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

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Abstract

Objective: In analyses without adjustment for World Trade Center (WTC) noise exposure, people with WTC and neighborhood exposures from the September 11, 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 with 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

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, posttraumatic 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} and 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 3 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 nonresponders 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 New York City Fire Department (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 with 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 11, 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 11, 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 sociodemographic 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 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 ($n = 2028$), 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 12 or more months apart. Persistence of the hearing outcomes was classified as reported experience of the condition on at least two occasions that were 10 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 ($n = 2778$), EverPile ($n = 2553$), 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 attack (protective services; protective services), and cigarette smoking status (nonsmoker; nonsmoker) prior to the earliest outcome date. Missing data for occupation ($n = 1640$) 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 $n = 6771$; BMI $n = 1730$; smoking $n = 5960$).

Comorbidities and Occupational Exposures

While persistent headaches, 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 overspecification, 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 6889 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 $\geq 90\%$ statistical power. To compare our results with those published for other WTC responders and for disaster-affected area nonresponders, 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). 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 ($\pm$ 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 noncases (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 (noncases) 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 (Fig. 1). Of those studied, 12,479 (25.4%) reported persistent hearing loss, 12,379 (25.1%) reported persistent tinnitus, and 7490 (15.2%) reported persistent ear pain (Fig. 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 sociodemographic 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 10, 2001, had higher risks of hearing loss, tinnitus, and ear pain (Tables 3–5).

Without considering other measures of WTC exposure, exposure to noise while working on the WTC effort increased the risk of incident hearing loss (adjusted relative risk [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, Fig. 2), tinnitus (Table 4), and ear pain (Table 5).

Compared with 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 with 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, 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 EMS workers, disaster-affected area nonresponders, 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 underidentification 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 that 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 with members occupied in protective services. While military service has been associated with increased risk of hearing loss, very few members who 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 22-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 was 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 that 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 underadjustment 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 2 years of WTC exposure and the last examination before September 11, 2001, of pure-tone audiograms using supra-aural earphones.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 40% reported some persistent 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.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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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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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

