise | 1.09 (0.97, 1.21) | | |
| Very high exposure, no WTC Noise | 1.08 (0.73, 1.58) | | |
| Low exposure, had WTC Noise | 1.14 (1.04, 1.26) | | |
| Intermediate exposure, had WTC Noise | 1.25 (1.16, 1.35) | | |
| High exposure, had WTC Noise | 1.33 (1.22, 1.45) | | |
| Very high exposure, had WTC Noise | 1.33 (1.19, 1.48) | | |
| Ever worked on WTC Pile & WTC Noise Interaction | | | |
| Never Pile, no WTC Noise | | 1.0 (Ref) | |
| Ever Pile, no WTC Noise | | 1.05 (0.98, 1.12) | |
| Never Pile, had WTC Noise | | 1.14 (1.09, 1.20) | |
| Ever Pile, had WTC Noise | | 1.26 (1.1 , 1.32) | |
| Days on WTC effort & WTC Noise Interaction | | | |
| <8 Days, no WTC Noise | | | 1.0 (Ref) |
| 8-31 Days, no WTC Noise | | | 1.05 (0.97, 1.14) |

| | | |
|---|---|---|
| 32-91 Days, no WTC Noise | | 1.00 (0.90, 1.10) |
| >91 Days, no WTC Noise | | 1.11 (1.01, 1.22) |
| <8 Days, had WTC Noise | | 1.21 (1.12, 1.30) |
| 8-31 Days, had WTC Noise | | 1.21 (1.13, 1.29) |
| 32-91 Days, had WTC Noise | | 1.20 (1.12, 1.27) |
| >91 Days, had WTC Noise | | 1.23 (1.16, 1.31) |

ARR: Adjusted relative risk; CI: Confidence interval; DaysWTC: total days worked on WTC effort; EverPile: Ever worked on the WTC debris pile; Exp4 composite measure of WTC exposure; WTC: World Trade Center*Adjusted for age, body mass index highest and level of education at first monitoring visit, sex, race, Hispanic ethnicity and cigarette smoking status before persistent hearing loss

†Low Exp4= no dust cloud or debris pile exposure, worked <40 days on WTC effort
Intermediate Exp4 = no dust cloud, either had debris pile work and worked <40 days on the WTC effort or did not work on the debris pile and worked ≥40 days on WTC effort
High Exp4 = had dust cloud exposure, and either worked on the debris pile or worked on WTC effort >90 days
Very high Exp4 = had dust cloud exposure, worked on the debris pile and worked on WTC effort >90 days

**TABLE 5**. Adjusted* Risk Ratios (95% CI) for Incident Persistent Ear Pain on or after September 11, 2001 associated with Occupation on September 10, 2001 and WTC exposure