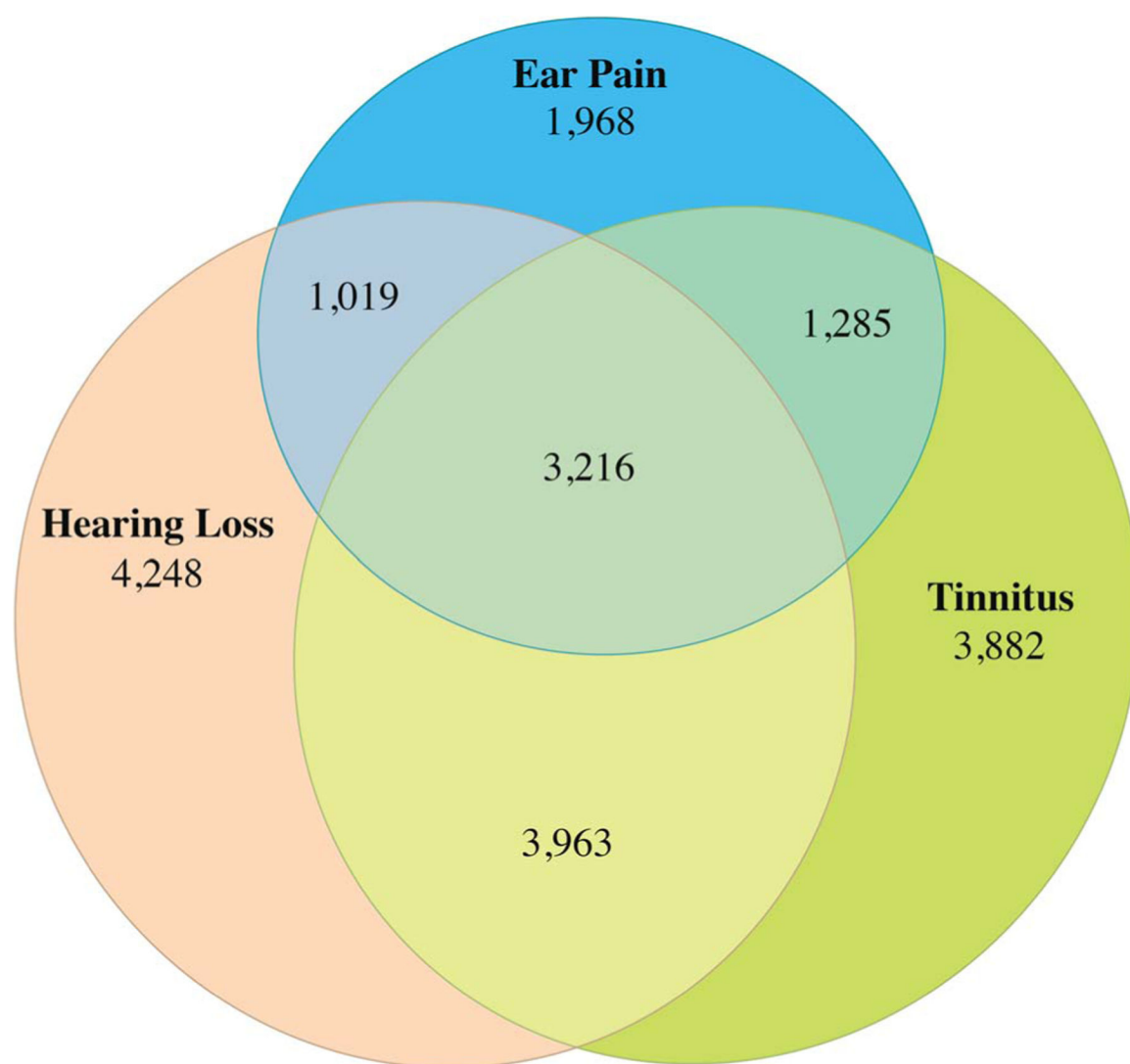


FIGURE 1.
Distribution of incident, persistent hearing loss, tinnitus, and ear pain on or after September 11, 2001.