| Occupation on September 10, 2001 and WTC exposure | Exp4† (n=45,454) ARR (95% CI) | EverPile (n=46,618) ARR (95% CI) | DaysWTC (n=48,311) ARR (95% CI) |
|---|---|---|---|
| Occupation on September 10, 2001 | | | |
| Protective services, military | 1.0 (Ref) | 1.0 (Ref) | 1.0 (Ref) |
| Construction | 1.49 (1.41, 1.59) | 1.48 (1.40, 1.57) | 1.45 (1.37, 1.54) |
| Telecommunications & other installation & repair | 1.35 (1.23, 1.48) | 1.36 (1.24, 1.48) | 1.32 (1.21, 1.44) |
| Transportation & material moving | 1.37 (1.24, 1.51) | 1.37 (1.24, 1.51) | 1.34 (1.22, 1.47) |
| Other jobs | 1.38 (1.30, 1.47) | 1.38 (1.30, 1.46) | 1.36 (1.29, 1.45) |
| Unemployed, retired | 1.66 (1.46, 1.89) | 1.65 (1.45, 1.88) | 1.62 (1.43, 1.84) |
| Not reported | 0.79 (0.62, 1.02) | 0.76 (0.59, 0.98) | 0.78 (0.61, 0.99) |
| Exp4† & WTC Noise Interaction | | | |
| Low exposure, no WTC Noise | 1.0 (Ref) | | |
| Intermediate, no WTC Noise | 1.19 (1.05, 1.36) | | |
| High exposure, no WTC Noise | 1.21 (1.02, 1.43) | | |
| Very high exposure, no WTC Noise | 1.63 (1.01, 2.61) | | |
| Low exposure, had WTC Noise | 1.40 (1.22, 1.61) | | |
| Intermediate exposure, had WTC Noise | 1.54 (1.37, 1.74) | | |
| High exposure, had WTC Noise | 1.63 (1.43, 1.85) | | |
| Very high exposure, had WTC Noise | 1.89 (1.62, 2.20) | | |
| Ever worked on WTC Pile & WTC Noise Interaction | | | |
| Never Pile, no WTC Noise | | 1.0 (Ref) | |
| Ever Pile, no WTC Noise | | 1.02 (0.92, 1.13) | |
| Never Pile, had WTC Noise | | 1.26 (1.17, 1.35) | |
| Ever Pile, had WTC Noise | | 1.46 (1.36, 1.57) | |
| Days on WTC effort & WTC Noise Interaction | | | |
| <8 Days, no WTC Noise | | | 1.0 (Ref) |
| 8-31 Days, no WTC Noise | | | 1.18 (1.04, 1.34) |

| | | |
|---|---|---|
| 32-91 Days, no WTC Noise | | 1.15 (1.00, 1.32) |
| >91 Days, no WTC Noise | | 1.42 (1.24, 1.62) |
| <8 Days, had WTC Noise | | 1.54 (1.37, 1.72) |
| 8-31 Days, had WTC Noise | | 1.54 (1.39, 1.70) |
| 32-91 Days, had WTC Noise | | 1.54 (1.40, 1.69) |
| >91 Days, had WTC Noise | | 1.58 (1.43, 1.74) |

ARR: Adjusted relative risk; CI: Confidence interval; DaysWTC: total days worked on WTC effort; EverPile: Ever worked on the WTC debris pile; Exp4 composite measure of WTC exposure; WTC: World Trade Center

*Adjusted for age, body mass index highest and level of education at first monitoring visit, sex, race, Hispanic ethnicity and cigarette smoking status before persistent hearing loss

†Low Exp4= no dust cloud or debris pile exposure, worked <40 days on WTC effort
Intermediate Exp4 = no dust cloud, either had debris pile work and worked <40 days on the WTC effort or did not work on the debris pile and worked ≥40 days on WTC effort
High Exp4 = had dust cloud exposure, and either worked on the debris pile or worked on WTC effort >90 days
Very high Exp4 = had dust cloud exposure, worked on the debris pile and worked on WTC effort >90 days

**TABLE 6** WTC exposure measure sample sizes (cases and non-cases), by outcomes

| | | Hearing loss | Tinnitus | Ear Pain |
|---|---|---|---|---|
| | **WTC Exposure** | **n** | **n** | **n** |
| Exp4* | Low exposure, no WTC Noise | 2761 | 2763 | 2757 |
| | Intermediate, no WTC Noise | 7081 | 7081 | 7078 |
| | High exposure, no WTC Noise | 1897 | 1899 | 1895 |
| | Very high exposure, no WTC Noise | 103 | 103 | 103 |
| | Low exposure, had WTC Noise | 3835 | 3834 | 3834 |
| | Intermediate exposure, had WTC Noise | 22626 | 22623 | 22601 |
| | High exposure, had WTC Noise | 5550 | 5549 | 5548 |
| | Very high exposure, had WTC Noise | 1684 | 1684 | 1679 |
| EverPile | Never Pile, no WTC Noise | 7067 | 7068 | 7058 |
| | Ever Pile, no WTC Noise | 5069 | 5071 | 5065 |
| | Never Pile, had WTC Noise | 17348 | 17346 | 17329 |
| | Ever Pile, had WTC Noise | 17186 | 17184 | 17166 |
| DaysWTC | <8 Days, no WTC Noise | 5338 | 5340 | 5331 |
| | 8-31 Days, no WTC Noise | 3405 | 3405 | 3401 |
| | 32-91 Days, no WTC Noise | 2117 | 2119 | 2116 |
| | ≥92 Days, no WTC Noise | 1845 | 1845 | 1841 |
| | <8 Days, had WTC Noise | 3591 | 3593 | 3591 |
| | 8-31 Days, had WTC Noise | 7248 | 7246 | 7243 |
| | 32-91 Days, had WTC Noise | 12394 | 12392 | 12388 |
| | ≥92 Days, had WTC Noise | 12429 | 12428 | 12400 |

DaysWTC: total days worked on WTC effort; EverPile, Ever worked on the WTC debris pile; Exp4 composite measure of WTC exposure; WTC: World Trade Center

*Low Exp4= no dust cloud or debris pile exposure, worked <40 days on WTC effort
Intermediate Exp4 = no dust cloud, either had debris pile work and worked <40 days on the WTC effort or did not work on the debris pile and worked ≥40 days on WTC effort
High Exp4 = had dust cloud exposure, and either worked on the debris pile or worked on WTC effort >90 days
Very high Exp4 = had dust cloud exposure, worked on the debris pile and worked on WTC effort >90 days

**TABLE 7.** Cox Proportional Hazards Ratios of Time-to-Event Model 1 Adjusted* Exp4† - WTCNoise Interaction Odds Ratios (95% Confidence Intervals) for Incident Persistent Hearing Loss, Tinnitus and Ear Pain on or after September 11, 2001

| Exp4†-WTCNoise | Hearing loss (n=45,397)‡ HR (95% CI) | Tinnitus (n=45,396) ‡ HR (95% CI) | Ear Pain (n=45,355) ‡ HR (95% CI) |
|---|---|---|---|
| Low exposure, no WTC Noise | 1.0 (Ref) | 1.0 (Ref) | 1.0 (Ref) |
| Intermediate, no WTC Noise | 1.13 (1.03, 1.25) | 1.12 (1.02, 1.24) | 1.22 (1.06, 1.41) |
| High exposure, no WTC Noise | 1.32 (1.17, 1.50) | 1.12 (0.99, 1.27) | 1.24 (1.03, 1.49) |
| Very high exposure, no WTC Noise | 1.11 (0.71, 1.73) | 1.09 (0.70, 1.68) | 1.69 (1.01, 2.85) |
| Low exposure, had WTC Noise | 1.31 (1.18, 1.46) | 1.25 (1.12, 1.38) | 1.51 (1.30, 1.75) |
| Intermediate exposure, had WTC Noise | 1.58 (1.45, 1.72) | 1.42 (1.30, 1.55) | 1.73 (1.53, 1.97) |
| High exposure, had WTC Noise | 1.79 (1.62, 1.97) | 1.56 (1.42, 1.73) | 1.86 (1.62, 2.14) |
| Very high exposure, had WTC Noise | 1.93 (1.71, 2.18) | 1.57 (1.38, 1.78) | 2.21 (1.87, 2.61) |

Exp4: four level composite measure of WTC exposure; HR: hazards ratio; WTC: World Trade Center; HR: Hazards Ratio

*Adjusted for age, body mass index highest and level of education at first monitoring visit, sex, race, Hispanic ethnicity and cigarette smoking status before persistent hearing loss

†Low Exp4= no dust cloud or debris pile exposure, worked <40 days on WTC effort
Intermediate Exp4 = no dust cloud, either had debris pile work and worked <40 days on the WTC effort or did not work on the debris pile and worked ≥40 days on WTC effort
High Exp4 = had dust cloud exposure, and either worked on the debris pile or worked on WTC effort >90 days
Very high Exp4 = had dust cloud exposure, worked on the debris pile and worked on WTC effort >90 days

‡140 missing observations of responders with unknown first dates of work on the WTC effort