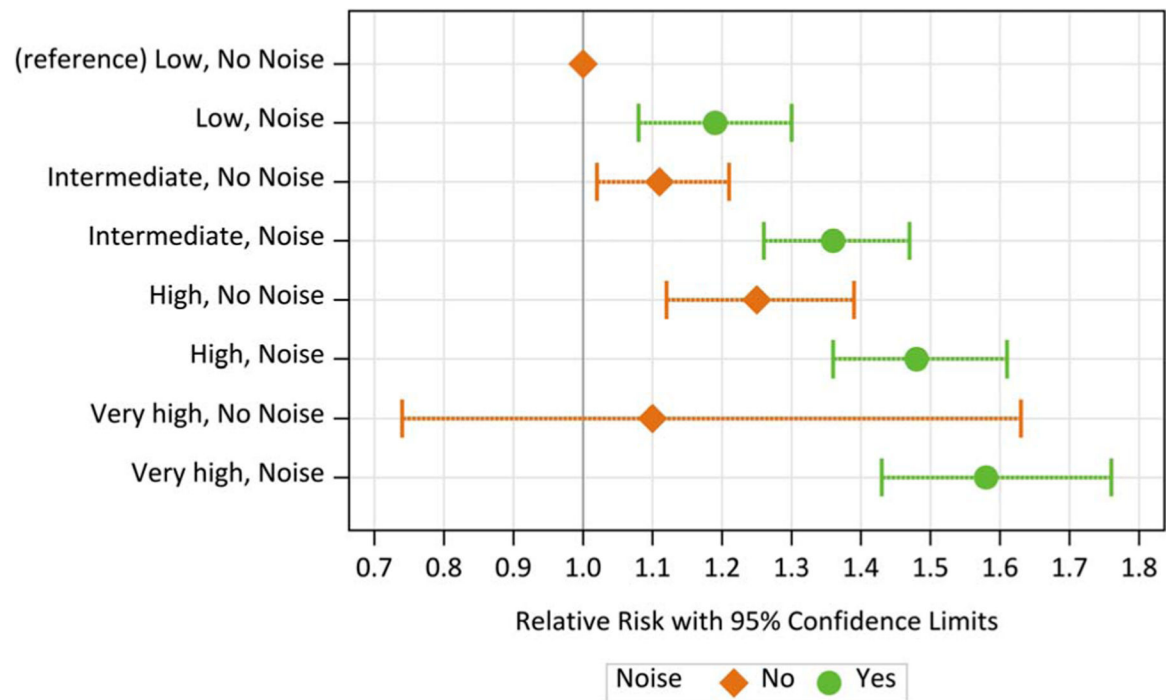


FIGURE 2.

Adjusted relative risk for incident hearing loss on or after September 11 by Exp4 WTC composite exposure levels and WTC noise exposure.

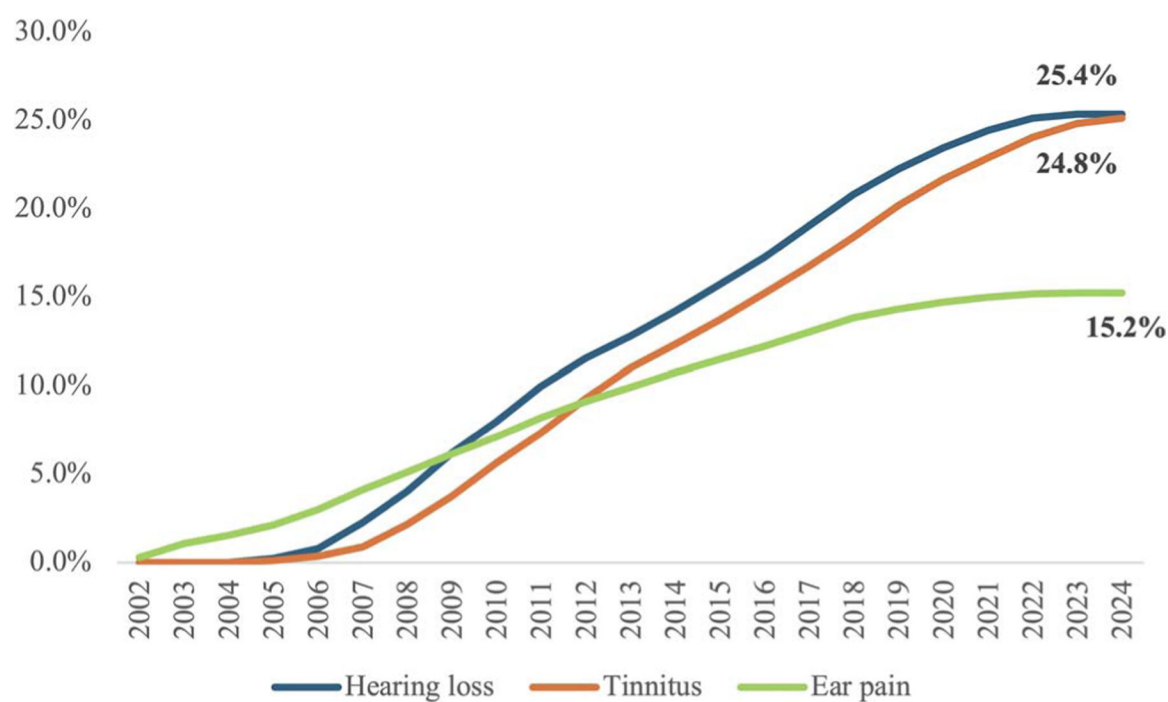


FIGURE 3.
Cumulative incidence of persistent hearing loss, tinnitus, and ear pain in the World Trade Center General Responder Cohort.

TABLE 1.

Classification of Levels for Composite Measure of 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

WTC, World Trade Center.

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 $\pm$ SD]	Yes $(n = 12,479)$ n (%) [mean $\pm$ SD]	Total $(N = 49,054)$ n (%) [mean $\pm$ SD]
Age September 11, 2001 [mean $\pm$ SD] ($P \leq 0.001$)	[37.4 $\pm$ 8.5]	[41.0 $\pm$ 8.9]	[38.3 $\pm$ 8.7]
Age (years) at visit 1 ($P \leq 0.001$)			
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 $\pm$ SD]		[53.4 $\pm$ 9.4]	
Age (years) at tinnitus [mean $\pm$ SD] [†]		[52.1 $\pm$ 9.1]	
Age (years) at ear pain [mean $\pm$ SD] ^{††}		[48.5 $\pm$ 9.2]	
Observation time (years) at hearing loss [mean $\pm$ SD] ($P \leq 0.001$) [*]	[7.9 $\pm$ 6.7]	[12.1 $\pm$ 6.1]	[9.0 $\pm$ 6.8]
Observation (years) at tinnitus [mean $\pm$ SD] ($P \leq 0.001$) [*] , [†]	[7.8 $\pm$ 6.7]	[10.6 $\pm$ 6.6]	[9.0 $\pm$ 6.8]
Observation (years) at ear pain [mean $\pm$ SD] ($P \leq 0.001$) [*] , ^{††}	[7.8 $\pm$ 6.7]	[11.4 $\pm$ 6.4]	[9.0 $\pm$ 6.8]
Follow-up time (years) at hearing loss [mean $\pm$ SD] ($P \leq 0.001$)	[18.2 $\pm$ 5.3]	[11.9 $\pm$ 4.6]	[16.6 $\pm$ 5.8]
Follow-up time (years) at tinnitus [mean $\pm$ SD] ($P \leq 0.001$) ^{**} , [†]	[17.9 $\pm$ 5.5]	[14.8 $\pm$ 5.6]	[16.6 $\pm$ 5.8]
Follow-up time (years) at ear pain [mean $\pm$ SD] ($P \leq 0.001$) ^{**} , ^{††}	[18.4 $\pm$ 5.2]	[14.6 $\pm$ 6.7]	[17.1 $\pm$ 6.0]
Gender ($P \leq 0.001$)			
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 ^{***} ($P \leq 0.001$)			
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 ^{***} ($P \leq 0.001$)			

Characteristics	No		Yes		Total	
	<i>n</i> (%) [mean $\pm$ SD]		<i>n</i> (%) [mean $\pm$ SD]		<i>n</i> (%) [mean $\pm$ SD]	
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 *** ($P \leq 0.001$)						
<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 *** ($P \leq 0.001$)						
<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 (noncases) *** ($P \leq 0.001$)						
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 ($P \leq 0.001$)						
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 and other installation and repair	2,337 (6.4)		1,033 (8.3)		3,370 (6.8)	
Transportation and 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) $\dagger$ ($P \leq 0.001$)						
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)	

Characteristics	No		Yes		Total	
	(n = 36, 741)		(n = 12,479)		(N = 49,054)	
	n (%)	[mean ± SD]	n (%)	[mean ± SD]	n (%)	[mean ± SD]
Ever worked on the WTC debris pile (EverPile) ($P \leq 0.001$)						
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)
No. days worked on WTC effort (DaysWTC) ($P \leq 0.001$)						
<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 days	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 ($P \leq 0.001$)						
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; 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 (noncases) 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.

† Number of cases = 12,379.

†† Number of 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 and other installation and repair	1.41 (1.33, 1.50)	1.44 (1.36, 1.53)	1.40 (1.32, 1.49)
Transportation and 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† and 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 and WTC noise interaction		1.0 (Ref)	
Never pile, no WTC noise		1.12 (1.05, 1.19)	
Ever pile, no WTC noise		1.21 (1.15, 1.28)	
Never pile, had WTC noise		1.38 (1.31, 1.46)	
Ever pile, had WTC noise			
Days on WTC effort and 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)

Occupation on September 10, 2001, and WTC exposure	<u>Exp4^f (n = 45,537)</u>		<u>EverPile (n = 46,670)</u>		<u>DaysWTC (n = 48,367)</u>	
	ARR (95% CI)		ARR (95% CI)		ARR (95% CI)	
>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)	

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.