A Longitudinal Assessment of Hearing Loss in the World Trade Center General Responder Cohort STROBE Statement—Checklist of items that should be included in reports of ***cohort studies***



| | Item No | Recommendation | Page No |
|---|---|---|---|
| **Title and abstract** | 1 | (*a*) Indicate the study's design with a commonly used term in the title or the abstract | 1 |
| | | (*b*) Provide in the abstract an informative and balanced summary of what was done and what was found | 1 |
| **Introduction** | | | |
| Background/rationale | 2 | Explain the scientific background and rationale for the investigation being reported | 3-4 |
| Objectives | 3 | State specific objectives, including any prespecified hypotheses | 4 |
| **Methods** | | | |
| Study design | 4 | Present key elements of study design early in the paper | 4-9 |
| Setting | 5 | Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection | 4-6 |
| Participants | 6 | (*a*) Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up | 5-7 |
| | | (*b*) For matched studies, give matching criteria and number of exposed and unexposed | NA |
| Variables | 7 | Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable | 6-7 |
| Data sources/ measurement | 8* | For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group | 5-8 |
| Bias | 9 | Describe any efforts to address potential sources of bias | 8-9 |
| Study size | 10 | Explain how the study size was arrived at | 5 9 |
| Quantitative variables | 11 | Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why | 6-9 |
| Statistical methods | 12 | (*a*) Describe all statistical methods, including those used to control for confounding | 8-9 |
| | | (*b*) Describe any methods used to examine subgroups and interactions | 8 |
| | | (*c*) Explain how missing data were addressed | 5-8 |
| | | (*d*) If applicable, explain how loss to follow-up was addressed | 8-9 |

| | | | |
|---|---|---|---|
| | | (*e*) Describe any sensitivity analyses | 8 |
| **Results** | | | |
| Participants | 13* | (a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed | 5-7 |
| | | (b) Give reasons for non-participation at each stage | 5-7 |
| | | (c) Consider use of a flow diagram | |
| Descriptive data | 14* | (a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders | 9 |
| | | (b) Indicate number of participants with missing data for each variable of interest | 5-7 |
| | | (c) Summarise follow-up time (eg, average and total amount) | 9 |
| Outcome data | 15* | Report numbers of outcome events or summary measures over time | 9; Tables 2-8 |
| Main results | 16 | (*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included | 9-12; Tables 2 – 8 |
| | | (*b*) Report category boundaries when continuous variables were categorized | NA |
| | | (*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period | |
| Other analyses | 17 | Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses | 10-12 |
| **Discussion** | | | |
| Key results | 18 | Summarise key results with reference to study objectives | 12 |
| Limitations | 19 | Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias | 13-15 |
| Interpretation | 20 | Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence | 15 |
| Generalisability | 21 | Discuss the generalisability (external validity) of the study results | 13-15 |
| **Other information** | | | |
| Funding | 22 | Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based | Title page |

**Authors' Note regarding AI:** AI was not utilized by any author in any stage or for any part of the hypothesis development or design, data collection, data evaluation or manuscript preparation.

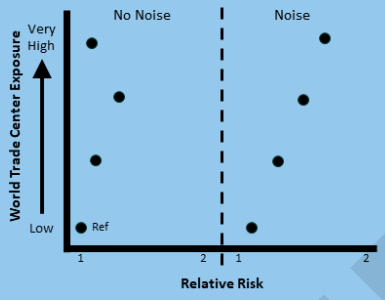
*Give information separately for exposed and unexposed groups.

**Note:** An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at http://www.strobe-statement.org.

World Trade Center (WTC) general responder cohort has increased risk of persistent hearing loss associated with intensity of WTC exposures and WTC noise

20% of adults have hearing loss

Hearing loss can :
- Increase social isolation
- Harm economic status
- Hinder communication
- Increase disability
- Increase death risk




WTC noise exposure increased hearing loss. Exposure to WTC noise should be considered when evaluating WTC exposures on hearing loss.

**A Longitudinal Assessment of Hearing Loss in the World Trade Center General Responder Cohort**

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