^f 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 and other installation and repair	1.32 (1.24, 1.40)	1.36 (1.28, 1.44)	1.33 (1.25, 1.41)
Transportation and 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† and 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 and 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 and 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)

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)
>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 9/11.

[†] 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 and other installation and repair	1.35 (1.23, 1.48)	1.36 (1.24, 1.48)	1.32 (1.21, 1.44)
Transportation and 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 [†] and 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 and 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 and 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)

Occupation on September 10, 2001, and WTC exposure	Exp4 ^f (n = 45,454) ARR (95% CI)	EverPile (n = 46,618) ARR (95% CI)	DaysWTC (n = 48,311) ARR (95% CI)
>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 ear pain

^f 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 Noncases), by Outcomes

	WTC Exposure	Hearing Loss		Tinnitus		Ear Pain	
		n	n	n	n	n	n
Exp4*	Low exposure, no WTC noise	2,761	2,763	2,763	2,757		
	Intermediate, no WTC noise	7,081	7,081	7,081	7,078		
	High exposure, no WTC noise	1,897	1,899	1,899	1,895		
	Very high exposure, no WTC noise	103	103	103	103		
	Low exposure, had WTC noise	3,835	3,834	3,834	3,834		
	Intermediate exposure, had WTC noise	22,626	22,623	22,623	22,601		
EverPile	High exposure, had WTC noise	5,550	5,549	5,549	5,548		
	Very high exposure, had WTC noise	1,684	1,684	1,684	1,679		
	Never pile, no WTC noise	7,067	7,068	7,068	7,058		
	Ever pile, no WTC noise	5,069	5,071	5,071	5,065		
	Never pile, had WTC noise	17,348	17,346	17,346	17,329		
	Ever pile, had WTC noise	17,186	17,184	17,184	17,166		
DaysWTC	<8 days, no WTC noise	5,338	5,340	5,340	5,331		
	8–31 days, no WTC noise	3,405	3,405	3,405	3,401		
	32–91 days, no WTC noise	2,117	2,119	2,119	2,116		
	≥92 days, no WTC noise	1,845	1,845	1,845	1,841		
	<8 days, had WTC noise	3,591	3,591	3,593	3,591		
	8–31 days, had WTC noise	7,248	7,246	7,246	7,243		
	32–91 days, had WTC noise	12,394	12,392	12,392	12,388		
	≥92 days, had WTC noise	12,429	12,428	12,428	12,400		

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	Tinnitus	Ear Pain
	(n = 45,397) [†] HR (95% CI)	(n = 45,396) [†] HR (95% CI)	(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.

* 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, tinnitus or ear pain

[†] 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.

[†] One hundred forty missing observations of responders with unknown first dates of work on the WTC effort.

TABLE 8.

Adjusted* Exp4[†] - WTC Noise Interaction with Covariate and Comorbidity Relative Risk and Odds Ratios (95% CI) for Incident Persistent Hearing Loss, Tinnitus, and Ear Pain on or after September 11, 2001

Characteristic	Hearing Loss (n=45,537)		Tinnitus (n=45,536)		Ear Pain (n=45,495)	
	ARR (95% CI)	AOR (95% CI)	ARR (95% CI)	AOR (95% CI)	ARR (95% CI)	AOR (95% CI)
Age (years) at visit 1						
20-29	1.0 (Ref)	1.0 (Ref)	1.0 (Ref)			
30-39	1.36 (1.19, 1.56)	1.50 (1.27, 1.78)	1.30 (1.15, 1.46)	1.43 (1.22, 1.67)	1.18 (1.04, 1.33)	1.24 (1.05, 1.47)
40-49	1.73 (1.52, 1.98)	2.07 (1.76, 2.45)	1.45 (1.29, 1.63)	1.65 (1.42, 1.92)	1.12 (0.99, 1.26)	1.15 (0.98, 1.35)
50-59	1.91 (1.67, 2.18)	2.38 (2.02, 2.82)	1.47 (1.31, 1.65)	1.69 (1.44, 1.97)	0.91 (0.80, 1.03)	0.88 (0.75, 1.04)
≥60	1.91 (1.66, 2.19)	2.38 (2.00, 2.83)	1.23 (1.09, 1.39)	1.32 (1.12, 1.55)	0.52 (0.45, 0.61)	0.47 (0.39, 0.57)
Sex						
Female vs male	0.96 (0.92, 1.02)	0.96 (0.90, 1.03)	1.08 (1.03, 1.13)	1.11 (1.03, 1.18)	1.87 (1.77, 1.97)	2.31 (2.15, 2.48)
Race [‡]						
White	1.0 (Ref)	1.0 (Ref)	1.0 (Ref)			
Black	0.74 (0.69, 0.79)	0.66 (0.61, 0.72)	0.92 (0.87, 0.97)	0.89 (0.83, 0.97)	0.92 (0.85, 1.00)	0.90 (0.82, 0.99)
Asian	0.89 (0.76, 1.05)	0.85 (0.69, 1.05)	1.02 (0.88, 1.18)	1.03 (0.84, 1.25)	0.91 (0.74, 1.12)	0.90 (0.70, 1.16)
Other	1.31 (1.24, 1.39)	1.50 (1.37, 1.65)	1.44 (1.36, 1.53)	1.71 (1.56, 1.87)	1.38 (1.29, 1.48)	1.53 (1.38, 1.69)
Hispanic ethnicity [‡]						
Hispanic (vs non-Hispanic)	0.84 (0.80, 0.89)	0.77 (0.71, 0.84)	0.92 (0.87, 0.97)	0.87 (0.81, 0.94)	1.00 (0.94, 1.07)	1.01 (0.93, 1.11)
Education [‡]						
<High school graduate	1.0 (Ref)	1.0 (Ref)	1.0 (Ref)			
High school graduate	0.99 (0.93, 1.05)	0.99 (0.90, 1.09)	0.93 (0.88, 1.00)	0.91 (0.82, 1.00)	0.93 (0.86, 1.00)	0.84 (0.75, 0.94)
<Bachelor of art or science degree	0.84 (0.79, 0.89)	0.78 (0.71, 0.85)	0.85 (0.80, 0.90)	0.78 (0.72, 0.86)	0.81 (0.75, 0.88)	0.70 (0.63, 0.78)
Bachelor of art or science graduate	0.91 (0.85, 0.97)	0.86 (0.78, 0.95)	0.83 (0.78, 0.89)	0.77 (0.70, 0.85)	0.66 (0.58, 0.75)	0.67 (0.60, 0.75)
Body Mass Index At Visit 1 [‡]						
<25	1.0 (Ref)	1.0 (Ref)	1.0 (Ref)			
25-<30	1.12 (1.09, 1.18)	1.17 (1.09, 1.25)	1.01 (0.96, 1.06)	1.01 (0.96, 1.06)	1.06 (1.00, 1.13)	1.07 (0.99, 1.17)
≥30	1.14 (1.09, 1.20)	1.20 (1.12, 1.29)	1.01 (0.96, 1.06)	1.01 (0.96, 1.06)	1.12 (1.05, 1.20)	1.16 (1.07, 1.26)
Occupation on September 10, 2001						
Protective services, military	1.0 (Ref)	1.0 (Ref)	1.0 (Ref)			

Characteristic	Hearing Loss (n=45,537)			Tinnitus (n=45,536)			Ear Pain (n=45,495)		
	ARR (95% CI)	AOR (95% CI)		ARR (95% CI)	AOR (95% CI)		ARR (95% CI)	AOR (95% CI)	
Construction	1.60 (1.53, 1.67)	1.95 (1.83, 2.07)		1.38 (1.32, 1.45)	1.56 (1.47, 1.66)		1.49 (1.41, 1.59)	1.65 (1.53, 1.78)	
Telecommunications and other installation and repair	1.41 (1.33, 1.50)	1.61 (1.48, 1.75)		1.32 (1.24, 1.40)	1.45 (1.33, 1.58)		1.35 (1.23, 1.48)	1.44 (1.29, 1.61)	
Transportation and material moving	1.32 (1.23, 1.41)	1.44 (1.31, 1.58)		1.20 (1.12, 1.29)	1.26 (1.15, 1.39)		1.37 (1.24, 1.51)	1.46 (1.29, 1.65)	
Other jobs	1.34 (1.27, 1.40)	1.47 (1.38, 1.57)		1.28 (1.22, 1.34)	1.39 (1.30, 1.48)		1.38 (1.30, 1.47)	1.51 (1.39, 1.63)	
Unemployed, retired	1.71 (1.53, 1.91)	2.13 (1.78, 2.53)		1.52 (1.35, 1.70)	1.79 (1.50, 2.14)		1.66 (1.46, 1.89)	2.00 (1.62, 2.48)	
Not reported	0.88 (0.76, 1.02)	0.85 (0.70, 1.02)		0.88 (0.75, 1.02)	0.84 (0.70, 1.02)		0.79 (0.62, 1.02)	0.78 (0.59, 1.03)	
Smoking status before persistent hearing loss [‡]									
Never smoker	1.0 (Ref)	1.0 (Ref)		1.0 (Ref)					
Former smoker	0.84 (0.76, 0.86)	0.79 (0.75, 0.83)		0.76 (0.73, 0.79)	0.69 (0.66, 0.73)		0.57 (0.53, 0.60)	0.50 (0.47, 0.54)	
Current smoker	1.04 (0.98, 1.09)	1.08 (0.99, 1.16)		0.94 (0.89, 1.00)	0.92 (0.85, 0.99)		0.68 (0.63, 0.75)	0.62 (0.55, 0.69)	
Exp4 [†] and WTC noise interaction									
Low exposure, no WTC noise	1.0 (Ref)	1.0 (Ref)		1.0 (Ref)					
Intermediate Exp4, no WTC noise	1.11 (1.02, 1.21)	1.17 (1.04, 1.30)		1.10 (1.01, 1.19)	1.13 (1.02, 1.26)		1.19 (1.05, 1.36)	1.25 (1.07, 1.45)	
High exposure, no WTC noise	1.25 (1.12, 1.39)	1.37 (1.19, 1.58)		1.09 (0.97, 1.21)	1.12 (0.97, 1.30)		1.21 (1.02, 1.43)	1.27 (1.04, 1.55)	
Very high exposure, no WTC noise	1.10 (0.74, 1.63)	1.15 (0.70, 1.91)		1.08 (0.73, 1.58)	1.13 (0.69, 1.84)		1.63 (1.01, 2.61)	1.78 (1.00, 3.17)	
Low exposure, had WTC noise	1.19 (1.08, 1.30)	1.26 (1.12, 1.42)		1.14 (1.04, 1.26)	1.20 (1.06, 1.35)		1.40 (1.22, 1.61)	1.50 (1.27, 1.76)	
Intermediate exposure, had WTC noise	1.36 (1.26, 1.47)	1.54 (1.39, 1.70)		1.25 (1.16, 1.35)	1.36 (1.22, 1.52)		1.54 (1.37, 1.74)	1.72 (1.50, 1.98)	
High exposure, had WTC noise	1.48 (1.36, 1.61)	1.73 (1.55, 1.94)		1.33 (1.22, 1.45)	1.46 (1.29, 1.64)		1.63 (1.43, 1.85)	1.84 (1.58, 2.14)	
Very high exposure, had WTC noise	1.58 (1.43, 1.76)	1.94 (1.68, 2.24)		1.33 (1.19, 1.48)	1.45 (1.24, 1.69)		1.89 (1.62, 2.20)	2.20 (1.83, 2.65)	

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, tinnitus or ear pain

[†] 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.

[‡] Missing values for race ($n = 12,969$), ethnicity ($n = 13,312$), education ($n = 6771$), BMI ($n = 1730$), and smoking ($n = 5960$) were coded to their mode values.